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New Zealand Fisheries Assessment Research Document 88/4

A generalised bioeconomic simulation model for fish population dynamics

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December 1988

MAFFish, N.Z. Ministry of Agriculture and Fisheries

New Zealand Fishery Assessment
Research Document 88/4

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by

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Introduction

Simulation models are useful for investigating the dynamic behaviour of complex systems. The model presented here is reasonably simple, yet flexible. It has been developed gradually over the past two years in response to the needs for summarising existing biological and economic data, performing stock assessments with sparse data and/or large uncertainty in parameter estimates, and evaluating the likely biological and economic consequences of alternative management actions.

We first outline the purposes of the model and its general features. This is followed by the focus of the paper: a detailed description of the equations and options used in the model. The description is developed with reference to a flow chart showing the sequence of calculations (Figure 1), and a table that lists and describes the parameters that can be specified, and the variables that can be tabulated or graphed (Table 1). Alternative models that represent slight variations of the main model are then presented. Limitations of the models are discussed briefly. Three appendices contain supplementary information: how to run the model(s) on the Pyramid 98xe at Fisheries Research Centre (Appendix I); an annotated demonstration example (Appendix II); and an annotated library of sets of commands that can be used to manipulate the model (Appendix III).

Purposes of the Model

The overall objectives of the model are to:

(i) Synthesise existing biological and economic data
(ii) Calculate estimates of optimum yield
(iii) Investigate the effects of uncertainty in parameter estimates
(iv) Investigate the effects of variability in stock production
(v) Determine the likely consequences of alternative management strategies, from both biological and economic perspectives
(vi) Identify priority areas for future research.

General Features of the Model

The model is a discrete time, dynamic pool (age-structured) simulation model written in FORTRAN 77. It is linked with SIMCON, a SIMulation CONtrol language (original source: R. Hilborn, J. Stander and W. Webb, Institute of Animal Resource Ecology, University of British Columbia, Vancouver, Canada) that handles all input, output and intervention needs. The reader is referred to the SIMCON user's guides (Mace 1988, Beals 1981) housed at Fisheries Research Centre, Greta Point, Wellington for instructions on the use of SIMCON. Although the model cannot be run without SIMCON, it is only necessary to learn about ten SIMCON commands to perform all necessary functions.

Parameters can be set interactively, or stored in a special file. Alternative sets of parameters can be stored in named MACROs (a MACRO is a set of SIMCON commands) and called interactively by name when required. MACROs may also be created interactively or stored in the special file. Simple SIMCON commands can be used to set parameter values (SET command), display the current value of a variable or parameter (DI command), change the value of a variable at a specified time (AT time command), perform a specified number of iterations of the model (SIM, GO and CONTINUE commands), tabulate the values of variables over simulated time (PR command), graph the values of variables over simulated time (VIEW, GRAPH and PLOT commands), compute basic statistics (minimum, maximum, mean, standard deviation, standard error) for specified variables over simulated time (STATS, ONSTAT commands), and restore any previous model state (TIME command).

Simulations begin with virgin recruited biomass and a stable (equilibrium) age distribution. Virgin biomass can be back-calculated using recent biomass, the catch history and demographic parameters. The parameters used to calculate virgin biomass, natural mortality, age of recruitment, age of maturity and growth can either be specified explicitly or drawn from probability distributions. Mean length of any subset of the population can be calculated for a specified age or length interval. There are four stock-recruitment relationships to choose from. Recruitment can be either deterministic or stochastic. There are four options for representing fishing: zero, or strategies based on specified fishing mortality, specified catch, or specified escapement. The economic submodel allows separate specification of fob price, fixed costs, variable harvesting costs and variable processing costs. There are four options for representing harvesting costs. A discount rate can be applied to calculate net present value.

The biological submodel can be run without the economic submodel, but the economic submodel cannot be run on its own.

The maximum number of iterations for a single run is about 1000. The model is sufficiently small and fast that results can be viewed interactively.

Model Description

The model is based on mid-season estimates of biomass. For example, it is assumed that the beginning of season number of fish of age 1 (i.e. recruitment to the population) is produced by the spawning biomass present at mid-season in the previous year. Thus to achieve accurate results mid-season should correspond approximately to the mid-point of the spawning season, fishing mortality should be spread more or less evenly either side of spawning and the von Bertalanffy growth curve should be calibrated (by altering t_0) so that the first birthday (age = 1) of the fish is approximately half a year after spawning.

Table 1 lists and describes the parameters and variables used in the model. In general, the user will want to set parameter values, and tabulate or graph variable values. Figure 1 summarises the sequence of calculations. The numbers used below correspond to those in the figure. FORTRAN names are given in brackets in upper case letters. Refer to Table 1 for further details on their usage.

1. Seeding the random number generator (ISEED)

The random number generator is reseeded in the same way (whether it is needed or not) each time the model is restarted. This means that the same random number sequence will be generated for consecutive runs (provided there is no change in the number of calls to the random-number generator) and results from different runs will be directly comparable.

2. Demographic parameters

Virgin biomass (VIRBIO), natural mortality (M), age of recruitment (AR), age of maturity (AM) and growth (K, LINF, TO) can be defined by their expected values or drawn from probability distributions. Separate random number indicators are set to "off" or "on" respectively depending on which option is required. The parameters are calculated at the beginning of a run and remain fixed throughout a simulation. They cannot be changed unless the model is restarted.

a) Virgin biomass (VIRBIO)

If the random number indicator (IRANDBIO) is 0, virgin biomass is set equal to a user specified constant (VIRBIOM).

If the random number indicator (IRANDBIO) is 1, virgin biomass is defined as follows. Mean biomass $\bar{B}$ is drawn from a uniform distribution such that

$$\bar{B} = \text{uniform}\,(\bar{B}_L, \bar{B}_H)\,\bar{\bar{B}}$$

with

$$\frac{\bar{B}_L + \bar{B}_H}{2} = 1$$

where $\bar{\bar{B}}$ is the mean of the distribution of means (VIRBIOM)

$\bar{B}_L$ is the smallest multiplier of $\bar{\bar{B}}$ (VIRBIOL)

$\bar{B}_H$ is the largest multiplier of $\bar{\bar{B}}$ (VIRBIOH)

Virgin biomass is then drawn from a normal distribution with mean $\bar{B}$, standard deviation σ (VIRSD), lower bound L (VIRMIN) and upper bound H (VIRMAX). Note that virgin biomass is assumed to be the mid-season recruited biomass.

(b) Instantaneous natural mortality rate (M)

If the random number indicator (IRANDM) is 0, natural mortality is set equal to a user specified constant (MMEAN).

If the random number indicator (IRANDM) is 1, natural mortality is drawn from a uniform distribution with lower bound L (MMIN) and upper bound H (MMAX).

(c) Age of recruitment (AR) and age of maturity (AM).

If the random number indicator (IRANDA) is 0, ages of recruitment and maturity are set equal to user-specified constants (ARMEAN and AMMEAN respectively).

If the random number indicator (IRANDA) is 1, ages of recruitment and maturity are drawn from uniform distributions with lower bound L-0.5 (ARMIN - 0.5 or AMMIN - 0.5) and upper bound H + 0.5 (ARMAX + 0.5 or AMMAX + 0.5). They are then rounded to the nearest integer. (Example: if ARMIN = 4 and ARMAX = 6 there will be an equal probability that AR = 4, 5 or 6).

(d) Growth parameters (K, LINF and TO)

If the random number indicator (IRANDG) is 0, growth parameters are set equal to user-specified constants (KMEAN, LINFMEAN and TO respectively).

