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A User's Manual for MAXIMS

A Computer Program for Estimating the Food Consumption of Fishes from Diel Stomach Contents Data and Population Parameters

by

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A Computer Program for Estimating the Food Consumption of Fishes from Diel Stomach Contents Data and Population Parameters

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Abstract

A user-friendly two-diskette BASIC software package for IBM and compatible personal computers is presented which estimates the size-specific daily food consumption of fishes from a 24 hours cycle of stomach contents data for either one or two feeding periods per day, as well as population food consumption (Q/B) and related parameters. The ingestion and stomach evacuation, as incorporated in the model, can be expressed by rates proportional to different powers of the stomach contents. The precision of these estimate can be assessed through jackknifing. The Q/B estimates are based on one or several estimates for weight-specific daily ration and population growth and mortality parameters, the influence of which can be estimated by sensitivity parameters, the influence of which can be estimated by sensitivity analysis. Graphic outputs of 24-h cycles of stomach contents, and of gross conversion efficiency or ration vs. weight are available.

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1. Introduction

MAXIMS is a menu-driven software package providing routines for the estimation of daily ration of fishes from a 24 hours cycle of stomach contents data, and the estimation of population based food consumption from daily ration and population parameters. The software is written in Microsoft QuickBasic 4.5.

For the estimation of (size-specific) daily ration, routines are implemented which allow for either one or two feeding periods per day. At present, these models assume a simple exponential evacuation rate and two models of food intake, (i) as a constant ingestion during the feeding period or (ii) with ingestion decreasing in time, i.e. with increasing stomach contents.

These two approaches are based on Sainsbury (1986), who presented models for a single feeding period of arbitrary duration and implemented the search algorithm for mainframe computers. The standardization for a 24 hours cycle and the respective extensions of the models for two feeding periods are documented in Jarre et al. (1989). The software estimates the ingestion and evacuation rates and the feeding times by estimating 4 to 7 parameters (the number depends on the model selected). A nonlinear search algorithm is used to vary the parameter values such as to minimize the sum of squared residuals. Initial estimates for all parameters are required for the search routine; they must be reasonably close to the final estimates to yield a successful search. Whereas an initial estimate of the feeding times can be straightforwardly obtained from the data, this may not always be the case for the feeding rates and/or the asymptotic stomach contents. The program hence provides a routine which derives initial values for the feeding rates and, when necessary, the asymptotic stomach contents.

Population-based estimates of food consumption (Q/B) can be obtained from one or several estimates of daily ration, and population growth and mortality parameters. The approach used in the program is based on von Bertalanffy growth (von Bertalanffy 1938) and a constant mortality rate, and is documented in Pauly (1986) and Palomares and Pauly (1989). The influence of these growth and mortality parameters and the coefficient 'β' (beta) on the resulting Q/B estimate can be assessed using a simple form of sensitivity analysis. The Q/B subprogram also allows for estimation of the β coefficient from daily ration data, and for computation of daily ration from given weights, if beta is known. Finally, graphic outputs for K_1 and R_d *versus* weight are available.

2. Theoretical background

2.1. Estimating daily ration

Estimating the food consumption of animals is a key problem in investigating the ecology of a particular species as well as in modelling trophic relations between different species in an ecosystem. Sainsbury (1986) suggested a method to estimate daily ration from a set of parameters including ingestion and evacuation rates, and beginning and end of the feeding period from a feeding cycle of arbitrary length. He presented two models, the first of which ("Model I") assumes an ingestion rate constant in time, and the second one ("Model II") an ingestion rate inversely proportional to stomach contents. Model II requires the estimation of one additional parameter, the "asymptotic stomach contents". Both models assume simple exponential evacuation.

As the obvious duration for such a feeding cycle is one day, and most fishes feed either once or twice per day (i.e. during the day, during the night or twice daily, during twilight), the two models proposed by Sainsbury for one feeding period have been implemented for a cycle length of 24 hours and extended for two feeding periods per day.

The time trajectory of a simple exponential evacuation is the solution to the differential equation

$$dS/dt = - E * S \qquad ...1)$$

that is

$$S = S_0 * \exp(-E * (t-t_0)) \qquad ...2)$$

where

- t is the time
- S is the stomach content at time t;
- E the instantaneaous evacuation rate (in $hour^{-1}$),
- S_0 the stomach contents at the beginning of a given period
- t_0 the time at the beginning of the period in question.

As stomach contents are continuously evacuated, this process has to be taken into consideration also during the feeding period, i.e. the amount of food evacuated has to be substracted from the amount of food actually ingested. For Model I, the change in stomach contents is hence given by

$$dS/dt = J_1 - E * S \qquad ...3)$$

which has the solution

$$S = S_r * \exp(-E * (t-t_0)) + J_1/E * (1 - \exp(-E * (t-t_0)) \qquad ...4)$$

where

- J_1 is the ingestion rate (in weight * $hour^{-1}$),
- Sr is the stomach content at the beginning of the feeding period,

and wherein the first addend represents the evacuation of the stomach content present before a given feeding period and the second addend incorporates ingestion and evacuation of the newly ingested food.

For Model II, the change in stomach contents during the feeding period is given by

$$dS/dt = J_2 * (S_m - S) - E * S \quad ...5)$$

where
J_2 is an instantaneous ingestion rate (in $hour^{-1}$); and
S_m the maximal possible stomach content.

The corresponding time trajectory is

$$S = S_r * \exp((-E + J_2) * (t - t_0))$$
$$" \quad + S_\infty * (1 - \exp((-E + J_2) * (t - t_0)) \quad ...6)$$

where

S_∞ is the asymptotic stomach contents weight; this is related to S_m through $S_\infty = J_2 * S_m *(J_2 * E)$.

During the feeding period, the graphs of both models increase from the value S_r towards the asymptote J_1/E (Model I) or S_∞ (Model II) (Fig.1).

