SOUTH PACIFIC COMMISSION

WORKSHOP ON PACIFIC INSHORE FISHERIES RESOURCES
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STOCK ASSESMENT: COMPUTER PROGRAMS FOR USE IN TROPICAL FISHERIES

Michael King

Abstract:

A suite of computer progams to estimate biological parameters and yield in tropical fisheries is presented. The programs are written in BASIC for the Apple MacIntosh and are easily adaptable for other computers in use in the Pacific region.
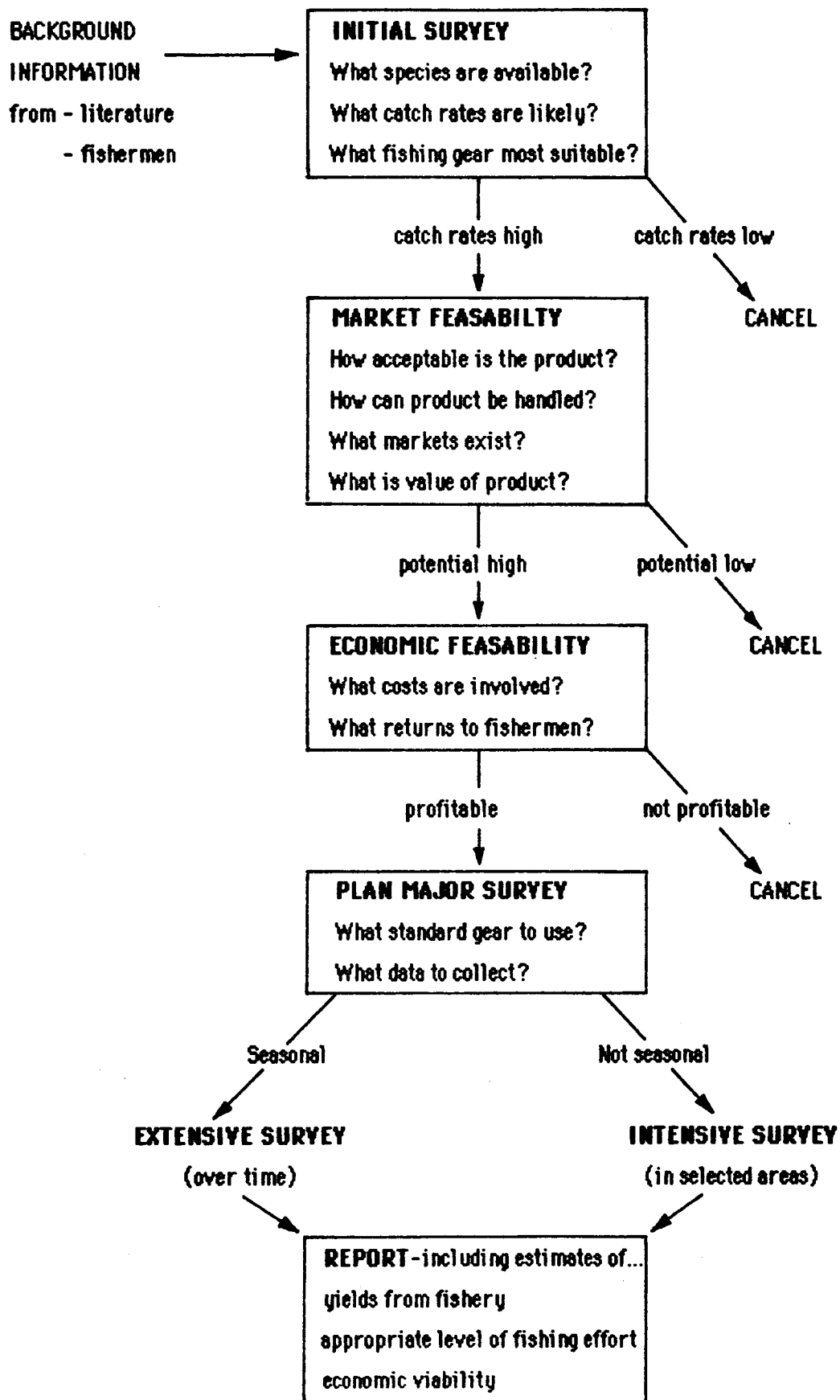
Introduction:

The assessment of a fishery involves a study of the stock, catch, marketing and economic viability. Surveys of potential or existing fisheries resources should attempt to address all of these aspects and a possible procedure is outlined in Figure 1. Two aspects of the suggested survey procedure are of note.

a) An initial or small-scale survey should always be carried out. If results are not encouraging, the option of cancelling or discontinuing should be invoked to cut the costs involved in a major survey.

b) Biological aspects are only a small (albeit important) part of the survey; in any case, all biological studies should be directed towards assessing the potential of the fishery.

Taking into account the above points, this paper addresses the biological assessment of tropical fish stocks. The problems involved are well known and include the large diversity of tropical species and the small amount of research effort available for assessing the stocks.

177/88

Figure 1: Sequential steps in appraising potential fishery resources. Note the option to cancel at each stage.

BACKGROUND
INFORMATION
from - literature
    - fishermen

INITIAL SURVEY

What species are available?

What catch rates are likely?

What fishing gear most suitable?

catch rates high   catch rates low

                          CANCEL

MARKET FEASABILTY

How acceptable is the product?

How can product be handled?

What markets exist?

What is value of product?

potential high   potential low

                        CANCEL

ECONOMIC FEASABILITY

What costs are involved?

What returns to fishermen?

profitable   not profitable

                    CANCEL

PLAN MAJOR SURVEY

What standard gear to use?

What data to collect?

Seasonal   Not seasonal

EXTENSIVE SURVEY   **INTENSIVE SURVEY**

(over time)   (in selected areas)

REPORT-including estimates of...

yields from fishery

appropriate level of fishing effort

economic viability

Fisheries biologists contribute to fisheries studies in two main areas; first, by studying the basic biology and distribution of resource species (which leads to the elucidation of the species' life-cycle) and secondly, by studying the population dynamics of the species. In both cases, research is directed towards gaining information which can be used to assess and manage the resource.

In order to discuss population dynamics, it is instructive to consider a fish stock as a simple biological system (Figure 2). In this system, the stock biomass is increased both by the growth of individuals and by recruitment (the addition of small individuals to the fishable stock). The stock also is being reduced by natural mortality (mostly by predation) and, in the case of exploited species, by fishing mortality as well.
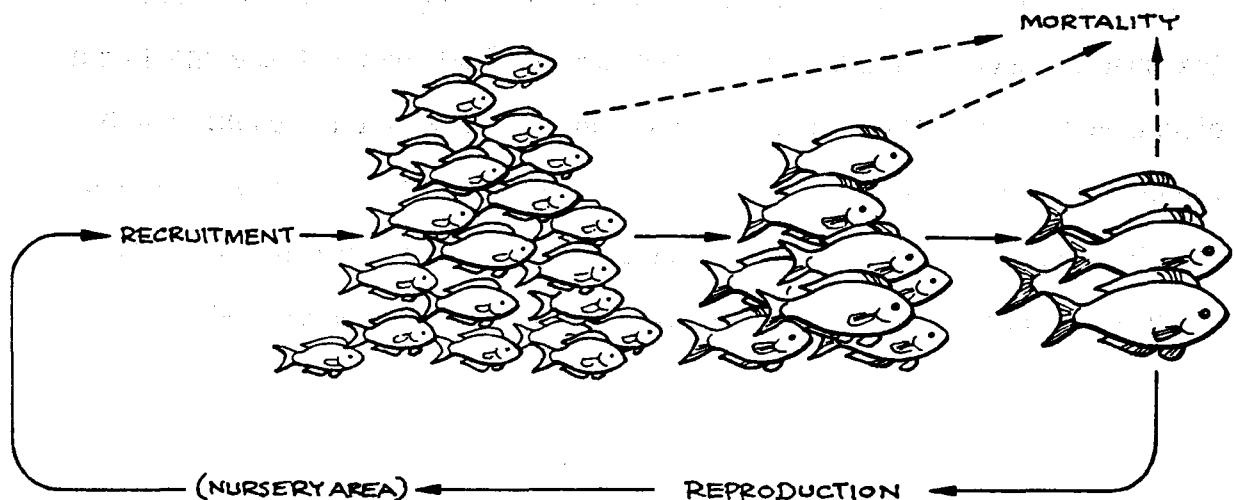

Figure 2: A fish stock viewed as a biological system. Three separate year classes are shown, all of which are reduced by mortality. In an equilibrium situation losses due to mortality are balanced by the recruitment of sub-adults, in some cases, from a nursery area.

In species which are unexploited or exploited at a low level, losses due to mortality are balanced, on the average, by gains through recruitment. Stock

abundance will, therefore, fluctuate around a mean level. If exploitation is high, however, the stock may be reduced to a level where reproduction and recruitment are affected.