If the random number indicator (IRANDG) is 1, growth parameters are defined as follows. The Brody growth coefficient (K) is drawn from a normal distribution with mean $\overline{K}$ (KMEAN), standard deviation σ (the square root of CORRKK), lower bound L (KMIN) and upper bound H (KMAX). The maximum average length L_∞ is then drawn from a normal distribution with mean

$$\mu_L + \frac{\sigma_{LK}}{\sigma_{KK}} (K - \mu_K)$$

and standard deviation

$$\sqrt{\sigma_{LL} - \frac{\sigma_{LK}^2}{\sigma_{KK}}}$$

where

μ_L is the mean value of L_∞ (LINFMEAN)

K is the Brody growth coefficient chosen in the previous step (K)

μ_K is the mean value of the Brody growth coefficient (KMEAN)

σ_{LK} is the covariance of L_∞ and K (CORRLK)

σ_{KK} is the variance of K (CORRKK)

σ_{LL} is the variance of L_∞ (CORRLL)

This procedure reflects the (negative) sampling correlation between L_∞ and K in the von Bertalanffy growth equation.

t_0 (TO) is unchanged from the user-specified value.

3. Mean weights at age (W)

Mean weights at age are calculated from the von Bertalanffy growth equation

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

combined with the length-weight relationship

$$W_t = a\, L_t^{\,b} / 1000$$

where

L_t is the mean mid-season length (cm) at age t (L_i)

L_∞ is the maximum average mid-season length (LINF)

K is the Brody growth coefficient (K)

t_0 is the x-intercept (TO)

W_t is the mean mid-season weight (kg) at age t (W_i)

a is the constant of the length weight relationship, for length in cm and weight in gm (A)

b is the power coefficient of the length-weight relationship (B)

The maximum average weight in kg, W_∞ (WINF), is calculated from the equation

$$W_\infty = a\, L_\infty^{\,b} / 1000$$

L_t (L_i) and W_t (W_i) are arbitrarily set to zero for all ages less than t_0 (TO).

4. Virgin recruitment (RVIRG) and the stable age distribution

Virgin recruitment is the initial beginning of season numbers at age 1. Its computation is based on the recruited mid-season virgin biomass in tonnes (VIRBIO) and the assumption of a stable age distribution. Virgin biomass can be expressed as

$$B_v = \sum_{i=ar}^{max} N_i W_i \qquad (1)$$

Similarily total mid-season virgin biomass (all ages combined) is given by

$$B_t = \sum_{i=1}^{max} N_i W_i \qquad (2)$$

The assumption of a stable age distribution implies that

$$N_t = N_1 \; e^{-M(t - 1)} \qquad (3)$$

where

B_v is recruited mid-season virgin biomass (VIRBIO)

B_t is total mid-season virgin biomass (TOTBIO)

N_i is the mid-season number of fish of age i

W_i is the mid-season weight (in tonnes) of a fish of age i

ar is the age of recruitment to the fishery (AR)

max is the maximum age used in the model (MAXAGE)

M is natural mortality (M)

Combining equations (1) and (3) gives

$$B_v = N_{ar} \sum_{i=ar}^{max} e^{-M(i - ar)} W_i \qquad (4)$$

Combining equations (2) and (3) gives

$$B_t = N_1 \sum_{i=1}^{max} e^{-M(i - 1)} W_i \qquad (5)$$

It also follows from equation (3) that

$$N_{ar} = N_1 \; e^{-M(ar - 1)} \qquad (6)$$

Dividing equation (5) by equation (4), substituting for N_{ar} from equation (6), cancelling and rearranging gives

$$B_t = \frac{B_v \sum_{i=1}^{max} e^{-M(i-1)} W_i}{e^{-M(ar-1)} \sum_{i=ar}^{max} e^{-M(i-ar)} W_i} \tag{7}$$

This equation consists only of known parameters. The mid-season number of fish at age 1, N_1, can thus be calculated from equation (5) using the value of B_t calculated from equation (7). Assuming that natural mortality is spread evenly throughout the year, the beginning of season number of fish at age 1 (RVIRG) is therefore given by

$$N_1 \;/\; e^{-M/2}$$

The beginning of season virgin stable age distribution is calculated from equation (3) with the virgin recruitment level (RVIRG) substituted for N_1. Note that N_i represents mid-season numbers in equations (1) - (6) inclusive during the computation of virgin recruitment. But since the model starts at the beginning of the season, the N_i are replaced by beginning of season numbers once the virgin stable age distribution has been calculated.

5. Virgin spawning biomass (VIRSPAWN)

In the model it is assumed that the beginning of season number of fish of age 1 (i.e. recruitment to the population) is produced by the spawning biomass present at mid-season in the previous year. The mid-season virgin spawning biomass (VIRSPAWN) is calculated as

$$\sum_{i=am}^{max} N_i \; W_i \; e^{-M/2}$$

where

N_i is the beginning of season virgin numbers at age i calculated from a stable age distribution

W_i is the weight of a fish of age i in tonnes

M is the instantaneous rate of natural mortality (M)

am is the age of maturity (AM)

max is the maximum age used in the model (MAXAGE).

NOTE: Steps 1 to 5 above are used to initialise the model. The variables and parameters calculated in these steps remain fixed throughout a simulation. They cannot be changed unless the model is restarted.

6. Beginning of season recruited biomass (BEGBIO)

Beginning of season recruited biomass (BEGBIO) is calculated as

$$\sum_{i=ar}^{max} N_i \; W_i$$

where

N_i is the beginning of season numbers at age i

W_i is the mean (mid-season) weight of a fish of age i (tonnes)

ar is the age of recruitment to the fishery (AR)

max is the maximum age used in the model (MAXAGE)

7. Annual removals (REMOVALS), catch (CATCH) and fishing mortality (F)

A user-specified fishing indicator (IFISH) is used to choose amongst four options for representing fishing.

If the fishing indicator (IFISH) is 0, there is no fishing and removals (REMOVALS), catch (CATCH) and fishing mortality (F) are set equal to zero.

If the fishing indicator (IFISH) is 1, fishing is represented by a fishing mortality level. A user-specified fishing mortality (FCON) is used to calculate an initial estimate of annual removals (REMOVALS) from the catch equation:

$$C = \sum_{i=ar}^{max} \frac{F}{F + M} \left(1 - e^{-(F+M)}\right) N_i \; W_i \tag{8}$$

where

C is annual removals in tonnes (REMOVALS)

F is the instantaneous rate of fishing mortality (F)

M is the instantaneous rate of natural mortality (M)

N_i is the beginning of season numbers at age

W_i is the mean (mid-season) weight of a fish of age i (tonnes)

ar is the age of recruitment to the fishery (AR)

max is the maximum age used in the model (MAXAGE)

In this option F in equation (8) is set equal to the user specified fishing mortality (FCON). If a user-specified parameter representing the difference between true removals and reported catch, expressed as a fraction of reported catch (WASTE) is 0, then removals (REMOVALS) and reported catch (CATCH) are both set equal to C in equation (8). Otherwise reported catch (CATCH) is set equal to C in equation (8), and removals (REMOVALS) are calculated by multiplying reported catch (CATCH) by (1 + WASTE). If the resulting removals (REMOVALS) are greater than the beginning of season recruited biomass (BEGBIO), then removals (REMOVALS) are set equal to the beginning of season recruited biomass (BEGBIO) and reported catch (CATCH) is recomputed by dividing removals (REMOVALS) by (1 + WASTE). A new value of fishing mortality (F) is then calculated iteratively from equation (8) with C set equal to the new estimate of removals (REMOVALS).