Assuming steady-state conditions (i.e., assuming that the stomach contents at the end of a 24 hours cycle is the same as the stomach contents at the onset of this cycle), S_r can be expressed by E, J_1, and the beginning and end of the feeding period for Model I (i.e., 4 parameters); and E, J_2, S_∞, and the beginning and end of the feeding period for Model II (i.e., 5 parameters).

In both models, the daily ration is computed as the integral of the time trajectory of the stomach contents over the feeding period.

Assuming the same ingestion and evacuation rates during the first and the second feeding period, the models for two feeding periods estimate two additional parameters, i.e. the beginning and end of the second feeding period, yielding 6 and 7 parameters, respectively (Table 1). Daily ration is accordingly computed as the sum of the integrals of the time trajectory over both feeding periods.

2.2. Estimating population food consumption

Modelling trophic relations between species implies extension of size-specific estimates of daily ration to entire populations. Information on the structure of the population in question can be obtained from growth and mortality parameters.

Growth can be estimated according to the von Bertalanffy growth function (VBGF), which has, for weight, the form

$$W_t = W_\infty * (1 - \exp(-K * (t-t_0))^b \quad ...7)$$

where

Table 1. Definitions of parameters as used in models of stomach content dynamics for estimation of daily ration.

Parameter description	Unit	Symbol in Text	Symbol in Sainsbury (1986)	Program variable[a]
Models with 1 feeding period				
Beginning of feeding period	hour	-	T_f	FeedBegin
End of feeding period	hour	-	-	FeedStop
Instantaneous rate of evacuation	$hour^{-1}$	E	c	Evacuation
Residual stomach content	g[b]	S_r	S_r	-
Model 1				
Ingestion rate	g[b]*$hour^{-1}$	J_1	a	Ingestion
Model 2				
Instantaneous rate of ingestion	$hour^{-1}$	J_2	a	Ingestion
Asymptotic stomach content	g[b]	S_w	(S_m)[c]	AsympCont
Models with 2 feeding periods				
Beginning of first feeding period	hour	-	-	FeedBegin1
End of first feeding period	hour	-	-	FeedStop1
Beginning of second feeding period	hour	-	-	FeedBegin2
End of second feeding period	hour	-	-	FeedStop2
Residual stomach content	g[b]	S_r	-	
Model 1				
Ingestion rate	g[b]*$hour^{-1}$	J_1	-	Ingestion
Model 2				
Instantaneous rate of ingestion	$hour^{-1}$	J_2	-	Ingestion
Asymptotic stomach content	g[b]	S_w	-	AsympCont

a 'Program variables' are those names that are used for software data input and/or output. The variables labeled '-' are computed internally.

b Any unit of weight can be used for stomach content, e.g., mg or kg

c The parameter S_m used by Sainsbury (1986) is related to S_w through $S_m = S_w * (1+E/J_2)$

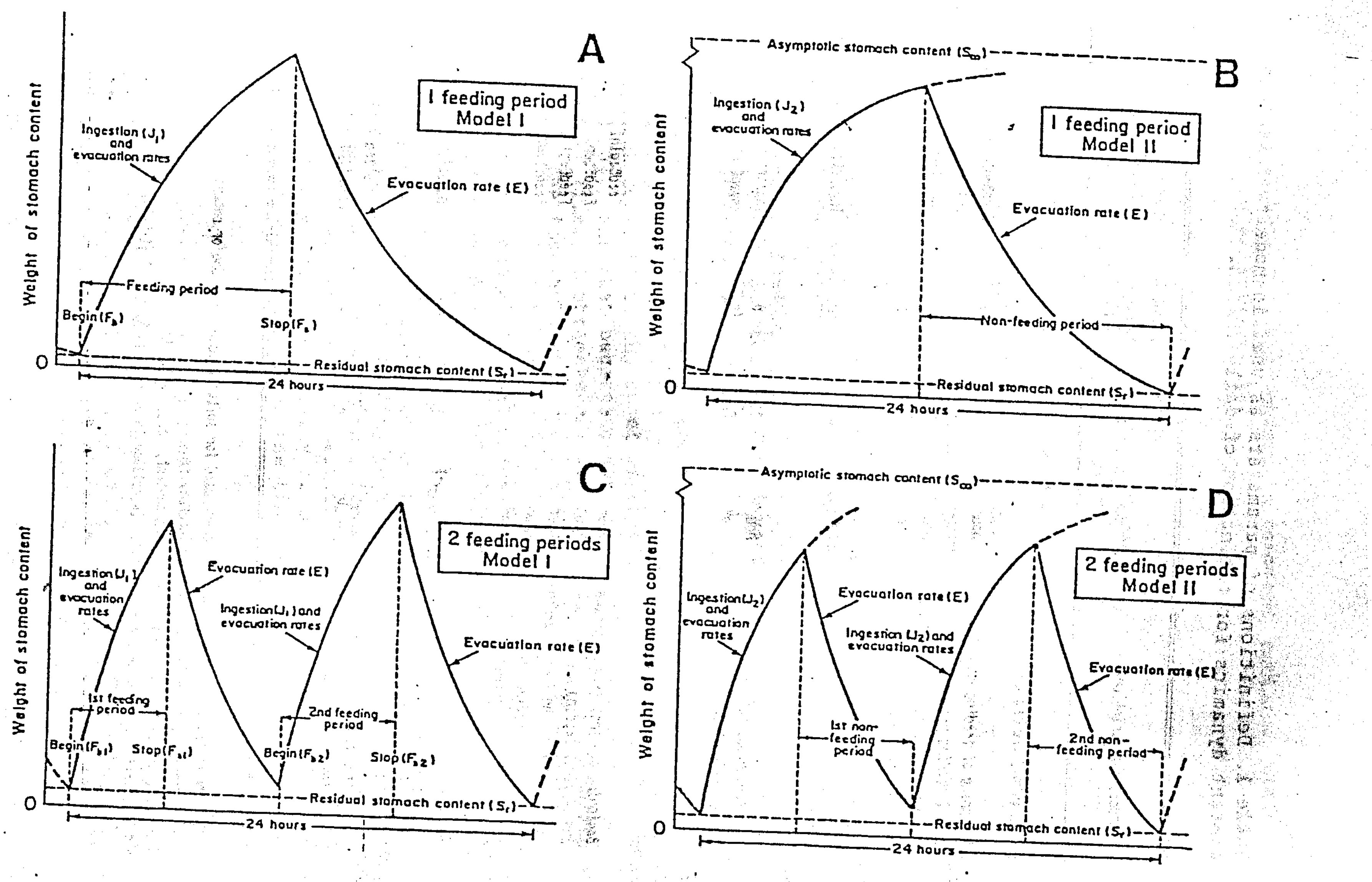

Fig. 1. Schematic representation of models of stomach contents dynamics presented. A. One feeding period per day, constant feeding rate; B. One feeding period per day, feeding rate inversely proportional to stomach contents; C. Two feeding periods per day, constant feeding rate; D. Two feeding periods per day, feeding rate inversely