A major task of biologists is to estimate the population parameters summarised or implied in Figure 2, namely stock abundance, growth, recruitment and mortality. It should be noted however, that the system is dynamic and values of the parameters may fluctuate widely, even in the absence of fishing. Several standard texts are devoted to methods of obtaining estimates of these parameters, including Ricker (1975), Pauly (1980), Pitcher and Hart (1982) and Gulland (1983). The use of computers in this respect is increasing, and in keeping with the aims of this workshop, simple methods of estimating stock parameters and yield are presented in the form of 'user-friendly' computer programs. Their ease-of-use should not discourage users from critically examining the bases of the models, which range from simple to more complex ones. In most cases, the more simple or "rough" the model is, the less input data are required - note that all models of complex systems are rough, but some are less rough than others!

STRATSAMP

M. King

Aim:

To estimate the abundance of a species over its area of distribution by stratified sampling.

Background:

The abundance of a species in a large area may be estimated by sampling - i.e. by counting the number of individuals in smaller areas or quadrats. The precision of such estimates can be improved by increasing the number of quatrats sampled and/or by concentrating sampling in areas of high density (stratified sampling - see Saville, 1977).

Based on an initial survey (or other prior information) the area is divided into strata of low and high density. The figure below represents (as black dots) the distribution of beche-de-mer around a sand bank - the total area is conveniently divided into two strata by the 10 m depth line. The following table can be constructed:

STRATUM	AREA RATIO	DENSITY RATIO	COMBINED RATIO
A (5-10m)	53	3	159
B (<5 and >10 m)	77	1	77

The combined ratio (approximately 2:1) suggests the relative sampling effort in each stratum. That is, if only 12 samples are used, 8 should be taken from A and 4 from B.

The Program:

The program requires the user to input the number of strata before entering the count from each quadrat. Outputs give all relevant statistics including an estimate of the total absolute abundance with 95% confidence limits.

```
  🍎 File  Edit  Search  Run  Windows
                    STRATSAMP
*****************************************
STRATSAMP                M.KING   JAN.1988
*****************************************
THIS PROGRAM WILL PROVIDE AN ESTIMATE OF
POPULATION SIZE BY STRATIFIED SAMPLING

ENTER NUMBER OF STRATA (maximum of 3)?
```

```
  🍎 File  Edit  Search  Run  Windows
 ▭ ═══════════════════ STRATSAMP ═══════
statistics for each stratum are...
************************************
                  STRAT A   STRAT B   STRAT C
************************************
        means =   16.25     6.50     0.00
     variance =   28.50     9.67     0.00
no. of samples =     8         4        0

statistics for total area are .......
*************************************
         stratified mean =   10.625
   variance of stratifed mean =  1.44203
  95% confidence limit (+/-) =  2.449725
       estimated STOCK SIZE =  1381.25
        range for 95% limits =  1062.786 to 1699.714
```
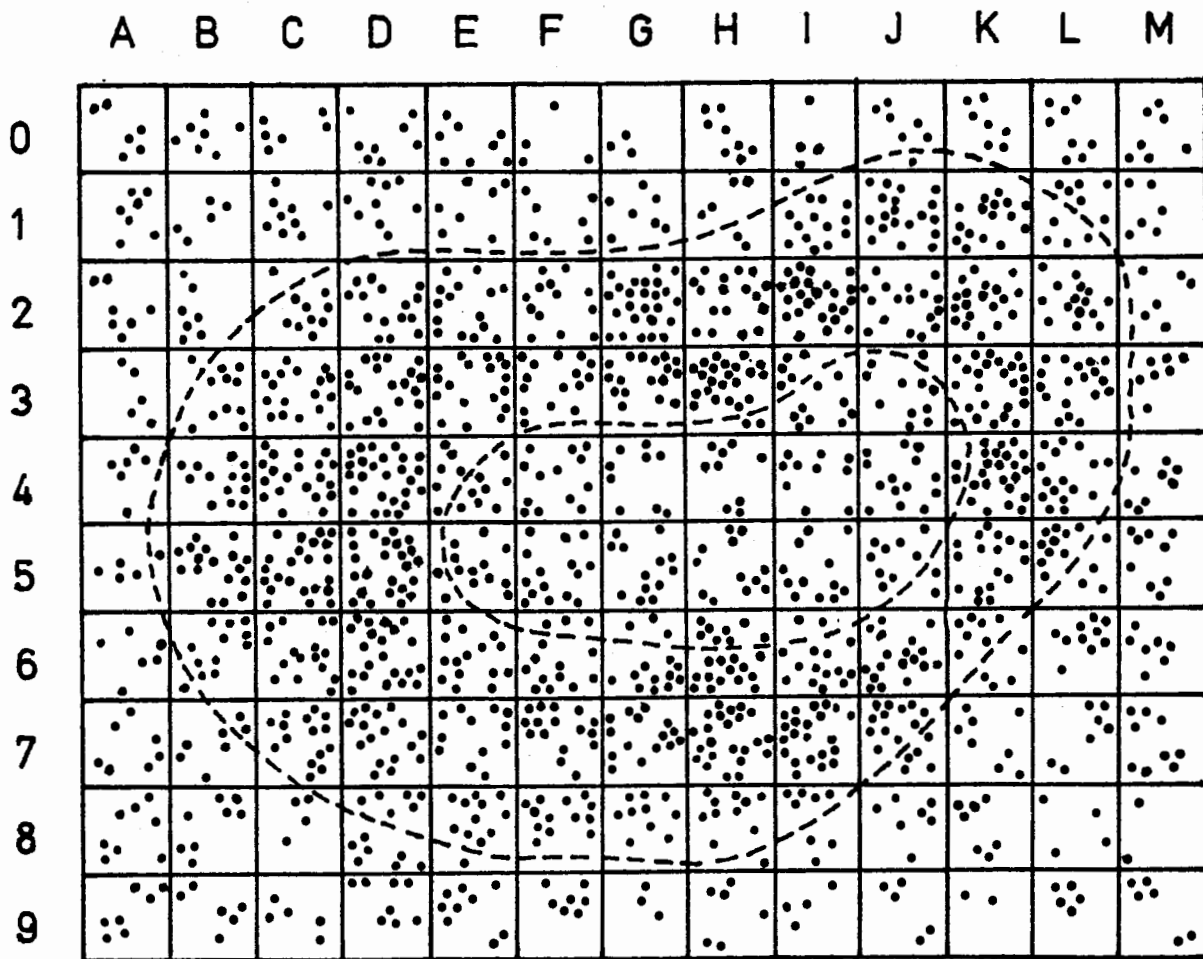
NOTE:

There are several rough estimators of yield (Y) which can be used if estimates of stock abundance, or biomass (B), are available:

$Y = 0.5 \, M \, B$ ....(if stock is unexploited; Gulland, 1983)...where M=natural mortality.

$Y = 0.5 \, (A + MB)$ ....(if stock is exploited; Cadima, 1977)..where A=annual catch.

Distribution of beche-de-mer (black dots) around a sand bank. 5m and 10m depth contours are shown by broken lines.

POWER   M. King

Aim:

To estimate the relationships between length and weight for a given species.

Background:

If an animal grows at the same rate in all linear dimensions, (i.e. increase in length, width and height are proportional) growth is said to be isometric. If an animal growing isometrically doubles in length, its weight will increase in relation to the increase in volume (by 2^3 times). Thus there is a cubic or power curve relationship between length (L) and weight (W):

$$W = aL^b$$

where b has a value close to three for isometric growth and a is a constant determined empirically. Power curves can be fitted to length and weight data by transforming the above equation to a linear form using natural logarithms as $Ln\ W = Ln\ a + b\ (Ln\ L)$....i.e., the data may be treated as a linear regression by plotting LnW against LnL to estimate a as the antilogarithm of the intercept anb b from the slope.

The program:

The program allows the user to either,

a)select sample data (from the Pacific oyster - in DATA statements which may be altered), or,

b) select to enter their own data from the key-board.