If the fishing indicator (IFISH) is 2, fishing is represented by a catch level. Reported catch (CATCH) is set equal to a user-specified value (CCON). If a user-specified parameter representing the difference between true removals and reported catch (WASTE) is 0, then removals (REMOVALS) are set equal to reported catch (CATCH). Otherwise removals (REMOVALS) are calculated by multiplying reported catch (CATCH) by (1 + WASTE). If the resulting removals (REMOVALS) are greater than the beginning of season recruited biomass (BEGBIO), then removals (REMOVALS) are set equal to the beginning of season recruited biomass (BEGBIO) and reported catch (CATCH) is recomputed by dividing removals (REMOVALS) by (1 + WASTE). Fishing mortality (F) is calculated iteratively from equation (8) with C set equal to removals (REMOVALS).

If the fishing indicator (IFISH) is 3, fishing is represented by a biomass (escapement) level. Removals (REMOVALS) are calculated as the difference between the beginning of season recruited biomass (BEGBIO) and a user-specified target biomass or escapement (BIOCON). If the difference is negative, removals (REMOVALS) are set equal to zero. Reported catch (CATCH) is calculated by dividing removals (REMOVALS) by (1 + WASTE), where WASTE is a user-specified parameter representing the difference between true removals and reported catch (it may be zero). Fishing mortality (F) is calculated iteratively from equation (8) with C set equal to removals (REMOVALS).

8. Mid-season numbers, recruited biomass (MIDBIO), total biomass (TOTBIO), biomass by age classes ($BIOAGE_i$), the relationship between current mid-season recruited biomass and virgin mid-season recruited biomass (PBIO), and mean length of fish (XLEN, XLENSD).

Mid-season numbers at age are calculated by multiplying beginning of season numbers by

$$e^{-(F + M)/2}$$

This assumes that fishing mortality (F) and natural mortality (M) are spread evenly on either side of the mid-season.

Mid-season biomass by age classes ($BIOAGE_i$) is calculated as

$$B_i = N_i W_i$$

Mid-season recruited biomass (MIDBIO) is given by

$$\sum_{i=ar}^{max} B_i$$

Mid-season total biomass (TOTBIO) is given by

$$\sum_{i=1}^{max} B_i$$

where

B_i is the mid-season biomass of fish of age i ($BIOAGE_i$)

N_i is the mid-season numbers at age

W_i is the mean (mid-season) weight of a fish of age i (tonnes)

ar is the age of recruitment to the fishery (AR)

max is the maximum age used in the model (MAXAGE).

The relationship between current mid-season recruited biomass (MIDBIO) and virgin mid-season recruited biomass (VIRBIO) is given by dividing the former by the latter (PBIO).

Mean length of fish (XLEN) is given by

$$\frac{1}{n} \sum_{i=min}^{max} N_i L_i$$

with standard deviation (XLENSD)

$$\sqrt{\frac{\sum_{i=min}^{max} (N_i L_i)^2 - \frac{1}{n}\left(\sum_{i=min}^{max} N_i L_i\right)^2}{n - 1}}$$

where

N_i is the mid-season numbers at age i

L_i is the average mid-season length for fish of age i (cm)

min is the minimum length (ILENL) or age (IAGEL) used in the calculations

max is the maximum length (ILENH) or age (IAGEH) used in the calculations

n is the number of fish in the selected portion of the population $\left(= \sum_{i=min}^{max} N_i \right)$

9. Mid-season mature biomass (MATWT)

Mid-season mature biomass (spawning stock biomass) is calculated as

$$\sum_{i=am}^{max} N_i W_i$$

where

N_i is the mid-season numbers at age

W_i is the mean (mid-season) weight of a fish of age i (tonnes)

am is the age of maturity (AM)

max is the maximum age used in the model (MAXAGE).

10. Recruitment to the population (R)

In the model recruitment to the population is defined as the beginning of season numbers at age 1 (R) that were produced by the spawning biomass present at mid-season in the previous year (MATWT).

A user-specified recruitment option indicator (ROPT) is used to select one of four stock-recruitment relationships. Recruitment (R) may also be deterministic or stochastic.

If the recruitment option indicator (ROPT) is 0, there is no recruitment (R=0).

If the recruitment option indicator (ROPT) is 1, next year's mean recruitment is set at the virgin recruitment level (RVIRG).

If the recruitment option indicator (ROPT) is 2, next year's mean recruitment is calculated from a knife-edge relationship (Figure 2a). If mid-season mature biomass (MATWT) is greater than or equal to 20% of the virgin spawning biomass (VIRSPAWN), next year's mean recruitment is set at the virgin recruitment level (RVIRG). Below this threshold, next year's mean recruitment is calculated as

$$\frac{R_v}{0.2\ B_{vs}}\ B_s \qquad (9)$$

where

R_v is the virgin recruitment level (RVIRG)

B_{vs} is the virgin spawning biomass (VIRSPAWN)

B_s is the current spawning biomass (MATWT)

If the recruitment option indicator (ROPT) is 3, next year's mean recruitment is calculated from a Beverton-Holt stock-recruitment relationship (Figure 2b). Next year's mean recruitment is given by

$$\frac{B_s}{\alpha + \beta B_s} \qquad (10)$$

where

B_s is the current spawning biomass (MATWT)

α, β are parameters.

The parameters α and β are calculated by specifying a reference point (VIRSPAWN, RVIRG) and the steepness, Δ (STEEP), of the relationship. Steepness is defined as the fraction of the virgin recruitment (RVIRG) that is attained when current spawning biomass (MATWT) is 20% of virgin spawning biomass (VIRSPAWN). This fraction must be less than 1.

Thus

$$\Delta R_v = \frac{0.2 B_{vs}}{\alpha + 0.2 \beta B_{vs}}$$

$$R_v = \frac{B_{vs}}{\alpha + \beta B_{vs}}$$

so that

$$\alpha = \frac{B_{vs}}{R_v} \left(1 - \frac{\Delta - 0.2}{0.8 \Delta}\right)$$

and

$$\beta = \frac{\Delta - 0.2}{0.8 \Delta R_v}$$

where all symbols are as defined immediately above.

The choice between deterministic and stochastic recruitment is determined by the user-specified value of a random number indicator (IRANDR).

If the random number indicator (IRANDR) is 0, recruitment (R) is set equal to next year's mean value, as calculated above.

If the random number indicator (IRANDR) is 1, recruitment (R) is drawn from a lognormal distribution with mean

$$\log (R_m) - 0.5 \sigma^2$$

where

R_m is next year's mean recruitment calculated from one of the latter three stock-recruitment relationships above

σ is the user-specified standard deviation of the logarithm of recruitment (RSD).

It is also necessary to specifiy lower and upper bounds on recruitment in numbers (RMIN and RMAX respectively). Since logarithms of the bounds are used in the lognormal distribution the bounds must be greater than or equal to one.

(NOTE: Beddington and Cooke (1983) compiled a table of variances of log recruitment for a variety of fish species (their Table 2). A summary of their results suggests that $\sigma = 0.4$ represents low recruitment variability, $\sigma = 0.7$ represents moderate recruitment variability and $\sigma = 1.0$ represents medium-high recruitment variability).

11. End of season numbers and recruited biomass (ENDBIO)

End of season numbers at age are calculated by multiplying mid-season numbers by

$$e^{-(F + M)/2}$$

This assumes that fishing mortality (F) and natural mortality (M) are spread evenly on either side of the mid-season.