t is the time,
W_t is the weight at age t
W_∞ the asymptotic weight
K a growth parameter (in $time^{-1}$)
t_0 the "age" at weight zero
b the exponent of a length-weight relationship of the form $W = a * L^b$.

The first derivative of this equation gives the change of weight in time (i.e., the growth rate) and reads

$$dw/dt = b * K * W * ((W_\infty/W)^{1/b} - 1) \quad ...8)$$

Relating the growth of an animal with its food consumption, Ivlev (1945) introduced the gross food conversion efficiency K_1, which is defined as

$$K_1 = \text{growth increment / food ingested} \quad ...9a)$$

This applies for any time interval and can thus be rewritten as

$$\text{Food consumption} = (dw/dt) / K_{1(t)} \quad ...9b)$$

where $K_{1(t)}$ is an estimate of gross food conversion efficiency referring to the age for which the value of dw/dt applies (see Eq. 8).

Pauly (1986) showed that K_1 can related to weight through

$$K_1 = 1 - (W/W_\infty)^{\beta} \quad ...10a)$$

for the entire size range from 0 to W_∞. Combined with the VBGF, K_1 can thus be given as a function of age, i.e.

$$K_{1(t)} = 1 - W * (1 - \exp(-K * (t-t_0)))^{\beta * b} \quad ...10b)$$

The biomass of the population is obtained as the integral over time of the numbers (N) times the corresponding weight. The population numbers can be again expressed as a function of time, if the total mortality Z is known, as

$$N_t = N_0 * \exp(-Z * (t-t_0)) \quad ...11)$$

The complete equation for population food consumption thus reads

$$Q/B = \text{Food consumption / biomass}$$

$$= \frac{\int_{t_r}^{t_{max}} \frac{(dw/dt) * N_t}{K_{1(t)}} dt}{\int_{t_r}^{t_{max}} W_t * N_t \, dt} \quad ...12)$$

where

t_r is the age at entry into the population in question, and
t_{max} the age of exit from that population.

Pauly (1986) presented a sensitivity analysis of this model, which showed that its output is strongly sensitive to β and b, less so to Z and K, and rather insensitive to changes of t_r and t_{max} (Fig. 2).

2.3. Allowing for other ingestion and evacuation models in the estimation of daily ration

A "fine-tuning" routine will allow to improve the estimated parameters by considering different models of ingestion and evacuation Statistical assessment of the daily ration estimates will be provided using the jackknife method. [This section to be completed later.]

3. Installing the program and getting started

The hardware needed to implement MAXIMS is an IBM or compatible personal computer with Hercules or CGA graphics card (or compatibles), and (optionally) an Epson or compatible printer.

The software is supplied on two 5 1/4" 360K diskettes. A small setup routine requires information on the type of graphics card your computer has. It is suggested that you copy the files from the MAXIMS diskettes to a directory on your harddisk (e.g. to C:\MAXIMS*.*) if your computer has one.

If you run MAXIMS for the first time on your computer, select the appropriate disk drive (with MAXIMS diskette No. 1) or directory and type

INSTALL

at the DOS prompt. The setup routine will be loaded, and you will be asked to indicate the type of graphics card your computer has. This information is written to a file called "INSTALL.INI".

To start the program, type

MAXIMS

at the DOS prompt. The entry screen will display general information about the program. If you do not want to return to DOS ([F3]), press any key to proceed to the main menu.

> *Note*: In case you run MAXIMS from diskettes, please make sure to copy the file "INSTALL.INI" to the second MAXIMS program diskette.

4. Main menu

You will be first prompted to select among five options.

Press D to select the data management routine (data entry and editing);
- R to estimate daily rations (continues to submenu);
- F to fine-tune the results on daily ration by adjusting the gastric evacuation model, or to jackknife the daily ration estimates;
- Q to estimate the parameter beta and population food consumption; or
- G to graph K_1 or R_d estimates against body weight.

5. Data management

The data management program allows you to enter your data into an ASCII file with the format needed by the estimation or graphing routines. It also allows editing of existing data files. A maximum of 42 data pairs can be entered.
Firstly, you are prompted to supply information on the nature of your data. Select
- R if you wish to enter (or edit) time and stomach content weight data pairs (for estimation of daily ration); or
- G if you wish to enter (or edit) weight and daily ration data pairs (for graphing K_1 or R_d *vs.* weight).

After this, press
- N if you wish to enter new data;
- E if you wish to edit an existing file; or
- V if you wish to view a plot of existing data.

5.1. Create a new file

The data entry screen displays an empty data table and prompts you to enter the data pairs. In case of time and stomach contents data, please note that the unit of time entries is the hour, on a 24 hours basis. Please enter fractions of hours in decimals (*not* minutes), e.g. 13.25 for 13 h 15 min (i.e., for 1:15 p.m.). You can select the unit for the stomach contents (e.g. g or mg). The daily ration estimate will be expressed in the same weight units as the stomach contents data, e.g. g/day or mg/day. Please also note, that the program only accepts weight or ration entries consisting of up to three digits before and and three digits after the decimal point.