The coefficient of determination (r^2) is provided to express the degree of association between the two variables and takes values between zero (no correlation) and one (perfect correlation). Statistical tables can be consulted to determine if the value of r^2 is significant; i.e., to find the probability of the correlation arising by chance alone.
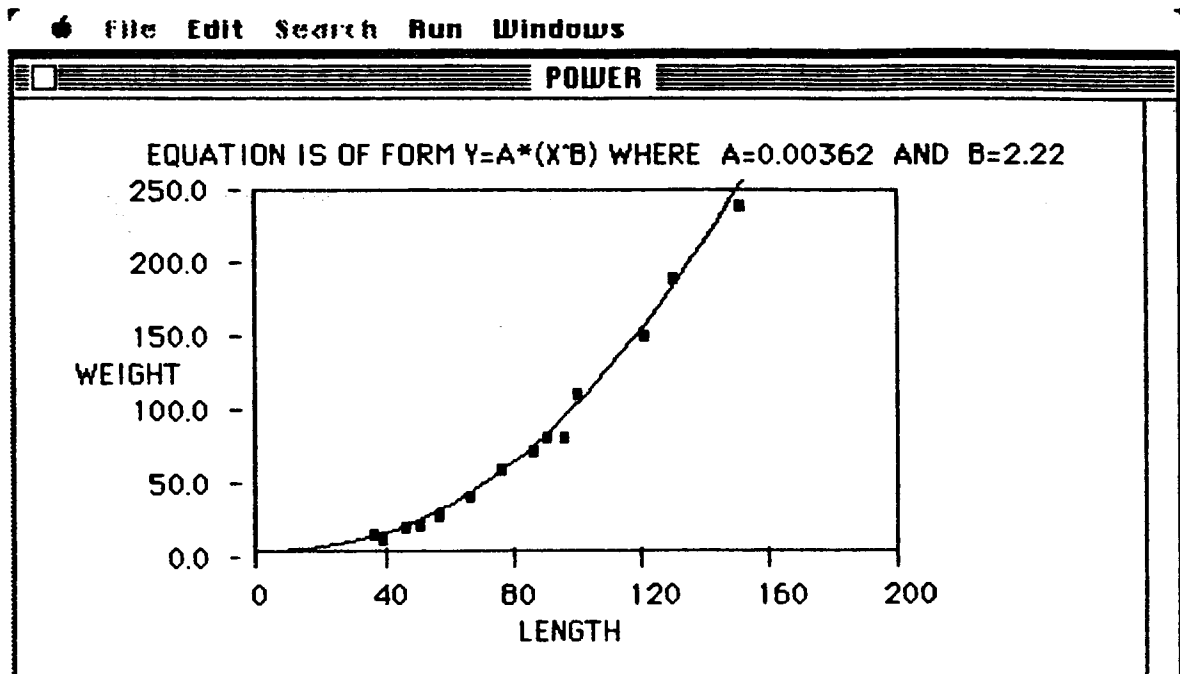
LOGISTIC   M. King

Aim:

To fit a logistic curve through data representing either...

   a) the proportion of ripe females by size: - to estimate the mean length at reaching sexual maturity, or,

   b) the selectivity of fishing gear such as traps - to estimate the mean length at first capture.
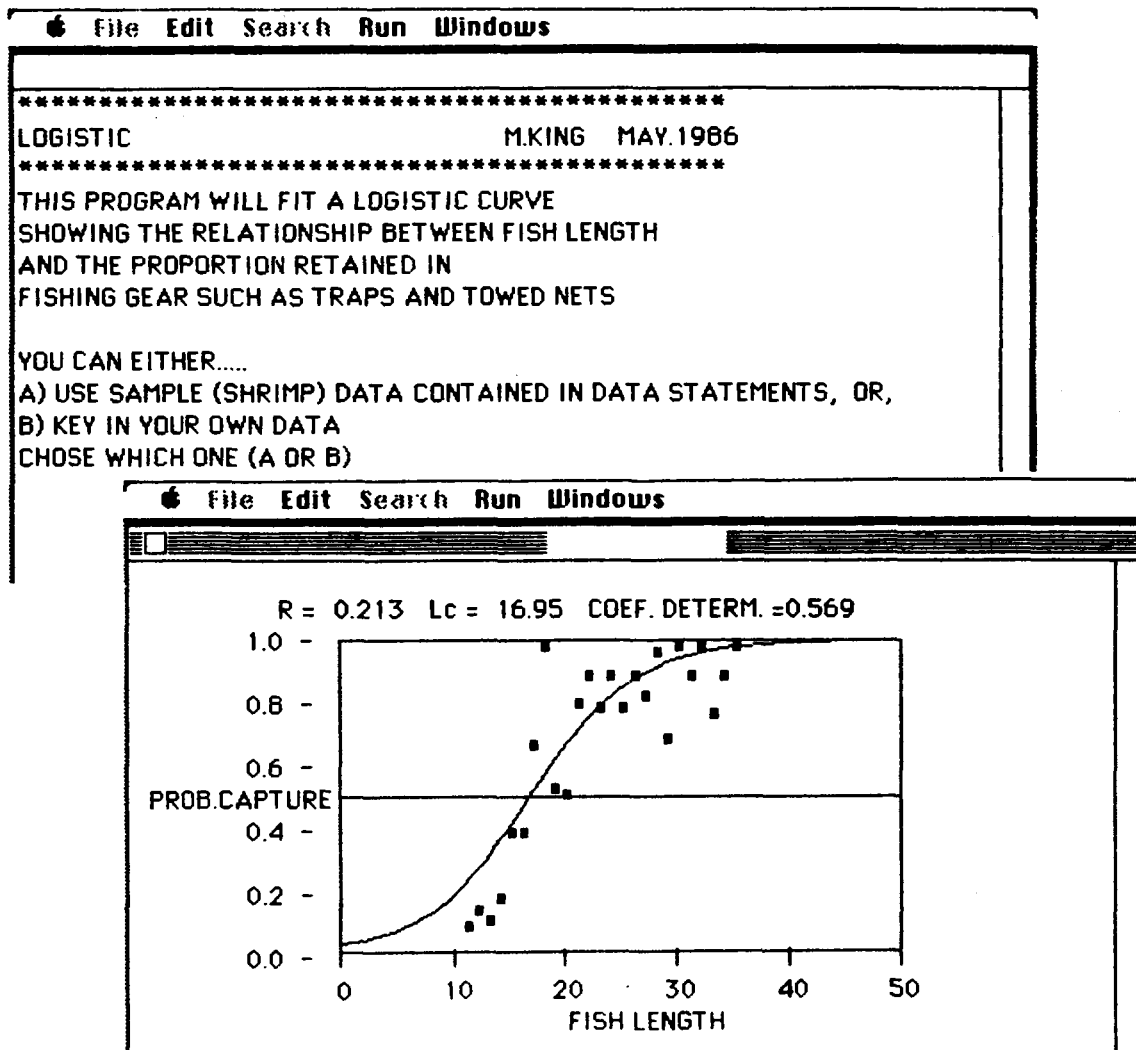
Background:

The logistic equation is ....

   $$P = 1/(1 + EXP[-r_m(L-L_c)])$$

......where (in terms of gear selectivity), P is the proportion retained, L is the length, r_m is the 'steepness' of the curve, and L_c is the mean length at first capture.

The Program:

The program prompts the user to enter a set of data representing the proportion retained (P) at each size class (L). Note that P must not take values less than zero or equal to or greater than one. Sample data are from deep-water shrimps caught in 18 mm chicken-wire traps in Fijian waters.

```
  🍎  File  Edit  Search  Run  Windows

**************************************************
LOGISTIC                        M.KING   MAY.1986
**************************************************
THIS PROGRAM WILL FIT A LOGISTIC CURVE
SHOWING THE RELATIONSHIP BETWEEN FISH LENGTH
AND THE PROPORTION RETAINED IN
FISHING GEAR SUCH AS TRAPS AND TOWED NETS

YOU CAN EITHER.....
A) USE SAMPLE (SHRIMP) DATA CONTAINED IN DATA STATEMENTS,  OR,
B) KEY IN YOUR OWN DATA
CHOSE WHICH ONE (A OR B)
```

```
  🍎  File  Edit  Search  Run  Windows


         R =  0.213   Lc =  16.95   COEF. DETERM. =0.569
    1.0 -

    0.8 -

    0.6 -
PROB.CAPTURE
    0.4 -

    0.2 -

    0.0 -
        0      10     20     30     40     50
                    FISH LENGTH
```

VONBERT   **M. King**

Aim:

To estimate the von Bertalanffy growth parameters and construct a growth curve.

Background:

Several models have been used to express growth using simple mathematical equations (Allen, 1971). The von Bertalanffy growth equation, possibly because of its incorporation into fisheries yield equations by Beverton and Holt (1957), has been most commonly used in studies on marine species. This model, based on physiological concepts, has been found to fit data from a wide range of species, although the use of any single model is unlikely to represent growth over the entire lifespan. The von Bertalanffy equation, in terms of length is:

$$L_t = L_\infty \left(1 - EXP[-K(t-t_0)]\right)$$

where L_t is the length at age t, L_∞ is the theoretical maximum (or asymptotic) length that the species would reach if allowed to grow indefinitely, and K is a growth coefficient. As a species is unlikely to grow according to the above equation throughout its whole lifespan (particularly in the pre-adult stage) the curve often cuts the x-axis at a value less than zero - hence t_0 (the theoretical age at zero length) often has a small negative value.