End of season recruited biomass (ENDBIO) is calculated as

$$\sum_{i=ar}^{max} N_i W_i$$

where

N_i is the end of season numbers at age

W_i is the mean (mid-season) weight of a fish of age i (tonnes)

ar is the age of recruitment to the fishery (AR)

max is the maximum age used in the model (MAXAGE).

Note that use of mid-season weights throughout the model means that growth from mid-season to end of season is not taken into account.

12. Moving age classes up

Numbers at age are moved up one year class at the end of each iteration. Old fish are cumulated in the last age class (MAXAGE); i.e. the last age class represents a plus group. New recruits (R) are moved into N_1.

Note that if numbers at age (N_i) are tabulated after a simulation they will represent the numbers present at this stage of the calculations (equivalent to the numbers present at the beginning of the next season) because the array N is updated throughout the season.

13. Calculate a discounting factor

A user-specified discounting indicator (IDISC) determines the year at which discounting begins.

If the discounting indicator (IDISC) is 0, the discounting factor (DISC) and discounted revenues (DISREV) are not calculated.

If the discounting indicator (IDISC) is 1, the discounting factor (DISC) is calculated as

$$e^{-\delta(t - 1)}$$

where

δ is the instantaneous discount rate (D)

t is the number of iterations for which the discounting indicator (IDISC) has been assigned a value of 1.

Annual fishing revenue (ANREV) is then discounted by this factor (DISC) and cumulated over time to produce net present value (DISREV).

(EXAMPLE: A simulation is run over the period 1970 to 2000 with the discounting indicator (IDISC) set to zero prior to 1988 and one in that year and thereafter. Discounted revenue (DISREV) will then represent the net present value in 1988 dollars).

14. Costs of fishing (COST, UCOST)

A user-specified cost indicator (ICOST) is used to select one of four options for representing harvesting costs.

If the cost indicator (ICOST) is 0, the total cost of harvesting (COST) is zero.

If the cost indicator (ICOST) is 1, the total cost of harvesting (COST) is the product of removals (REMOVALS) and a user-specified constant cost per tonne (COSTCC).

If the cost indicator (ICOST) is 2, the total cost of harvesting (COST) is related to fishing mortality (F) by a user-specified proportionality constant (COSTC). This option is based on the following assumptions

$$C = q\ f\ B$$

$$c \sim f$$

$$F \cong \frac{C}{B}$$

where

C is annual removals in tonnes (REMOVALS)

B is mid-season recruited biomass (MIDBIO)

q is a catchability coefficient

f is fishing effort (e.g. boat-days)

F is the instantaneous fishing mortality rate (F)

c is the total cost of harvesting (COST)

Thus total cost of harvesting (COST) is the product of fishing mortality (F) and a constant (COSTC) which is calculated from the ratio c/F for some representative combination of c and F. The assumptions are valid only if the relationship between removals and effort is linear and fishing mortality (F) does not exceed about 0.3.

If the cost indicator (ICOST) is 3, the unit cost of harvesting each tonne (UCOST) is inversely related to biomass (Figure 3). The unit cost of harvesting is given by the hyperbola

$$c = \frac{a + b\,B}{B} \qquad (11)$$

where

c is the current cost per tonne (UCOST)

B is the mid-season recruited biomass (MIDBIO)

a,b are parameters

The parameters a and b are calculated by specifying a reference point (REFB, REFC) on the hyperbola, specifying a parameter, Δ (COSTP), related to the steepness of the hyperbola, and assuming that b (the limit of c as B tends to infinity) is approximately equal to the unit harvesting costs at virgin biomass (VIRBIO, COSTBO). The reference point (REFB, REFC) might, for example, be the current mid-season recruited biomass and the current unit cost ($) of catching each tonne. Steepness is defined by the ratio of the unit cost of fishing when biomass (MIDBIO) is 20% of the virgin level (VIRBIO) to the unit cost at virgin biomass (COSTBO). This ratio must be greater than 1. Thus

$$\Delta\, C_{BV} = \frac{a + 0.2\, C_{BV}\, B_V}{0.2\, B_V}$$

$$R_C = \frac{a + C_{BV} R_B}{R_B}$$

so that

$$C_{BV} = \frac{R_C}{1 + \frac{0.2 B_V (\Delta - 1)}{R_B}}$$

and $$a = 0.2 B_V (\Delta - 1) C_{BV}$$

where

B_V is the recruited mid-season virgin biomass (VIRBIO)

C_{BV} is the cost of catching each tonne when biomass is at B_V (COSTBO)

R_C is a reference cost per tonne (REFC) corresponding to a reference biomass (REFB)

R_B is a reference biomass (REFB) corresponding to a reference cost per tonne (REFC)

Δ is the ratio of cost per tonne at 20% of B_V to the cost per tonne at B_V (COSTP).

In all cases the unit cost per tonne (UCOST) is equal to the total cost (COST) divided by the removals (REMOVALS).

15. Other economic parameters (PRICE, PCOST, FIXCOST)

All other economic parameters are input as user-specified constants. These comprise fob price per tonne (PRICE), processing costs per tonne (PCOST) and fixed annual costs (FIXCOST).

16. Annual fishing revenue (ANREV) and discounted revenues (DISREV)

Annual revenue ($) is calculated as

$$(P - c_p - c)\, C - c_f$$

where

P is the fob price per tonne (PRICE)

c_p is the processing costs per tonne (PCOST)

c is the current cost of harvesting each tonne (UCOST)

C is the current removals in tonnes (REMOVALS)

c_f is the fixed annual costs (FIXCOST)

Note that use of removals (REMOVALS) rather than reported catch (CATCH) means that it is assumed that removals are equivalent to true landings (i.e. the above equation only takes account of misreporting, not losses or discards at sea).

Discounted revenue (DISREV) or net present value is calculated as

$$\sum_{t=1}^{end} [(P - c_p - c) C - c_f] e^{-\delta(t-1)}$$

where

t is the number of years for which the discounting indicator (IDISC) has been activated

end is the last year of the simulation

δ is the instantaneous discount rate (D)

and the other parameters are as defined immediately above.

Control is now returned to the biological submodel and a new iteration begins.

Alternative models

Two alternative versions of the model have been created. They are identical to the model described above (main variation) in every respect except the following.

Variation 1.

This model is focussed on beginning of season biomass, not mid-season. In particular virgin recruited biomass is assumed to be a beginning of season estimate and so is not divided by $e^{-M/2}$ to back-calculate from mid-season to beginning of season. Similarily recruitment to the population is based on beginning of season mature biomass. Thus recruitment is lagged by a full year, rather than half a year (i.e. beginning of season numbers at age 1 are derived from the spawning biomass present at the beginning of the previous season). Cost of fishing are, however, still based on the recruited biomass present at mid-season.

Thus, the calculations in Figure 1 are changed so that the phrase "beginning of season" is substituted for "mid-season" in steps 5 and 9, and the sequence of calculations is changed so that steps 9 and 10 preceed steps 7 and 8. The calculations performed at step 8 (see text) are all moved back to step 6. All parameters and variables in Table 1 retain the same name and most retain the same meaning. The parameters and variables that slightly alter their meanings are:

VIRBIOM, VIRBIOL, VIRBIOH, VIRMIN, VIRMAX, VIRSD, VIRBIO, VIRSPAWN, TOTBIO, MATWT, PBIO, XLEN, XLENSD, $BIOAGE_i$

These are all now based on beginning of season numbers and weights, not mid-season.

Variation 2.