Start entering your data. Press RETURN to finish a single entry and proceed to the next one. You can use the UP and DOWN arrows of your keyboard in the first column on the screen to correct erroneous entries. To change your entries, simply move the highlighted bar to the erroneous entry, retype the time and stomach contents data pair, finish by pressing RETURN and move to the bottom of your table using the down arrow.

Press [F8] at the bottom of the table you entered when finished. The program prompts you for a filename (8 characters maximum length), which may be preceeded by a drive specification. Do *not* enter an extension name for your data: the extension .FOD is added automatically to easily distinguish your MAXIMS data files from other files on your disk. After your data have been written to the disk, the data management menu is reloaded.

> *Note:* If you have replicate contents data, it is strongly suggested that you use an appropriate statistical method to determine a single stomach contents value for a specific sampling time (e.g. the median, the mean etc.).

5.2. Edit an existing file

Enter the filename to be used (which may be preceeded by a drive specification but may *not* contain an extension name). Your data are displayed on the screen. Use the UP and DOWN arrow keys to move the highlighted bar to the data pair to be corrected and reenter the time and stomach contents values.

Proceed to the bottom of the table (one line below your last valid entry) and press [F8] when finished. You are again prompted to enter a filename for the data. Remember *not* to include an extension. The data management menu will then be automatically loaded.

5.3. View plot of data

Enter the filename to be used. This name may be preceeded by a drive specification but may *not* contain an extension name. The data points are displayed on the screen in chronological order, i.e. starting at 0.00 h and ending at 24.00 h. Press any key to return to the data management menu.

6. Estimation of daily ration

The second screen of the main menu lets you select the desired model in two steps. First, the software prompts you for the number of feeding periods.

Enter 1 if your data show one feeding cycle per day; or
2 if your data show two feeding cycles per day.

> *Note:* The decision on the number of feeding periods is up to you. The program searches for the best fit for a given number of peaks and a given model, but cannot compare the fit obtained for different models; *you* must do this!

6.1. One feeding period

You are prompted to select the desired model and may chose between two "full" models with estimation of ingestion and evacuation rates and feeding times and estimation of the daily ration from those parameters, and one "partial" model to estimate the evacuation rate only, and then to compute the daily ration from this estimate and the mean stomach content.

Enter
- 0 to select the "partial" model; or
- 1 to select "Model I", based on the assumption of a constant feeding rate; or
- 2 to select "Model II", based on a feeding rate decreasing with increasing stomach contents (one additional parameter to be estimated).

6.2. Two feeding periods

You are prompted to select the desired model.

Enter 1 to select "Model I", based on the assumption of a constant feeding rate; or
- 2 to select "Model II", based on a feeding rate decreasing with increasing stomach contents (one additional parameter to be estimated).

6.3. Full models: Parameter estimation routines

All parameter estimation routines start with an entry screen which lets you check whether you have indeed selected the model you intended to. Press any key to proceed or [F3] to return to the main menu. Upon proceeding, you are prompted to enter the filename of the data set to be used, which may be preceeded by drive specifications but must *not* include an extension name. The program will then prompt you whether you wish to be provided with program-generated initial estimates of the feeding rates and the asymptotic stomach content. If this is not the case, the program will directly proceed to the initial values screen.

Two data sets (for one and two feeding periods, respectively) with inital and final parameter estimates are given in Tables 2 and 3 for your orientation.

6.3.1. Program-generated initial estimates

A chronological plot of your data is displayed and you are prompted to enter the approximate time of beginning and end of the feeding period(s). These times will be used by the program to generate initial values for evacuation and ingestion rates and asymptotic stomach contents (Model II) from the selected data set. Please see Appendix B for details on the computations.

6.3.2. Initial values screen

The initial values screen displays the list of parameters to be estimated (corresponding to your choice of model), and the set of program-estimated initial values (default). You are prompted to fill in the two rightmost columns, "Actual initial values" and "Parameter to be varied (Y/N)?".

[F4] lets you return to the entry screen of this routine, which lets you select a different file; and

[F3] lets you quit to the main menu.

Table 2. Example for the estimation of feeding parameters and daily ration for one feeding period per day (data from Alamo (1989) and Rojas de Mendiola (1989) for Peruvian anchoveta *Engraulis ringens*). [From Jarre et al. (1989)]

Time (hour)	Stomac Weigh	Content (g)	Parameter Name	Parameter Unit	Initial Value	Estimated Value
0.75	0.191					
2.25	0.135		*Model I*			
3.75	0.074		Ingestion	$g*hour^{-1}$	0.050	0.0441
5.25	0.063		Evacuation	$hour^{-1}$	0.155	0.1550
6.75	0.068		FeedBegin	hour	13.00	12.85
8.25	0.067		FeedStop	hour	1.80	1.80
9.75	0.074					
11.25	0.067		*Model II*			
12.75	0.051		Ingestion	$hour^{-1}$	0.1216	0.0473
14.25	0.099		Evacuation	$hour^{-1}$	0.1172	0.1311
15.75	0.177		AsympCont	g	0.3712	0.2685
17.25	0.181		FeedBegin	hour	13.00	13.25
18.75	0.173		FeedStop	hour	2.00	1.70
20.25	0.152					
21.75	0.177					
23.25	0.199					

Table 3. Example for the estimation of feeding parameters and daily ration for two feeding periods per day (data from Arntz (1974) for juvenile Baltic cod *Gadus morhua*, length class 26-30 cm.) [From Jarre et al. (1989)].