The program:

The program produces a Ford-Walford plot from data (representing equal time intervals) entered from the keyboard. The estimated values of K and L_∞ are used to construct a growth curve.
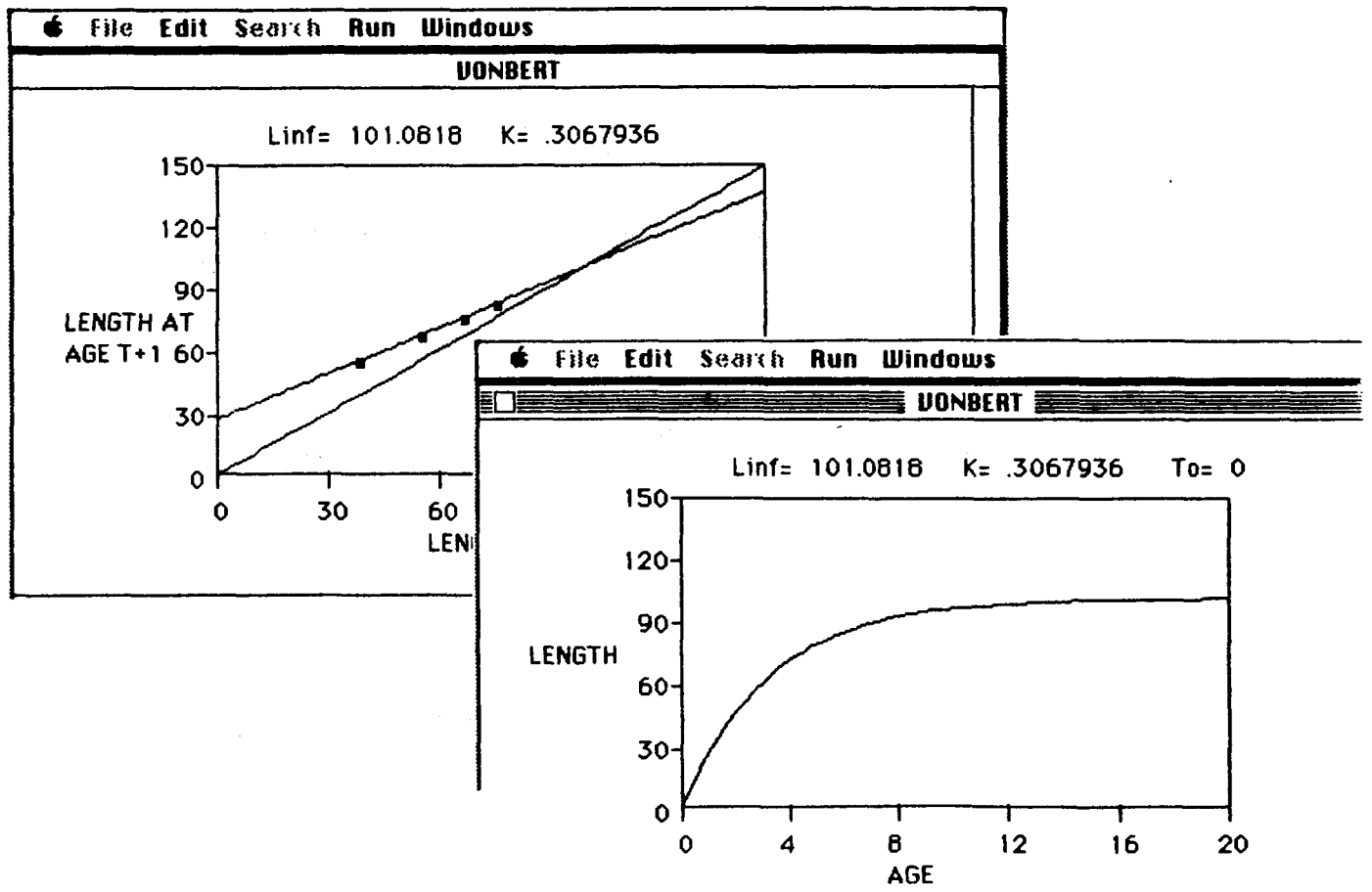
(various programs)

Aim:

To estimate growth from length - frequency data.

Background:

In a fast-growing species with a brief annual spawning period, several year classes may be clearly evident in length-frequency distributions. If the spawning period is long or growth is slow, the older size-classes in particular may "bunch" together in the length -frequency distribution, making separation difficult. In these cases, graphical or computer-based analyses may assist in "breaking up" the distributions into the component groups which represent separate age classes. Cassie's graphical method (1954) has now been superseded by computer programs such as ELEFAN 11 (Pauly et al., 1981) and MIX (Macdonald and Green, 1985). ELEFAN is claimed to separate the distribution into groups in a more objective manner than visual techniques although some subjectivity may still be involved in interpreting the results from difficult data sets.

The program:

The program MIX, which requires the user to indicate the asssumed number of age groups in the sample, is applied to the length-frequency data shown below.
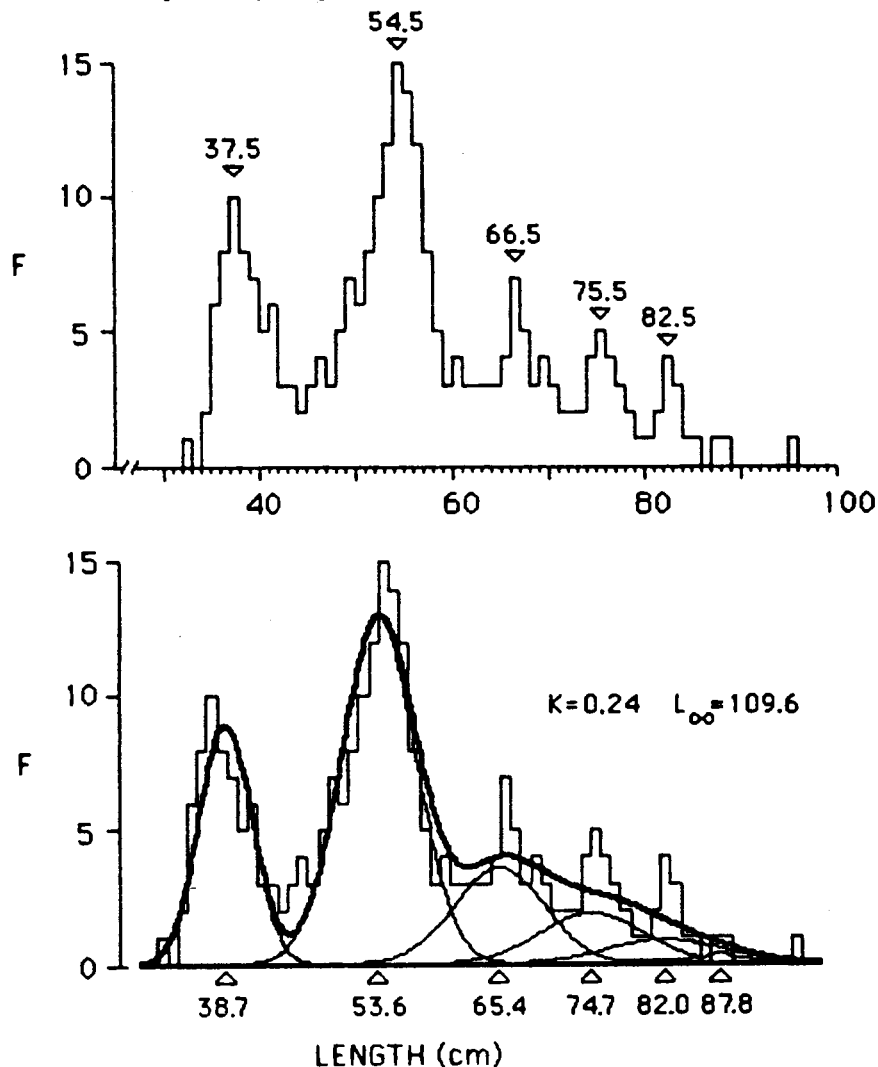
LENGTH (cm)

GULLHOLT   **M. King**

Aim:

To estimate the von Bertalanffy growth parameters from data collected at unequal time intervals.

Background:

If a fish has a length of L_1 at time T_1, and a length of L_2 at time T_2, the growth rate per unit time is

$(L_2-L_1)/(T_2-T_1)$. This growth rate can be plotted (Gulland and Holt, 1959) against the average

size of the animal between times one and two, $(L_1+L_2)/2$.

The method is useful where data (from modal progression or mark-recapture experiments) are
obtained at unequal time intervals. The table below shows a small set of length-frequency data for a
tropical bivalve (Amusium) - from Joll,1987.