The second variant of the model includes all the changes made for variation 1, along with a number of refinements that allow the user more flexibility in specifying initial conditions (biomass and age distribution), and the shapes of the stock-recruitment and cost of fishing functions (equations 9, 10 and 11).

All reference to virgin biomass is deleted. The user inputs the initial numbers of fish at age (N_i) for all ages in the population, including age 1 (the number of fish that would have resulted from the previous year's spawning). A new variable (FIRSTBIO) is used to store the initial recruited biomass.

Equation (9) is replaced by

$$R_m = \begin{cases} \text{a constant (RCON) if spawning biomass (MATWT) is above a specified threshold (CUTOFF)} \\ \dfrac{\text{(RCON) (MATWT)}}{\text{(CUTOFF)}} \text{ if it is below the threshold} \end{cases}$$

where

R_m is mean beginning of season recruitment at age 1, the constant (RCON) is expressed in terms of numbers at age 1, and the threshold (CUTOFF) is expressed in terms of spawning biomass.

The constant (RCON) is also used to specify the recruitment level under the constant recruitment option (ROPT = 1).

Equation (10) remains unchanged, but the parameters, α and β (ALPHA and BETA), must be specified directly. The steepness parameter (STEEP) used previously is deleted.

Equation (11) remains unchanged, but the parameters, a and b (ACOST and BCOST), must be specified directly. The steepness parameter (COSTP) and the reference points (REFB, REFC AND COSTBO) used previously are deleted.

Thus, the parameters and variables omitted from Table 1 are:

IRANDBIO, VIRBIOM, VIRBIOL, VIRBIOH,
VIRMIN, VIRMIN, VIRSD, STEEP, COSTP,
REFC, REFB, VIRBIO, VIRSPAWN, RVIRG,
COSTBO

The parameters added are:

FORTRAN name	TYPE	DESCRIPTION AND USAGE
RCON	R	A constant level of beginning of season recruitment to the population (numbers at age 1). Only needs to be specified if ROPT = 1 or 2.
CUTOFF	R	The spawning stock biomass in tonnes (MATWT) below which recruitment starts to decline. Only needs to be specified if ROPT = 2.
ALPHA, BETA	R	Parameters of the Beverton-Holt stock recruitment relationship (equation 10). Only need to be specified if ROPT = 3.
ACOST, BCOST	R	Parameters of the cost of fishing function (equation 11). Only need to be specified if ICOST = 3.

The only new variable added is FIRSTBIO, the initial beginning of season recruited biomass.

The advantage of this model is that it allows forward projections of populations with known current age distribution but unknown virgin condition.

Limitations of the models

The limitations of the models are that a) they are too complex, and b) they are too simple.

Because the models are age structured, they require many input parameters. Parameter estimates may be imprecise when there is little known about a species. However, the models are sufficiently flexible and fast that extensive sensitivity analysis can be conducted for numerous combinations of feasible parameter estimates.

Several potentially complex relationships are treated as constant. This applies particularly to the economic submodel, where data for New

Zealand fisheries are most lacking. But the FORTRAN source code has been set up in such a way that it can be readily modified by a competent computer programmer and customised to individual needs.

Probably the most important refinement that could be made to the models is to include restrictions on fishing effort. At present if the target catch for a constant catch strategy exceeds the stock size, then it is possible to fish out the entire recruited biomass in a single year. (Note that this does not necessarily lead to extinction immediately because the unrecruited year classes have yet to enter the fishery). This anomaly does not occur for fishing strategies based on fishing mortality or escapement.

Other possible refinements include a breakdown of the model into seasonal components with seasonal fish growth and seasonal fishing patterns; addition of spatial components; and modelling of between or within population variability in growth, mortality and reproduction.

Table 1. Parameters and variables used in the simulation model. The variable type is specified as either I (integer) or R (real).

(a) Parameters

Parameters are constants that can be set or displayed (tabulated and graphed) by the user, either interactively or in a MACRO library. + indicates the parameters that can be changed part way through a simulation by use of an "AT time SET var = value" command. * indicates those parameters that the user must, or should, set at the beginning of the simulation.

	FORTRAN name	TYPE	DESCRIPTION AND USAGE
+	ISEED	I	Indicator for seeding the random number generator; 0 = OFF, 1 = ON. Default is 1 on first iteration, 0 thereafter.
	INIT	I	Indicator for initialising the model; 0 = OFF, 1 = ON. Default is 1 on first iteration, 0 thereafter.
	IRANDBIO	I	Random number indicator for virgin biomass; 0 = OFF, 1 = ON. Default = 0.
	IRANDM	I	Random number indicator for natural mortality; 0 = OFF, 1 = ON. Default = 0.
	IRANDA	I	Random number indicator for ages of recruitment and maturity; 0 = OFF, 1 = ON. Default = 0.
	IRANDG	I	Random number indicator for growth parameters; 0 = OFF, 1 = ON. Default = 0.
	IRANDR	I	Random number indicator for recruitment; 0 = OFF, 1 = ON. Default = 0.
	MAXAGE	I	Maximum age considered in the model. Default = 70; must not be greater than 70.
*	VIRBIOM	R	Mean value of recruited mid-season virgin biomass (tonnes). Must be specified by the user.
	VIRBIOL	R	Lower bound on mean recruited mid-season virgin biomass (tonnes) expressed as a multiplier of the mean. Only needs to be specified if IRANDBIO = 1.
	VIRBIOH	R	Upper bound on mean recruited mid-season virgin biomass (tonnes) expressed as a multiplier of the mean. Only needs to be specified if IRANDBIO = 1.
	VIRMIN	R	Minimum level of recruited mid-season virgin biomass (tonnes). Only needs to be specified if IRANDBIO = 1.

Table 1. cont'd

FORTRAN name	TYPE	DESCRIPTION AND USAGE
VIRMAX	R	Maximum level of recruited mid-season virgin biomass (tonnes). Only needs to be specified if IRANDBIO = 1.
VIRSD	R	Standard deviation of recruited mid-season virgin biomass (tonnes). Only needs to be specified if IRANDBIO = 1.
* MMEAN	R	Mean value of instantaneous natural mortality rate. Must be specified by the user.
MMIN	R	Minimum level of instantaneous natural mortality rate. Only needs to be specified if IRANDM = 1.
MMAX	R	Maximum level of instantaneous natural mortality rate. Only needs to be specified if IRANDM = 1.
* ARMEAN	I	Mean age of recruitment to the fishery (years). Must be specified by the user.
ARL	R	Lower bound on age of recruitment to the fishery (years). Only needs to be specified if IRANDA = 1.
ARH	R	Upper bound on age of recruitment to the fishery (years). Only needs to be specified if IRANDA = 1.
* AMMEAN	I	Mean age of maturity (years). Must be specified by the user.
AML	R	Lower bound on age of maturity (years). Only needs to be specified if IRANDA = 1.
AMH	R	Upper bound on age of maturity (years). Only needs to be specified if IRANDA = 1.
* KMEAN	R	Mean value of Brody growth coefficient in von Bertalanffy equation. Must be specified by the user.
KMIN	R	Lower bound on Brody growth coefficient. Only needs to be specified if IRANDG = 1.
KMAX	R	Upper bound on Brody growth coefficient. Only needs to be specified if IRANDG = 1.
* LINFMEAN	R	Mean value of L_∞ (cm) in von Bertalanffy equation. Must be specified by the user.
LMIN	R	Lower bound on L_∞ (cm). Only needs to be specified if IRANDG = 1.
LMAX	R	Upper bound on L_∞ (cm). Only needs to be specified if IRANDG = 1.