Time (hour)	Stomach Content Weight (g)	Parameter Name	Parameter Unit	Initial Value	Estimated Value
		Model I			
		Ingestion	$g*hour^{-1}$	0.4059	0.6691
		Evacuation	$hour^{-1}$	0.1396	0.2518
0.00	0.500	FeedBegin1	hour	5.50	5.20
2.00	0.350	FeedStop1	hour	9.50	8.05
7.00	1.050	FeedBegin2	hour	15.00	13.90
10.00	0.900	FeedStop2	hour	19.00	18.55
11.80	0.700				
12.30	0.260	*Model II*			
15.00	0.850	Ingestion	$hour^{-1}$	0.0600	0.1430
17.00	1.650	Evacuation	$hour^{-1}$	0.3200	0.2504
19.00	0.700	AsympCont	g	2.0500	2.2190
		FeedBegin1	hour	5.25	5.50
		FeedStop1	hour	8.50	8.00
		FeedBegin2	hour	14.00	14.10
		FeedStop2	hour	19.00	18.60

Enter your own initial estimates or accept the defaults by moving through the column with the DOWN arrow. After that, select whether a parameter should be changed by the program during the iterations which follow, or not. The default is "Y", i.e. the parameter is to be varied. Move through the column using the DOWN arrow, or enter "Y" or "N" for the respective parameters.

After these two columns are filled in, select one of the options in the right message box:

[F6] brings you back to the top of the same screen. Use the arrow keys to move the highlighted bar to the item you wish to correct and enter the corrected value.

[F8] lets you proceed to the estimation routine.

[F10] lets you view the data and the graph computed from the initial data set on the screen. From there, you can either proceed to parameter estimation or return to the initial values screen to edit the initial values.

> *Note:* In case you select only "N" in the "Parameter to be varied?" colunmn, the software will display only your data and the curve derived from the parameter values you entered. Select [F8] for a printout or [F10] to get back to the initial values routine.

6.3.3. Parameter estimation screen

The parameter estimation proceeds by changing one parameter at a time in small steps, such as to minimize the sum of squared residuals. The actual parameter values are shown at the bottom of the screen, along with the number of iteration loops passed and the actual sum of squared residuals. Your data and the computed graph are displayed in the upper part of the screen. After each iteration loop, the graph is actualized, based on the current parameter set.
When the program is done, the daily ration is computed from the "final" parameter set and displayed at the bottom of the screen.

Select

[F8] to get a hardcopy of the results (see below)

[F4] to return to the opening screen of the same model (e.g. to try a different set of parameters or to use a different file) without printout

[F3] to quit to the main menu.

In case the iteration has not converged within 40 steps, you will be prompted to enter whether you wish to continue the ongoing parameter estimation or return to the menu, e.g. to select a different model or to reenter more suitable initial values.

> *Note*: As a direct estimation of the parameters to obtain the least sum of squared residuals is not possible, the program may stop at a local minimum. Try different initial parameter sets to optimize your results. Also try to obtain a similar estimate for the daily ration by approaching the final parameter set with initial rates that are (a) smaller and (b) larger than the estimates obtained before.

6.4. Partial model

A chronological plot of your data is displayed and you are prompted to enter the times at the end and the beginning of the feeding period. These times define the data to be used for the linear regression used in estimating the evacuation rate. The daily ration is then computed as

R_d = mean stomach content * evacuation rate * 24 hours,

and the results are displayed at the lower part of the screen.

Select

[F8] for a hardcopy of the results (see below)

[F4] to return to the opening screen of the same model (e.g. to select different times or to use a different file) without printout

[F3] to quit to the main menu.

6.5. Printing the results

The printout of the results consists of

- the selected model and file
- full models: a listing of the initial and final parameter sets
- full models: a listing of the observed data, the expected stomach contents and the residuals
- the estimate of daily ration
- a screen dump, showing your data points and (for the full models) the graph fitted to them.

Make sure your printer is on-line when you select the printing option ([F9]). You may repeat this option if you wish, or continue with the same model ([F4]), or return to the main menu ([F3]).

7. Fine-tuning of daily ration estimates and jackknifing

The "fine-tuning" routine will allow to improve the estimated parameters, by considering different models of ingestion and evacuation. Statistical assessment of the daily ration estimates will be provided using the jackknife method. Details on this section will be provided later.

8. Q/B and related estimates

8.1. Q/B Submenu

The menu offers four options,

1. Estimation of Q/B (from growth and mortality parameters and beta);
2. Sensitivity analysis (for Q/B, Gross Efficiency, and Maintenance Ration);
3. Computation of daily ration for given weights;
4. Estimation of beta from weight and R_d data pairs.

Move the highlighted field to the desired option and press RETURN.

8.2. Parameter entry

All routines for estimates related to Q/B will firstly prompt you to enter the name of the species you are working at and will then require the input of growth and mortality parameters. Table 4 gives a list of those parameters with brief explanation and a list of the routines for which their values are needed. Use the UP and DOWN arrow keys to correct erroneous entries in the parameter list.

Table 4. Parameter inputs related to computation of Q/B.

Name	Description	Unit	Subroutine
W_∞	Asymptotic weight	g[a]	All
K	growth parameter	$year^{-1}$	All
t_0	'age' at length zero	$year^{-1}$	All
b	exponent of length-weight relationship	$year^{-1}$	All
beta	coefficient relating K_1 to weight	-	Q/B, Sensitivity, Rd
Z	total mortality	$year^{-1}$	Q/B, Sensitivity
W_r	lower limit for Q/B integration (must be ≥ 0 and ≤ $0.95 \cdot W_\infty$)	g	Q/B, Sensitivity
W_{max}	upper limit for Q/B integration (must be > W_r and ≤ $0.95 \cdot W_\infty$)	g	Q/B, Sensitivity

[a] Any unit of weight can be used, e.g. also mg or kg. Please note, however, that it must be the same unit of weight as used for R_d.

8.3. Estimation of Q/B

After you have entered the required parameters, the program computes population-based food consumption (Q/B) and Maintenance Ration on annual and daily bases, the latter expressed in % body weight. Gross efficiency is computed as production/consumption (= (P/B)/(Q/B)).

Select any of the following keys to continue:

[F3] lets you exit directly to the main menu;

[F4] lets you return to the Q/B-submenu;

[F8] lets you print the results.