The program:

The user is prompted to enter time and length data from the key-board. The first output graphs
growth rate against mean length; the intercept on the x-axis (where the growth rate is zero) is
therefore an estimated of L_∞, and the slope (with sign changed) an estimate of K. The second output

is a von Bertalanffy growth curve.

GULLHOLT

LInf= 109.2554   K= 5.728715E-02

GROWTH (mm/wk)

MEAN LENGTH (mm)
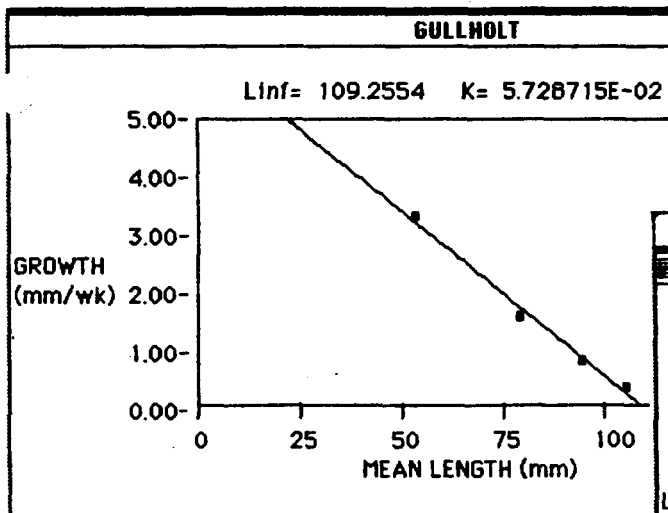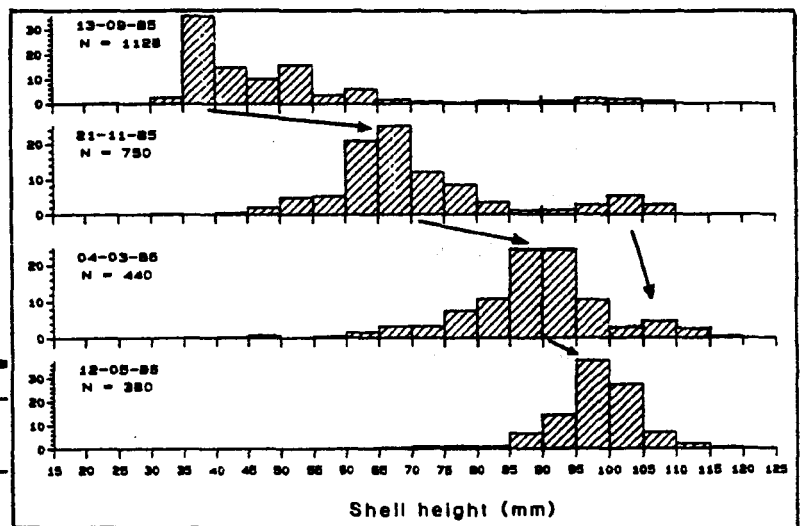
Note:

an alternative method of dealing
with the above data is by using the
program SEASONGROW -see appendix.

File Edit Search Run Windows

GULLHOLT

Linfinity= 109.2554   K= 5.728715E-02   assuming to=zero

LENGTH (mm)

AGE (weeks)
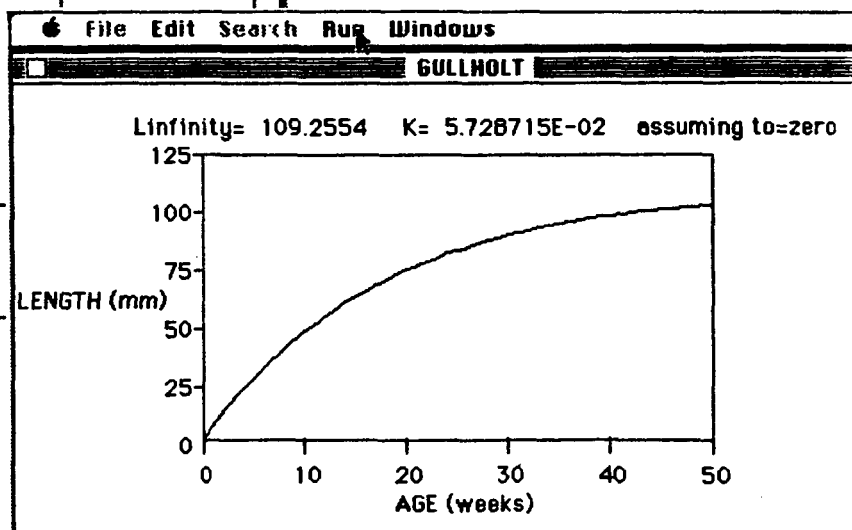
STOCKREC M. King

Aim:

To estimate the relationship between stock size and recruitment.

Background:

The relationship of the number of new recruits to the size of the spawning stock is of interest because it provides insight into what happens to recruitment when a fish stock is reduced by fishing. Two models have traditionally been used to describe stock-recruitment relationships. The Beverton and Holt (1957) equation suggests that recruitment approaches an asymptote at high stock densities.

$$R = S/(a+bS)$$

where R is the number of recruits, S is the number of individuals in the spawning stock and a and b are the parameters of the curve. The output below shows a series of Beverton and Holt curves for different values of a.

The Ricker (1975) equation describes the situation where recruitment reaches a maximum before decreasing at higher levels of stock abundance.

$$R = a S EXP(-bS)$$

where R is the number of recruits, S is the number in the spawning stock and a and b are the parameters of the curve. The output below shows a series of Ricker curves for different values of b. This model suggests the presence of density dependant mechanisms, perhaps adults complete more successfully for the same resources as juveniles, or adults prey on young of the same species.

The program:

The program (based on the Ricker equation) contains sample data from a penaeid prawn (DATA statements may be altered by the user).
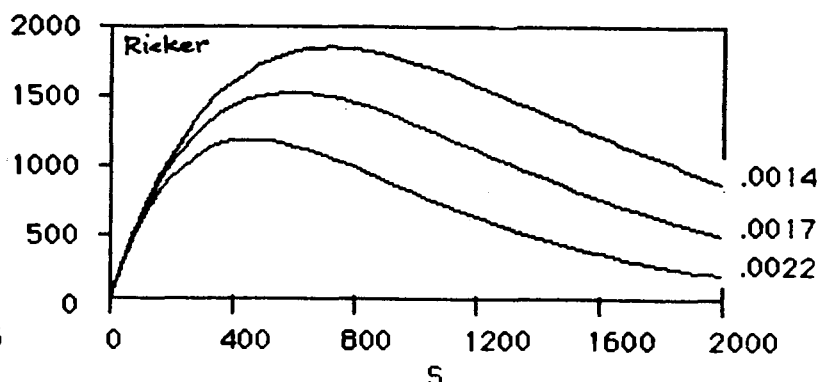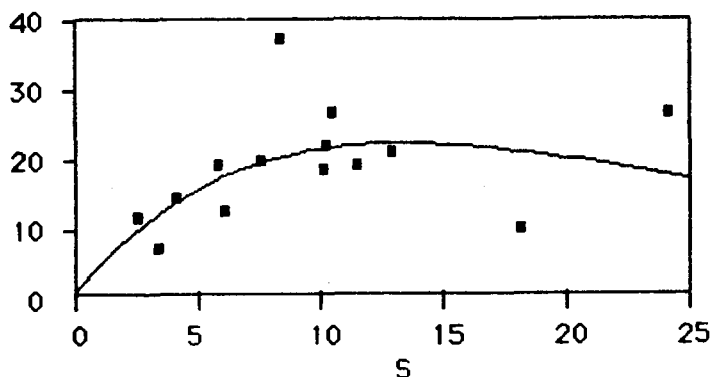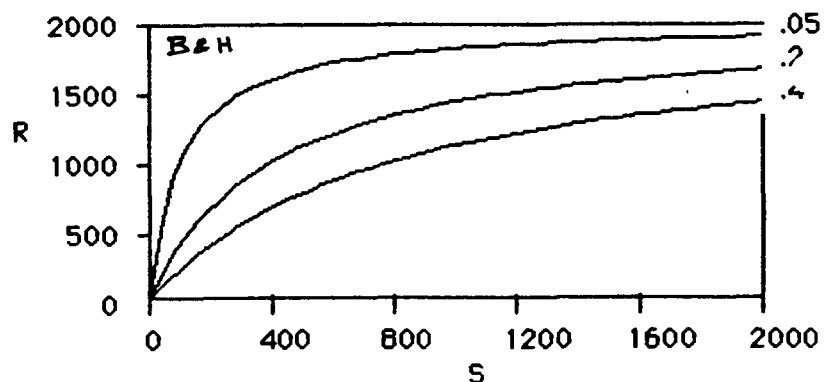
CATCHCURVE
M. King

Aim:

To estimate mortality rates by means of a catch curve.