Table 1. cont'd

FORTRAN name	TYPE	DESCRIPTION AND USAGE
CORRLK	R	Covariance of L_∞ and K. Only needs to be specified if IRANDG = 1.
CORRKK	R	Variance of K. Only needs to be specified if IRANDG = 1.
CORRLL	R	Variance of L_∞. Only needs to be specified if IRANDG = 1.
* TO	R	X-intercept of von Bertalanffy equation (years). Must be specified by the user.
* A	R	Constant of length-weight relationship (length in cm, weight in gm). Must be specified by the user.
* B	R	Power coefficient of length-weight relationship. Must be specified by the user.
+ ILENAGE	I	Indicator for calculation of mean and standard deviation of the length of a specified portion of the population: 0 = no calculations 1 = select by length 2 = select by age Default = 0.
+ ILENL	I	Lower limit of length (cm) to use in the calculation of mean length. Only needs to be specified if ILENAGE = 1.
+ ILENH	I	Upper limit of length (cm) to use in the calculation of mean length. Only needs to be specified if ILENAGE = 1.
+ IAGEL	I	Lower limit of age (years) to use in the calculation of mean length. Only needs to be specified if ILENAGE = 2.
+ IAGEH	I	Upper limit of age (years) to use in the calculation of mean length. Only needs to be specified if ILENAGE = 2.
+* ROPT	I	Recruitment option chosen by user: 0 = zero recruitment 1 = recruitment constant at the equilibrium level required to maintain the virgin biomass. 2 = Knife-edge recruitment: recruitment constant at the equilibrium level required to maintain the virgin biomass, as long as

Table 1. cont'd

FORTRAN name	TYPE	DESCRIPTION AND USAGE
		the spawning biomass is greater than or equal to 20% of the virgin spawning biomass; recruitment declining 3 = a Beverton-Holt stock recruitment relationship. Default = 1, but the user will often want to override this default.
+ STEEP	R	Steepness of the Beverton-holt stock recruitment relationship. STEEP is the fraction of the virgin recruitment that will be attained when the spawning stock falls to 20% of its virgin size. Must be less than 1. Only needs to be specified if ROPT = 3.
+ RMIN	R	Minimum amount of recruitment to the population at age 1 (numbers). Must be greater than or equal to 1. Only needs to be specified if IRANDR = 1.
+ RMAX	R	Maximum amount of recruitment to the population at age 1 (numbers). Only needs to be specified if IRANDR = 1.
+ RSD	R	Standard deviation of log (recruitment at age 1) (numbers). Only needs to be specified if IRANDR = 1.
+* IFISH	I	Fishing option chosen by user: 0 = no fishing 1 = constant fishing mortality (FCON) 2 = constant catch (CCON) 3 = constant biomass (BIOCON) Default = 0, but the user will often want to override this default.
+ FCON	R	Instantaneous fishing mortality rate. Only needs to be specified when IFISH = 1.
+ CCON	R	Catch (tonnes). Only needs to be specified when IFISH = 2.
+ BIOCON	R	Target recruited biomass level (tonnes). Only needs to be specified when IFISH = 3.
+ WASTE	R	Difference between true removals and reported catch, expressed as a fraction of reported catch.

Table 1. cont'd

FORTRAN name	TYPE	DESCRIPTION AND USAGE
		Removals = reported catch x (1 + WASTE). Default = 0.
+ IECON	I	Indicator for calculation of economic variables; 0 = OFF, 1 = ON. Default = 1.
+ IDISC	I	Indicator for commencement of discounting; 0 = OFF, 1 = ON. Default = 0. Only needs to be specified if IECON = 1.
+ D	R	Instantaneous discount rate. Default = 0.1. Only needs to be specified if IECON = 1.
+* PRICE	R	Fob price in $/tonne. Only needs to be specified if IECON = 1.
+* PCOST	R	Cost of processing fish in $/tonne. Only needs to be specified if IECON = 1.
+* FIXCOST	R	Fixed costs in $/fishing year. Only needs to be specified if IECON = 1.
+* ICOST	I	Cost of fishing option chosen by user: 0 = zero cost 1 = constant cost per tonne 2 = total cost proportional to fishing mortality (F) 3 = cost per tonne inversely related to stock size Default = 0, but the user will often want to override this default. Only needs to be specified if IECON = 1.
+ COSTCC	R	Current cost of catching fish in $/tonne. Only needs to be specified if IECON = 1 and ICOST = 1.
+ COSTC	R	The ratio between total costs of fishing ($/year) and fishing mortality (F). Only needs to be specified if IECON = 1 and ICOST = 2.
+ COSTP	R	A multiplier that specifies the increase in cost ($/tonne) at 20% of recruited virgin biomass compared with 100% of recruited virgin biomass. Must be greater than 1. Only needs to be specified if IECON = 1 and ICOST = 3.
+ REFC	R	A reference cost ($/tonne) that corresponds to REFB and determines

Table 1. cont'd

FORTRAN name	TYPE	DESCRIPTION AND USAGE
		the parameters of the cost-biomass relationship. Only needs to be specified if IECON = 1 and ICOST = 3.
+ REFB	R	A reference biomass (tonnes) that corresponds to REFC and determines the parameters of the cost-biomass relationship. Only needs to be specified if IECON = 1 and ICOST = 3.

(b) Variables

Variables can be displayed, tabulated and graphed, but cannot be set by the user (i.e. they are calculated within the model).

VIRBIO	R	Recruited mid-season virgin biomass (tonnes). The parameters VIRBIOM (VIRBIOL, VIRBIOH, VIRMIN, VIRMAX, VIRSD) are used in its computation.
VIRSPAWN	R	Mid-season virgin spawning biomass (tonnes). The variables VIRBIO, RVIRG and AM are used in its computation. (If AM = AR then VIRSPAWN = VIRBIO).
BEGBIO	R	Beginning of season recruited biomass (tonnes). The variables N_i, W_i and AR are used in its computation.
MIDBIO	R	Mid-season recruited biomass (tonnes). The variables N_i, W_i and AR are used in its computation.
TOTBIO	R	Mid-season total biomass (tonnes) (all ages included). The variables N_i and W_i are used in its computation.
MATWT	R	Mid-season spawning biomass (tonnes). The variables N_i, W_i and AM are used in its computation.
ENDBIO	R	End of season recruited biomass (tonnes). The variables N_i, W_i and AR are used in its computation.
PBIO	R	MIDBIO as a fraction of VIRBIO.
M	R	Instantaneous natural mortality rate. The parameters MMEAN (MMIN, MMAX) are used in its computation.
AR	I	Age of recruitment to the fishery (years). The parameters ARMEAN (ARL, ARH) are used in its computation.
AM	I	Age of maturity (years). The