8.4. Sensitivity analysis

After you have entered the required parameters, the program will compute Q/B, Maintenance Ration and Gross Efficiency, and then modify the parameters beta, K, Z, W_{max}, W_r, t_0 and b by the factors 0.5, 0.8, 0.9, 0.95, .99, 1.01, 1.05, 1.1, 1.2 and 1.5 and recompute those estimates. Depending on the speed of your computer, these computations may take some time. The factors by which the results change are displayed in tabular form. Although only the factors for the change of Q/B are initially displayed, the changes for Maintenance Ration and Gross Efficiency are available and you can quickly get them onto the screen by using the function keys as indicated below. A "---" entry in the W_{max} row of the table means that the corresponding modified value for W_{max} would equal or exceed W_∞, and that therefore the respective computations were not performed.

When the table is completed, you are prompted to select one of the following options:

[F4] to return to the Q/B submenu
[F5] to display the results for Q/B (default)
[F6] to display the results for Gross Effficiency
[F7] to display the results for Maintenance Ration
[F8] to obtain a printout of the results. (This printing option allows you to "jump" between result tables and printouts, so you do not need to redo the entire routine for a complete set of hardcopies of the results.)

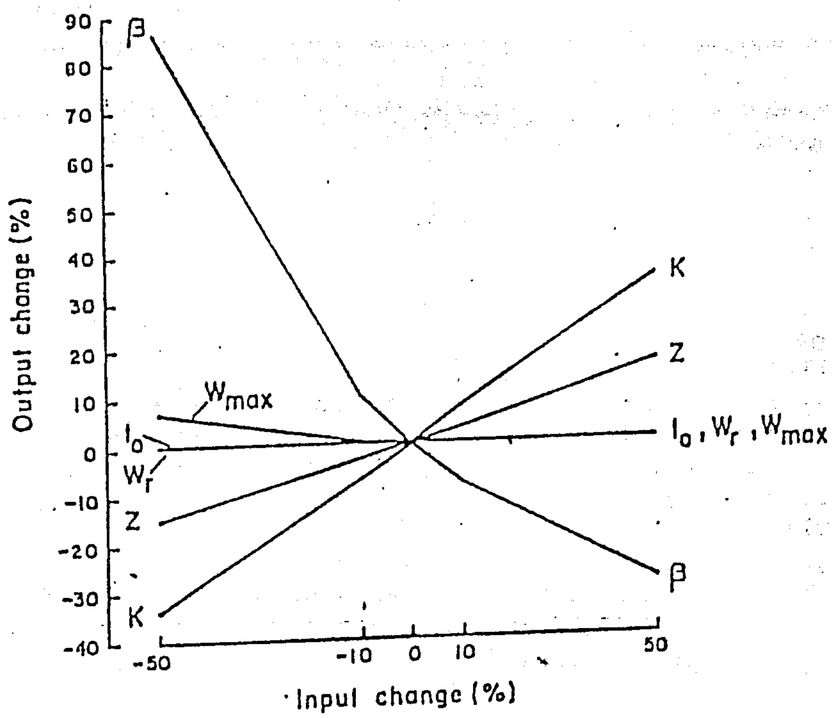

Fig. 2. Sensitivity analysis of text equation 12, based on W_∞ = 1,880 g, K = 0.24 $year^{-1}$, t_0 = 0.2 year, t_r = 0.35 year, t_{max} = 12 year, β = 0.136 and Z = 0.64 $year^{-1}$. Note strong effects of changes in β, intermediate effects of K and Z, and negligible effects of W_r, W_{max} and t_0. [From Pauly (1986)]

8.5. Computation of R_d

After you have entered the required parameters, you are prompted to enter the body weight for which you need the daily ration, which will then be immediately computed.

You can repeat this procedure for a maximum of 30 weight values, or press at any time:
[F4] to return to the Q/B Submenu; or
[F8] for a printout of the results.

8.6. Estimation of 'beta'

After you have entered the necessary parameters, you are prompted to enter weight and daily ration data pairs, from which the beta coefficient will directly be computed. In case you have two or more such data pairs, it is highly recommended that you use the [F9] option for a mean estimate of beta.

Upon pressing [F9], the estimate of the mean is displayed along with the "residual" for each input, i.e. the differences between the beta values computed directly and the mean estimate of beta. The residualsallow you to easily check for outliers. The program will prompt you whether you wish to exclude any inputs (i.e., an outlier) from the estimate of the mean. If so, you will be asked to enter the number of the data pair you wish to exclude, and the computations will be redone.

Note that you can exclude only one input at a time, but that the entire procedure itself can be repeated.

Pressing
[F4] allows you to return the Q/B-Submenu; and
[F8] allows you to print the results.

8.7. Printing the results

If you select the printing option (by pressing [F8] whenever this option is displayed), please make sure that your printer is switched on and also on-line. Pressing any key will then erase the message box and make a straightforward screen dump of the results.

You can then proceed by pressing
[F8] to repeat the printout;
[F4] to return to the Q/B submenu; or
[F3] to quit to the main menu.

9. Graph of K_1 or R_d *versus* body weight

9.1. Data entry

Use the data management routine to enter data pairs of body weight and daily ration. Select "K" when you are prompted whether you wish to enter data for estimation of daily ration or for the purpose of plotting K_1 and R_d *versus* weight.

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9.2. Plotting your data

You will firstly be prompted to enter the name of the file that contains your data. This name may be predeeded by a drive and/or directory specification, but must *not* contain an extension name.

Select

K for a plot of K_1 *vs.* weight

G for a plot of R_d *vs.* weight

You will then be asked to supply the value of W_∞, and the values of K, t_0, b, Z, and beta if you selected the plot of R_d *vs.* weight. These parameters are needed by the program for the computation of the graph. Your data are then loaded and plotted, and the computed graph of K_1 or R_d is displayed.

Select

[F8] for a prointout of the graph;

[F4] to return to the beginning of this routine; or

[F3] to return to the main menu of MAXIMS.

9.3. Printing the results

If you select the printing option ([F8]), please make sure that your printer is switched on and also on-line. Pressing any key will then erase any messages and print the screen.

You can proceed by pressing

[F8] to repeat the printout;

[F4] to return to the beginning of the routine; or

[F3] to quit to the main menu.