Background:

Under the assumption of a constant rate of mortality, population numbers surviving will tend to decline exponentially with time as :

$$N_t/N_0 = EXP\ (-Zt)$$

where N_0 is the initial number of individuals at time t=0 and N_t is the number remaining at time t.

Thus the number of individuals surviving over time is of the form of a negative exponential as shown in the output below right.

This equation can be rearranged to give the linear equation:

$$LnN_t = Ln\ (N_0) - Zt$$

Graphing the natural logarithms of numbers surviving over age will therefore produce a straight line relationship referred to as a "catch curve" (Beverton and Holt, 1957; Ricker, 1975). A line of best fit through these data will have a slope numerically equal to the instantaneous mortality rate Z.

The program:

The program requires the user to input the von Bertalanffy growth parameters K, L_∞ as well as length-frequency data.
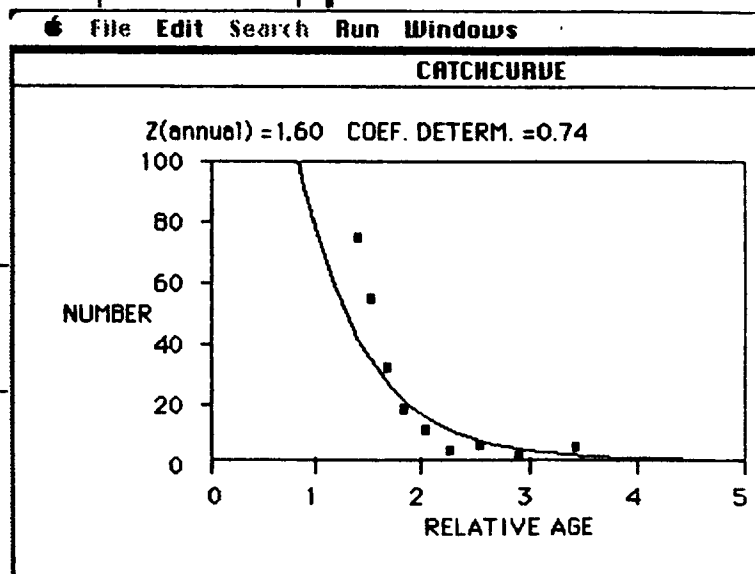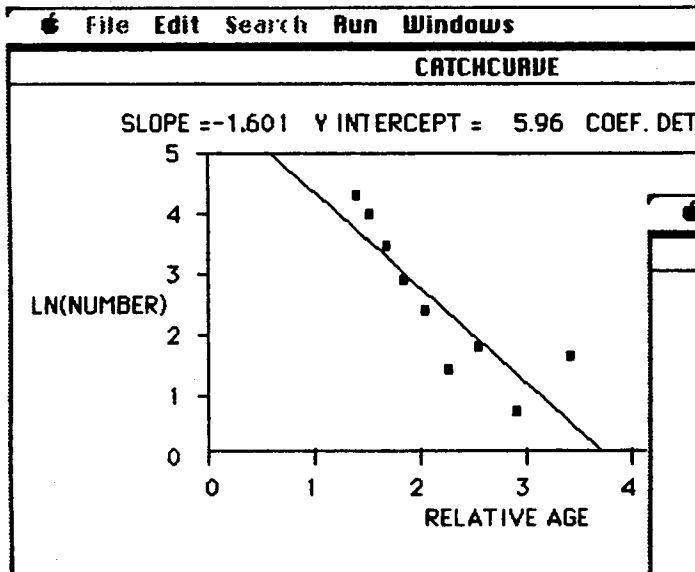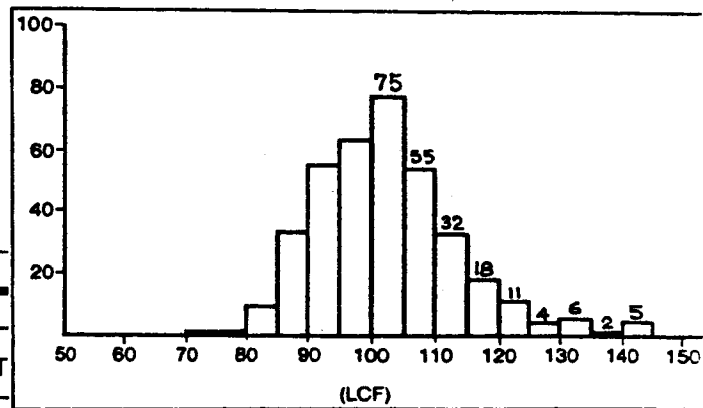
NOTE: The above case

(based on Spanish mackerel

data -from McPherson,1985)

assumes that recruitment either

does not vary, or does so randomly

SURPYIELD   M. King,

Aim:

To estimate the maximum sustainable yield and the corresponding level of fishing effort.

Background:

When fishing mortality is imposed on a stock, the number of recruits to the fishery is often increased. Larger fish are removed from the stock, allowing more food and other resources to be made available for smaller, faster-growing individuals. These factors allow an increased harvestable surplus (recruitment plus growth minus mortality) under exploited conditions. Surplus yield models have been widely used in managing fisheries largely because they are based on catch and effort data, which are relatively easy to obtain. The main disadvantage with the models is that it ignores the biological processes (growth, recruitment and mortality) which affect the stock biomass. The assumption of an "equilibrium state" also fails to allow for the fact that the age structure of the stock, and therefore the biological parameters, will alter with increased exploitation.

More recent versions of the model allow for the influence of previous years on the current rate of biomass change, thereby avoiding the assumption of an equilibrium state. Another major advance is the incorporation of variability or randomness in the model (e.g. Schnute, 1977 - see Stochastic models).

The Program: Two yield curves are produced, based on ..
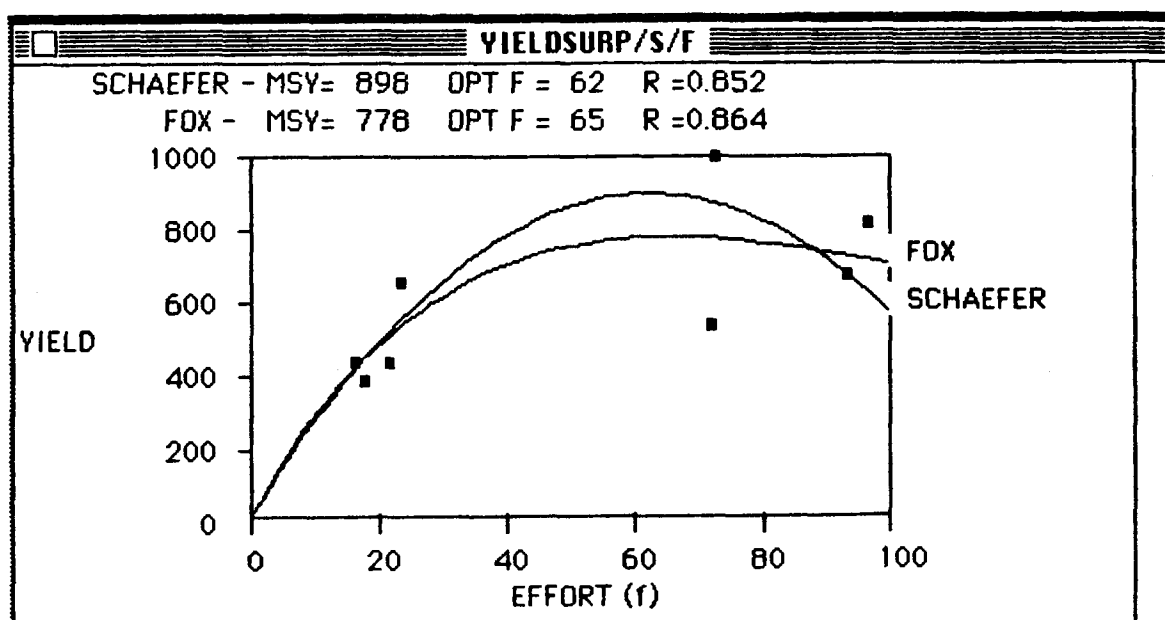
a) the original Schaefer (1965) model: $Y = af - bf^2$

where a and b are constants estimated by a reression of catch per unit effort (c/f) against fishing effort(f).

b) the Fox (1975) model: $Y = f\,EXP(a-bf)$

where a and b are constants estimated by a regression of the natural log of catch per unit effort (Ln c/f) against fishing effort (f).