Table 1. cont'd

FORTRAN name	TYPE	DESCRIPTION AND USAGE
		parameters AMMEAN (AML, AMH) are used in its computation.
K	R	Brody growth coefficient. The parameters KMEAN (KMIN, KMAX, CORRKK) are used in its computation.
LINF	R	Maximum average fish length (cm). The parameters LINFMEAN (LMIN, LMAX, CORRLK, CORRKK, CORRLL) are used in its computation.
WINF	R	Maximum average fish weight (kg). The variable LINF and the parameters A and B are used in its computation.
XLEN	R	Mean length (cm) of fish over a specified range of lengths or ages. The parameters ILENAGE (ILENL, ILENH, IAGEL, IAGEH) are used in its computation.
XLENSD	R	Standard deviation (cm) of fish length over a specified range of lengths or ages. The parameters ILENAGE (ILENL, ILENH, IAGEL, IAGEH) are used in its computation.
R	R	Beginning of season recruitment at age 1 (numbers). The parameters ROPT (RMIN, RMAX, RSD) are used in its computation.
RVIRG	R	Equilibrium beginning of season virgin recruitment at age 1 (numbers) required to maintain the virgin biomass.
N_i	R	End of season number of fish of age i (i = 1, MAXAGE).
L_i	R	Length (cm) of fish of age i (i = 1, MAXAGE). The parameters and variables K, LINF and TO are used in its computation.
W_i	R	Weight (kg) of fish of age i (i = 1, MAXAGE). The parameters and variables L_i, A and B are used in its computation.
$BIOAGE_i$	R	Mid-season biomass (tonnes) of fish of age i (i = 1, MAXAGE). The variables N_i and W_i are used in its computation.
F	R	Instantaneous rate of fishing mortality. The parameters IFISH (FCON, CCON, BIOCON, WASTE) and the variables N_i, W_i, CATCH and REMOVALS are used in its

Table 1. cont'd

FORTRAN name	TYPE	DESCRIPTION AND USAGE
		computation.
REMOVALS	R	Biomass (tonnes) removed by fishing. The parameters IFISH (FCON, CCON, BIOCON, WASTE) and the variables N_i, W_i, CATCH and F are used in its computation.
CATCH	R	Biomass (tonnes) reported by fishers. The parameters IFISH (FCON, CCON, BIOCON, WASTE) and the variables N_i, W_i, REMOVALS and F are used in its computation.
ANREV	R	Annual (non-discounted) revenue from fishing in $. The parameters PRICE, PCOST, FIXCOST, ICOST (COSTCC, COSTC, COSTP, REFC, REFB) and the variables REMOVALS (MIDBIO) are used in its computation.
DISREV	R	Cumulative annual revenue from fishing in $ discounted over time. The parameters IDISC and D and the variables ANREV and DISC are used in its computation.
DISC	R	Cumulative discounting factor. The parameters IDISC and D are used in its computation.
COST	R	Total cost of catching the current REMOVALS ($). The parameters ICOST (COSTCC, COSTC, COSTP, REFC, REFB) and the variables REMOVALS (MIDBIO) are used in its computation.
UCOST	R	Unit cost of catching ($/tonne). The variables COST and REMOVALS are used in its computation.
COSTBO	R	Cost of catching one tonne of fish ($) at virgin biomass levels. Computed only if ICOST = 3. The parameters COSTP, REFC and REFB and the variables MIDBIO and REMOVALS are used in its computation.

INITIALISATION

1. Seed the random number generator

↓

2. Choose parameters for virgin recruited biomass, natural mortality, age of recruitment to the fishery, age of maturity, growth

↓

3. Calculate mean weights at age

↓

4. Calculate virgin recruitment (numbers at age 1) and the associated stable age distribution

↓

5. Calculate the mid-season virgin spawning biomass

↓

6. Calculate beginning of season recruited biomass

↓

7. Calculate annual removals, annual catch and fishing mortality using one of four options

↓

8. Calculate mid-season numbers, recruited and total biomass

9. Calculate mid-season mature biomass

↓

10. Calculate recruitment (numbers at age 1) as deterministic or stochastic with one of four options for the stock recruitment relationship

↓

11. Calculate end of season numbers and recruited biomass

↓

12. Move age classes up one and add recruitment

13. Calculate a discounting factor

↓

14. Calculate costs of fishing using one of four options

↓

15. Choose parameters for fob price, processing costs and fixed costs

↓

16. Calculate annual fishing revenue and discounted revenues

Figure 1. Sequence of calculations in the simulation model

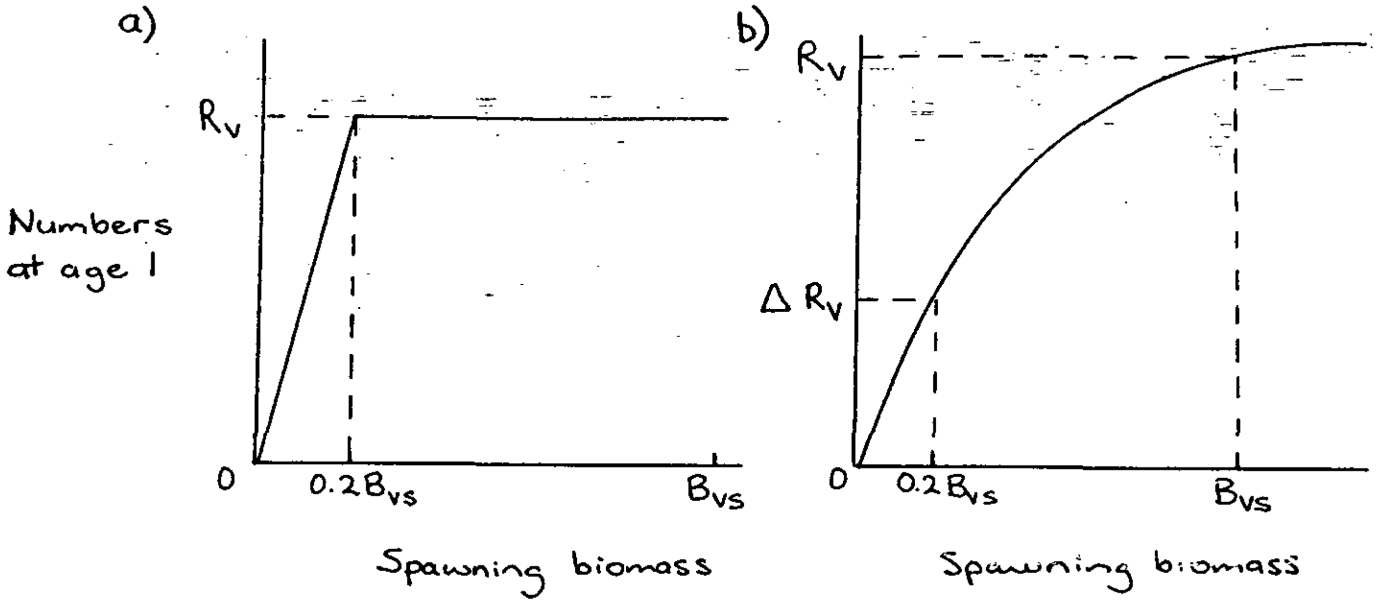

Figure 2. Two optional stock-recruitment relationships used in the model. a) Knife-edge recruitment, b) Beverton-Holt stock-recruitment relationship. Symbols are defined in the text (equations 9 and 10).