Acknowledgements

We wish to thank Dr. K.J. Sainsbury for providing the source code of his program for estimation of daily ration and for useful discussion, and Mr. Felimon Gayanilo, Jr. for assistance with hardware setup.

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Appendices

Appendix A
List of function keys

[F3] "Hot key" which lets you exit to DOS if you are in the main menu, or returns you to the main menu from wherever you are.

[F4] "Hot key", which lets you return to the entry screen or menu of the current program.

[F6] Lets you edit the entries in the initial value set.

[F8] Prints results; or saves data in data management program.

[F9] Lets you proceed to the next program step.

[F10] Toggles between initial values screen and plot of data plus the graph computed from the parameters entered.

Appendix B
Data requirements

The data used for the routines for the estimation of R_d are checked before entering the computations for the following:

1. Time values must be between ≥ 0.00 and ≤ 24.00 hours
2. Stomach content weights must be ≥ 0 and ≤ 999.999 (in weight units)
4. Depending on the model selected, a minimum of different data pairs must have been entered:

Minimum No. of data pairs	Model No. 1.1	1.2	2.1	2.2
Total	5	6	7	8
Different time values	4	5	6	7
Different weight values	3	3	4	4

If these requirements are not met, a warning is displayed and the program execution will be suspended. Please use the data editing routine to correct erroneous entries.

Appendix C

Program- generated initial estimates for daily ration

You are prompted to enter your initial estimate of the feeding times. From these estimates, the program attempts to compute inital values for the feeding rates and (for Model II) the asymptotic stomach contents, following the procedure below. The methods for computing the initial values are different for Model I and Model II, but the number of feeding periods (one or two) in this exercise are relevant mainly for "bookkeeping".

Generally, the evacuation rate is estimated from the nonfeeding period. Given an estimate for the evacuation, the ingestion rate and (for Model II) asymptotic stomach contents can be estimated from the feeding period. In case of two feeding periods per day, the intervals bracketing the larger number of data points are selected. If the period include the same number of data points, the first feeding/nonfeeding periods are selected.

Evacuation rate (Models I and II)

The evacuation of stomach contents follows the time trajectory

$$S = S_0 * \exp(-E * (t-t_0))$$

or, for t_0 set to zero (by subtracing this value from all times concerned),

$$\ln S = \ln S_0 - E * \ln t.$$

From this equation, E can be estimated as the slope (with sign changed) of a linear regression (of ln S vs. ln t)

Should the data lead to the slope (and hence, evacuation) to have the wrong sign, the program will attempt to compute E from the slope between the first two nonfeeding data points or, if this still does not yield a positive result, from the slope between the last feeding point and the following data point (which might be either feeding or nonfeeding, depending on the selection of feeding times). In case none of the previous attempts is successful, the evacuation rate is set to 0.2 (in units weight^{-1}), as this has so far appeared to be a reasonable value to begin with.

Model I: Ingestion rate

The time trajectory of the feeding period reads

$$S = S_r * \exp(-E * (t-t_0)) + J_1/E * (1- \exp(J_1 * (t - t_0)))$$

The program takes the smallest stomach weight from the data as residual stomach content, and then computes the ingestion rate by solving the above equation for J_1, using the total duration of the feeding period. In case too few data points are available, ingestion is estimated from the last nonfeeding point and the following one and the time difference between them. Should this not lead to a positive estimate of the ingestion rate, the program sends an "error" message, i.e. informs the user that it cannot estimate initial values from the data and/or the initial guesses for the feeding times.

Model II: Ingestion rate and asymptotic stomach contents

The time trajectory of stomach contents, for Model II, is

$$S = S_r * \exp(-(J_1 + E) * (t - t_0)) + S_\infty * (1 - \exp(-(J_1^* + E) * (t - t_0))).$$

Setting S_r to zero and subtracting t_0 from all values of t leads to the simplified equation

$$S = S_\infty * (1 - \exp(-(J_1 + E) * t))$$

From this (J_1+E) and S_∞ can be simultaneously estimated from a regression of stomach content increments vs. the average stomach content weight of the corresponding time intervals, or

$$\frac{S_2-S_1}{t_2-t_1} = a + b * \frac{S_1 + S_2}{2}$$

with slope $b = -(J_1 + E)$ and $S_\infty = a/(J_1+E)$. (Fisheries biologists among the users will be familiar with this method which is analogous as the Gulland-and-Holt-plot for estimation of of the parameters L_∞ and K of the VBGF for length.)
If this method does not provide a reasonable estimate of S_∞, the asymptotic stomach content is set equal to the maximum observed weight divided by 0.8, and J_1+E is computed from the means of all "$(S_1+S_2)/2$" values (M_1) and of all weight increment values (M_2), using

$$J_2 = M_2/(S_\infty - M_1) - E .$$

If this does not yield a reasonable estimate either, an "error" message is displayed, informing the user that the program cannot estimate these initial values.

Troubleshooting

in case the "error" message is displayed, you may wish to reconsider your initial guesses of the feeding times. Try to rerun the routine, assigning new data points to the feeding period. If this still doesn't work, enter your own initial guesses directly on the initial estimates screen, starting with the feeding times you consider reasonable and an initial evacuation rate between 0.15 and 0.3 (in weight^{-1}). Use the [F10] key to toggle between graphics sceen and initial values screen to find a reasonable initial estimate for the ingestion rate (and for the asymptotic stomach contents in case of Model 2).

Appendix D
Equations for estimates related to Q/B

Computation of Q/B

$$Q/B = \frac{\int_{t_r}^{t_{max}} \frac{(dw/dt) * N_t}{K_{1(t)}} \, dt}{\int_{t_r}^{t_{max}} W_t * N_t \, dt}$$

Computation of R_d

$$R_d = \frac{3 * K/365 * W * ((W_\infty/W)^{1/b} - 1)}{1 - (W/W_\infty)^{\beta}}$$

Computation of beta

(a) Direct computation from a weight and R_d data pair

$$dw/dt = 3 * K/365 * W * ((W_\infty/W)^{(1/b)} - 1)$$

$$K_1 = \frac{dw/dt}{R_d}$$

$$beta = \frac{\log(1-K_1)}{\log(W/W_\infty)}$$

(b) Estimate of mean beta from several single estimates

$$beta = \frac{\overline{\log(1-K_1)}}{\log W_\infty - \overline{\log W}}$$

Appendix E
Using K_1 or R_d values when only Z/K is known

If a value of the growth parameter K is not available, but Z/K is known, estimates of the Gross Efficiency (GE) and the population food consumption Q/B divided by K (i.e., Q/(B*K)) can be obtained as demonstrated below.