Goodness-of-fit values are included to assess the most appropriate model. Sample data (from a tropical estuarine fish) are included in DATA statements which may be altered for different cases.

```
═══════════════════════════ YIELDSURP/S/F ═══════════════════════════
     SCHAEFER - MSY= 898    OPT F = 62    R =0.852
         FOX -  MSY= 778    OPT F = 65    R =0.864
```


SCHAEFER - MSY= 898   OPT F = 62   R =0.852
FOX - MSY= 778   OPT F = 65   R =0.864

BIOMASS   **M. King**

Aim:

To estimate the age at which stock biomass is maximised for a given recruitment .

Background:

After recruitment, the total weight or biomass of a stock changes in response to growth in individual weight and the reduction in numbers due to natural mortality. Growth and mortality curves may be combined to give a biomass curve, which reaches a maximum or "critical point" at a particular age.
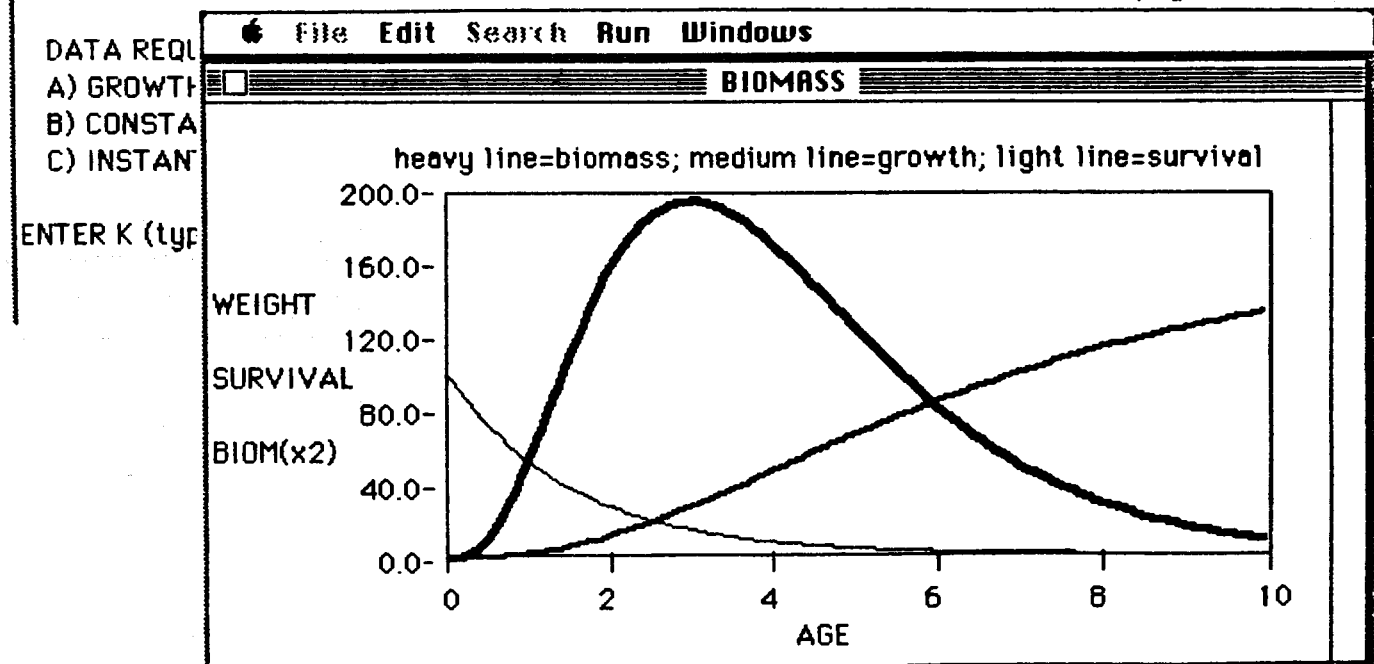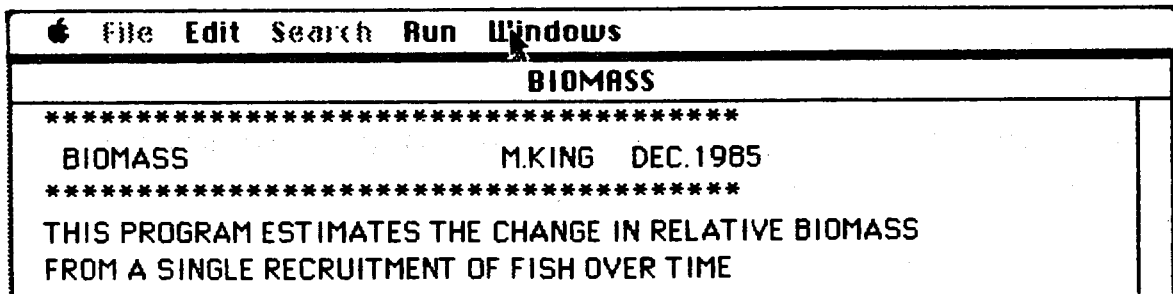
The program:

The program requires the user to input (from the keyboard) ....

a) the von Bertalanffy growth parameters K and L_∞.

b) the constants a and b in the length to weight conversion equation $W=aL^b$

c) the natural mortality rate M

An example of the program output (for the deep-water shrimp, Heterocarpus laevigatus)is given below and suggests that the stock reaches a maximum biomass at about 3 years of age.

Inputs were $K = 0.27$, $L_\infty = 57$, $a = 0.0009$, $b = 3$ and $M = 0.66$

⌘ File   Edit   Search   Run   Windows

BIOMASS

```
*********************************
   BIOMASS                M.KING   DEC.1985
*********************************
THIS PROGRAM ESTIMATES THE CHANGE IN RELATIVE BIOMASS
FROM A SINGLE RECRUITMENT OF FISH OVER TIME

DATA REQU
A) GROWTH
B) CONSTA
C) INSTAN

ENTER K (typ
```

⌘ File   Edit   Search   Run   Windows

BIOMASS

heavy line=biomass; medium line=growth; light line=survival

BEVHOLT   **M. King**

Aim:

To predict likely changes in yield resulting from changes in fishing effort and age at first capture.

Background:

The classical Beverton and Holt model (1957) considers the dependence of yield upon growth, age at first capture, and fishing mortality in particular.

The yield (catch in weight) of a single year class of fish from age at first capture (t_c) to some maximum age (t_m) is an integral of the fishing mortality (F), the number of fish present (N) and their mean weight (W). Integrated, the expression for yield per recruit becomes:

$$Y/R = [\, F.EXP(-M(t_c-t_r))\, W_{oo}]\, \sum_{n=0}^{3}\, [\, U_n\, EXP(-nK(t_c-t_0))/(Z+nK)\,]\, [1-EXP(-(Z+nK)(t_m-t_c))]$$

where U is the summation constant in the cubic expansion of the growth equation and n is the number of summations $(U_0=1,\ U_1=-3,\ U_2=3$ and $U_3=-1)$.

The main disadvantages of the classical model are its assumptions of a steady state (whereas parameters in an exploited stock may be changing), and the exclusion of recruitment (which is often highly variable).

The program:

The user is prompted to enter the parameters of the above equation to produce a Beverton & Holt yield curve, as shown below (example from deep-water shrimp - Fiji).
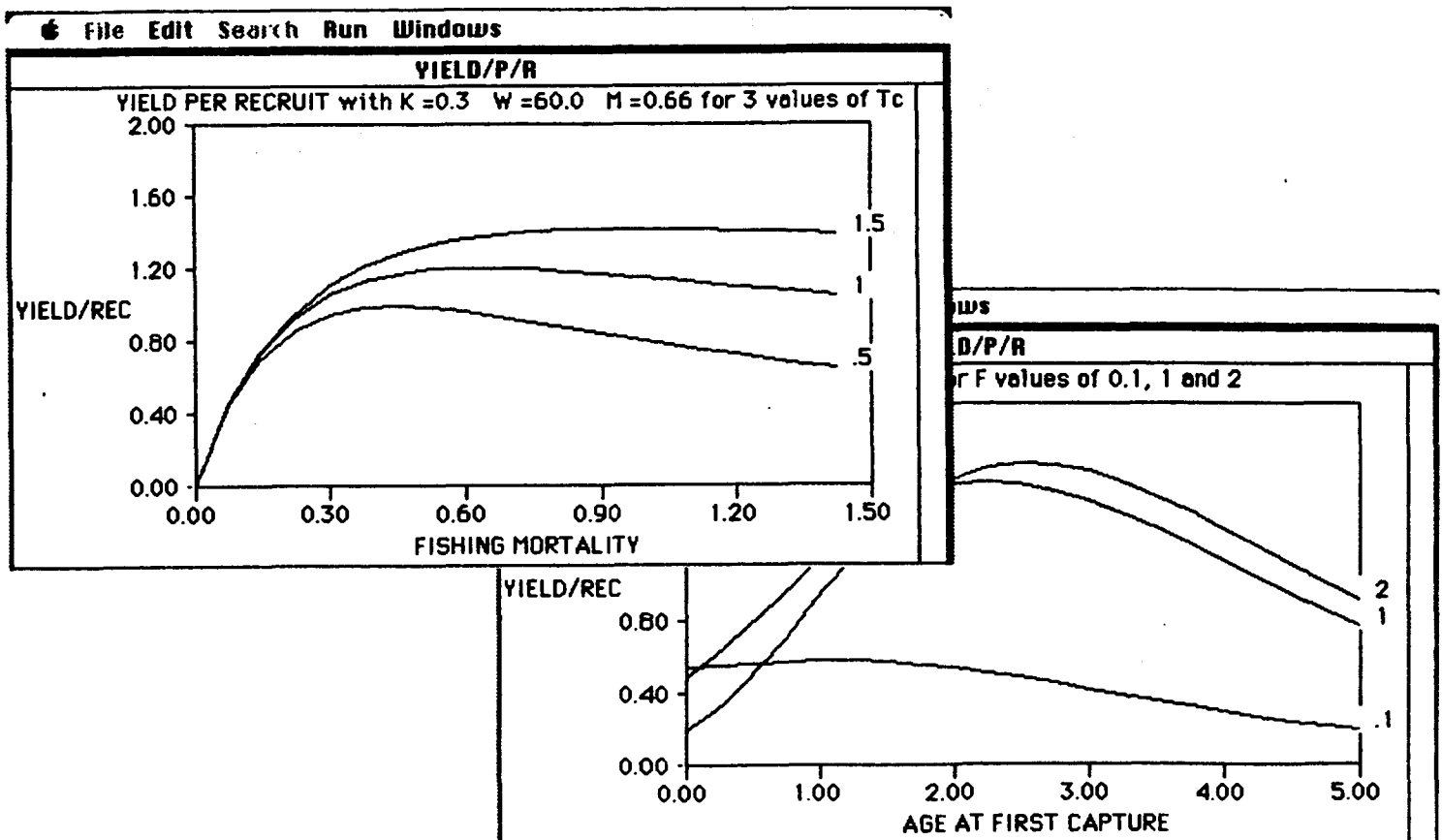
REEFGAME

M. King

Aim:

To estimate the optimum number of fishing units per km^2 of coral reef.

Background:

Simulation models allow the user to deal with complex systems and "try out" various management strategies. In a technique known as Monte Carlo modelling, simulations may be run repeatedly to estimate the probability of obtaining desirable outcomes (and the risk of undesirable ones!).

The Program:

The program has statements defining stock per km^2 of reef (S), natural mortality (M), fixed costs (FC), running costs (RC), and value of catch (V); these may be altered for particular fisheries. Recruitment (which is often unknown)is related to stock size using Ricker's (1954) equation although other models could be substituted. The program is stochastic in that recruitment is allowed to vary randomly (within a given range) above and below the predicted value.

The program allows the user to observe the effects of various levels of fishing effort on recruitment and catch; it is in the form of an instructional "game" in which the object is to maximise profits over a 50 year period.

Screen outputs during the progress of different runs are shown below.

Game ready >>

Hit return to start

Hit S to stop and

alter fishing effort

RECRUITMENT of juveniles	REEFGAME
	THIS PROGRAMME SIMULATES A REEF FISHERY OVER 50 YEARS
	YOU CAN USE UP TO 12 BOATS AND FISH UP TO 365 DAYS PER YEAR
FISHING EFFORT (hours)	- if you put in too many boats the fishery will collapse
	THE AIM IS TO MAXIMISE PROFITS
CATCH (nos.)	HIT RETURN TO START?

Recruitment increases >>

as the user adds 5 boats

- then crashes with

12 boats.

RECRUITMENT of juveniles	REEFGAME
	RECRUITMENT FAILURE AT YEAR 30 WITH 12 BOATS FISHING 100 DAYS PER YEAR
FISHING EFFORT (hours)	HIT RETURN TO RESTART?
CATCH (nos.)	

Game completed >>

with overall profit

RECRUITMENT of juveniles	REEFGAME
	HIT S TO STOP and alter fishing effort (max.12 boats)
	BOATS NOW 8 MEAN DAYS FISHED/YEAR 28
FISHING EFFORT (hours)	YEAR 50
	FISHING COSTS($)= 60800.0 CATCH VALUE($) = 91947 PROFIT($) = 31147
CATCH (nos.)	TOTAL PROFIT (m$)= 1.41
	ENTER 1 TO FINISH OR 2 TO RESTA:

REFERENCES (including further information and data sources):

Allen, K. R. (1971). Relation between production and biomass. J. Fish. Res. Board Can. 28, 1573-1581.

Beverton, R. J. H., and Holt, S. J. (1957) On the dynamics of exploited fish populations. Fish. Invest. Minist. Agric. Fish. Food UK. Series 2, 19.

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APPENDIX

A program for fitting an oscillating growth curve to length-age data when growth is seasonal

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This program is written in Microsoft Basic for the Apple Macintosh and is based on a modification of the von Bertalanffy growth equation suggested by Pauly and Gaschutz. The modification incorporates a sine wave into the usual growth formula so that:

$$L_t = L_\infty \{1 - \exp[-k(t-t_0) + ck/2\pi \sin 2\pi(t-t_s)]\}$$

where

L_t is length at age t

L_∞ is the asymptotic length

k is the growth constant

t_0 is the age at zero length

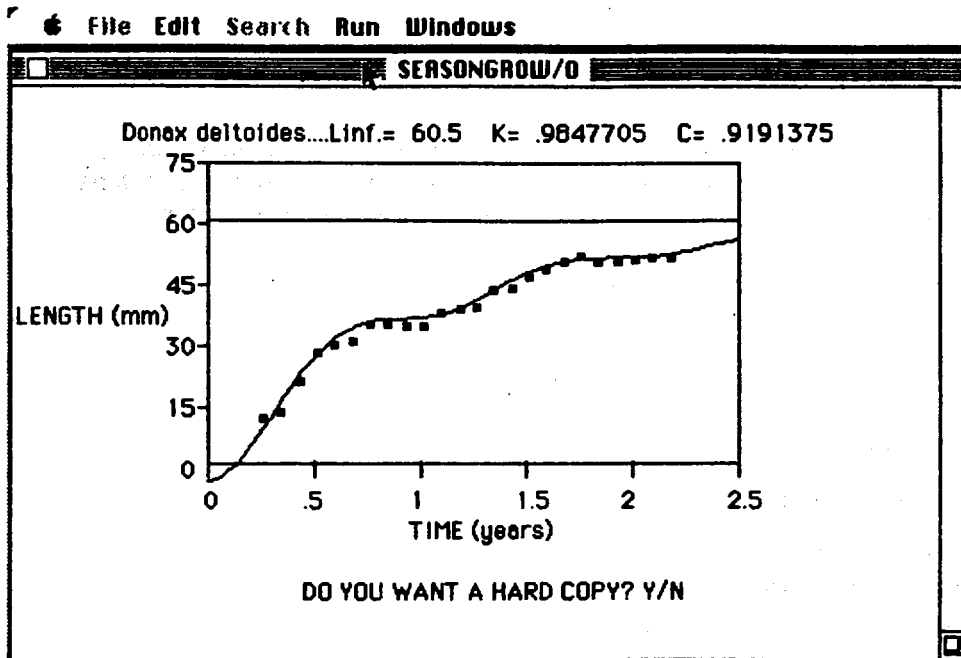c is the amplitude of the growth oscillation

t_s is the start of the growth oscillation with respect to t_0.

This program is useful in analysing length-age data where there are suspected seasonal variations in growth although it can also be used where there are no such variations. When $c=1$ the mid-winter growth rate is zero. Values less than 1 indicate a seasonal slowing down of growth and when $c=0$ the equation is equivalent to the unseasonalised von Bertalanffy formula.

Two versions of the program have been written. One which has sample data contained in data statements and another which prompts the user to enter length and age data pairs from the keyboard. The program provides estimates of all parameters in the seasonalised equation except L_∞ (an independent estimate of this parameter is required).

In each version the user has the option of producing a graph which includes the data points. The example below uses sample data (in version one) from length-frequency distributions of the Goolwa cockle or pipi *Donax deltoides* near the mouth of the Murray River, South Australia.

(The following graph is a reproduction of a Macintosh screen snapshot; the program gives you the option of producing a hardcopy - ed)

 File   Edit   Search   Run   Windows

 SEASONGROW/0

Donax deltoides....Linf.= 60.5   K= .9847705   C= .9191375

LENGTH (mm)

TIME (years)

DO YOU WANT A HARD COPY? Y/N