We have defined

Q/B = Food consumption / biomass

$$= \frac{\int_{t_r}^{t_{max}} \frac{(dw/dt) * N_t}{K_{1(t)}} dt}{\int_{t_r}^{t_{max}} W_t * N_t \; dt} \quad ...1a)$$

or, explicitly for N_t and $K_1(t)$

$$Q/B = \frac{N_o * \int_{t_r}^{t_{max}} \frac{(dw/dt) * exp(-Z * (t-t_o))}{(1 - W_t/W_\infty)^\beta} dt}{N_o * \int_{t_r}^{t_{max}} W_t * exp(-Z * (t-t_o)) \; dt} \quad ...1b)$$

wherein N_o is the initial number of individuals entering the population.

The VBGF for weight

$$W_t = W_\infty * (1 - exp(-K * (t-t_0)))^b \quad ...2a)$$

is readily rewritten as

$$(W_t/W_\infty)^{1/b} = 1 - exp(-K * (t-t_0)) \quad ...2b)$$

adn this equation solved for t then reads

$$t = t_0 + 1/K * ln\ (1 - (W_t/W_\infty)^{1/b}) \quad ...2c)$$

The first derivative of the VBGF is

$$dw/dt = W_\infty * b * K * (1 - exp(-K*(t-t_0)))^{b-1} * exp(-K*(t-t_0)) \quad ...3a)$$

Using Eq. 2b twice, this derivative can be rewritten as

$$dW/dt = W_\infty * b * K * (W_t/W_\infty)^{(b-1/b)} * (1-W_t/W_\infty)^{1/b} \quad ...3b)$$

and hence, using Eq. 3b and 2a, we can reformulate Eq. 1b) as

$$Q/B = b * K * \Gamma \quad ...1c)$$

wherein

$$\Gamma = \frac{\displaystyle\int_{t_r}^{t_{max}} \frac{(W_t/W_\infty)^{b-1/b} * (1-(W_t/W_\infty)^{1/b}) * \exp(-Z * (t-t_0))}{1-(W_t/W_\infty)^{\beta}}\, dt}{\displaystyle\int_{t_r}^{t_{max}} (W_t/W_\infty) * \exp(-Z * (t-t_0))\, dt}$$

From Eq. 2c we obtain (by multiplication with -Z)

$$-Z * (t-t_0) = Z/K * \ln(1 - (W_t/W_\infty)^{1/b}) \quad ...4)$$

and hence, for Γ,

$$\Gamma = \frac{\displaystyle\int_{t_r}^{t_{max}} \frac{(W_t/W_\infty)^{(b-1)/b} * (1-(W_t/W_\infty)^{1/b}) * (1-(W_t/W_\infty)^{1/b})^{Z/K}}{1-(W_t/W_\infty)^{\beta}}\, dt}{\displaystyle\int_{t_r}^{t_{max}} (W_t/W_\infty) * (1-(W_t/W_\infty)^{1/b})^{Z/K}\, dt} \quad ...5)$$

This yields an estimate of the population food consumption divided by K, as

$$Q / (B * K) = b * \Gamma \quad ...6)$$

The Gross Efficiency GE can be defined as GE = P/Q, which, according to Allen (1971) equals

$$GE = Z / (Q/B) \quad ...7a)$$

and hence, with Eq. 6,

$$GE = (Z/K) / (b * \Gamma) \quad ...7b)$$

such that an estimate of the Gross Efficiency can be obtained when K is unknown, if Z/K is available.

Appendix F
Directory of MAXIMS diskettes

Diskette No. 1

```
BRUN45.EXE   - Runtime module
BRUN45.LIB   - Runtime library
MSHERC.COM   - Hercules Graphics Support
INSTALL.EXE  - Installation for MAXIMS
RDMENU.EXE   - Main Menu
QBNEW.EXE    - Population Food Consumption
```

created during installation: MAXIMS.BAT
INSTALL.INI

Diskette No.2

```
RDDATA.EXE   - Data Management
RDMENU.EXE   - Main Menu
RD11.EXE     - Daily Ration, Model 1.1
RD12.EXE     - Daily Ration, Model 1.2
RD21.EXE     - Daily Ration, Model 2.1
RD22.EXE     - Daily Ration, Model 2.2
```

In case you run MAXIMS from diskettes, please make sure that you always start from Diskette No.1 and put the appropriate disk in the drive when running the program. Installation is required when you run the program for the first time, after that you start it by typing MAXIMS.

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).

- **Estimation and comparison of fish growth parameters from pond experiments: a spreadsheet solution.** J.M. Vakily. 1988. ICLARM Software 3, 12 p. Distributed with one 5-1/4" diskette for US$15 (airmail).

- **MAXIMS: A computer program for estimating the food consumption of fishes from diet stomach contents data and population parameters.** A. Jarre, M.L. Palomares, M.L. Soriano, V.C. Sambilay, Jr. and D. Pauly. ICLARM Software 4. Distributed with 2 5-1/4" diskettes for US$20.

- **CDS ASSISTANT.** F.C. Gayanilo, Jr. 1990. ICLARM Software 5, 19 p. Distributed with one 5-1/4" diskette for US$15 (airmail).

- **A draft guide to the ECOPATH II program (ver. 1.0).** 1990. ICLARM Software 6, 22 p. Distributed with one 5-1/4" MS-DOS diskette for US$20 (airmail). Software 6 is available free of cost for cooperators of the ICLARM project "Global Comparisons of Multispecies Trophic Models". Please contact V. Christensen for further details.

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