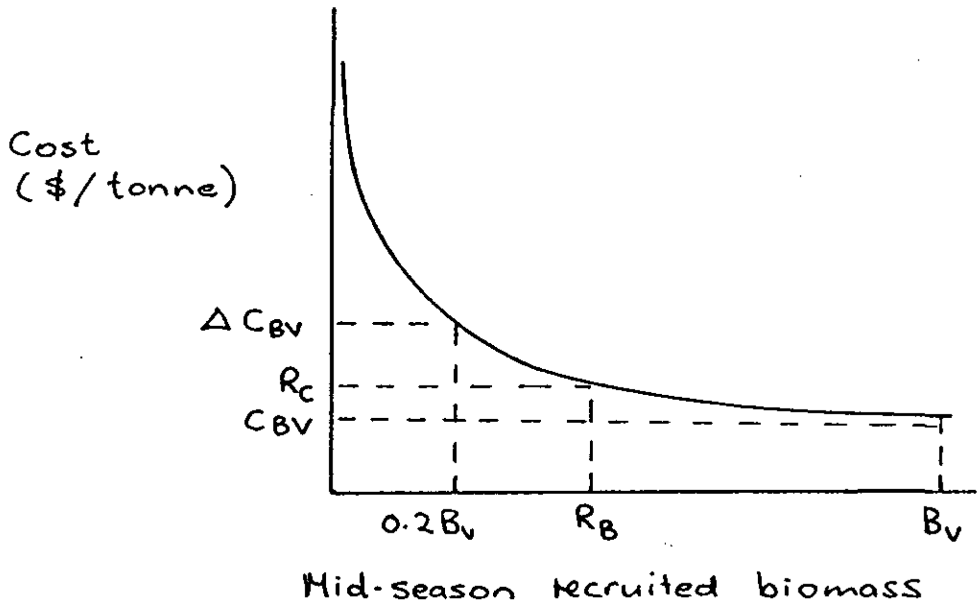

Figure 3. *Optional relationship between cost of harvesting and biomass. Symbols are defined in the text.*

APPENDIX I. HOW TO RUN THE MODELS ON THE PYRAMID 98xe

The models and associated files are contained in the directory

/grp2/publicmodels/bioec_models

Users may copy the required files from here to their own directories. The directory in which the model will be run must contain the following files:

System files:	simcon makefile SUPCOM.
Model files:	usermodel.f usermodelC. usermodelB.

The names of the files must be exactly as given above except that the term "usermodel" is replaced by the name of the desired model. The model names are:

bioecon:	Main variation (based on mid-season estimates of biomass; initialised with virgin biomass and a stable age distribution)
bbioecon:	Variation 1 (based on beginning of season estimates of biomass; initialised with virgin biomass and a stable age distribution)
ubioecon:	Variation 2 (based on beginning of season estimates of biomass; initialised with user-specified numbers at age).

The system file, simcon, links the other files together and executes the model. It calls makefile, which specifies the location of the compiled SIMCON library, uses the FORTRAN compiler, f77, to compile the usermodel if it is not up to date, and links the two together into an executable file called usermodel.runnable. The file SUPCOM. contains the system common block (system parameters).

With the possible exception of makefile, the system files should never need to be changed. Modification of makefile will be necessary if either the pathname to the SIMCON libraries changes, or the user wishes to change the flags used to compile the usermodel (see SIMCON user's guide, Mace 1988).

The model files consist of the model name followed by the extensions .f (FORTRAN source code), C. (referred to as the COMMON file, containing the user COMMON block) and B. (referred to as the setfile, containing a set of commands used to initialise the model and an optional library of SIMCON macros). In general the novice user should not edit the files usermodel.f and usermodelC.. An experienced FORTRAN programmer should be consulted if changes to the structure of the models are required.

However, all users will probably want to customise the usermodelB. files to their own needs. This requires only rudimentary knowledge of an editor and the structure of SIMCON commands (see SIMCON user's guides: Mace 1988, Beals 1981).

All usermodelB. files contain brief descriptions of the parameters of the models, initialisations for some parameters and a library of MACROs (sets of SIMCON commands) with descriptive names. The model bioecon contains an extensive library of (27) MACROs. An annotated list of these MACROs, specifying their structure and purpose, is given in Appendix III. The models bbioecon and ubioecon contain abbreviated MACRO libraries with examples of valid formats that can be used to construct individualised MACROs.

None of the MACROs are required to run the models. MACROs are used only if they are called by name from within SIMCON. The models can be parameterised interactively using SIMCON commands without the use of MACROs. MACROs can also be defined and called interactively. The advantage of storing MACROs in a usermodelB. file is that they do not need to be recreated each time the model is run. The MACROs currently stored in usermodelB. files are provided for convenience, and as examples on which to base individualised MACROs. Since there is a limit on the number of MACROs that can be stored, the user may wish to delete those not required.

Creation of a customised version of the usermodelB. file is all that is required prior to running a model. A session is begun by issuing the command:

simcon usermodel

where usermodel is the name of the model to be run. For example, if the main variation of the model is being used, the appropriate command is:

simcon bioecon

If a file called usermodel.runnable does not already exist it will be created by compiling usermodel.f and linking it to the SIMCON library. If it does exist, the message 'usermodel.runnable is up to date' will be issued. SIMCON will then print out about eight lines of irrelevant and partially erroneous information (see Appendix II). Due to a system problem the SIMCON libraries cannot be edited and recompiled to erase these statements. They should be ignored. (Other spurious messages are also highlighted in the example in Appendix II).

SIMCON then performs a number of initialisations and returns with the prompt

?

when it is ready to accept commands. The user must then press the CAPS LOCK key since SIMCON will only accept upper case commands. Use of lower case will result in an UNKNOWN COMMAND message.

At the end of a session type

Q

to quit and exit SIMCON.

It should be noted that when a new SIMCON session begins, all parameters are automatically given a value of zero. The zeros are then overridden by any SET commands contained in the first part of the usermodelB. file (i.e. SET commands that are not part of a MACRO). When a MACRO is called all SET commands therein override previous SET commands. Similarily any SET command entered interactively during a SIMCON session overrides a previous SET command. This sequential overriding does not, however, apply to "AT time SET" commands. All AT commands that have been specified remain in effect until the command "AT CLEAR" is given. Use the command "AT LIST" to obtain a list of active AT commands.

An annoted demonstration run for the model bioecon is contained in Appendix II. In this example a MACRO called DEMO is created and run interactively. An identical MACRO has been stored in the file bioeconB.. It is suggested that new users repeat this demonstration by calling DEMO with their own values for virgin biomass and catch. For example, issue the command

CALL DEMO 300000 20000

where

CALL is an optional part of the command

the first number is the virgin biomass in tonnes

the second number is the catch in tonnes from 1989 onwards

Users should refer to the SIMCON user's guides (Mace 1988, Beals 1981) for further information about SIMCON commands and conventions, and methods for obtaining hardcopy output and graphics.

APPENDIX II. ANNOTATED DEMONSTRATION EXAMPLE

```
Script started on Wed Jul 13 00:18:02 1988   -Script used to obtain hardcopy
frc%
frc%
frc% simcon bioecon     -Run the main variation of the model
'usermodel.runnable' is up to date.   - Model does not need to be recompiled

SIMCON CDC VERSION 2.7.1 - CONVERTED TO RUN UNDER VAX/VMS V3.7
  - then converted to unix, so remember to use UPPER case

IF YOU HAVE ANY PROBLEMS - SEE Pamela Mace on UUCP nzfish - F.R.D. ext 807 - See Ian Doonan
                                                                              ext 8544

New commands: MINMAX VARNAM(min,max) to specify min & max for "VARNAM" - doesn't work
 plus the command HELP will list current valid commands - also includes some invalid commands


  BATCH,COMMON,ULOG,and UFILE opened for   usermodel

  openms max    10000  - spurious message
   Q to quit, HELP for more info...

 Welcome to the generalised bioeconomic fish population dynamics
 simulation model constructed by Pamela mace and Ian Doonan.
   It is a good idea to CALL DEFAULTS at the start (only) of a
   session so that parameters you're not using aren't left as
   zeros in divisions

                                           Statements following ? are those entered
?   - SIMCON is ready to accept commands   by the user.
?DEFAULTS  - call default parameter values All other statements are SIMCON responses

 MACRO DEFAULTS has been called: all params given default values
 .....MACRO DUMMYRAND has been called
 .....MACRO DUMMYECON has been called

?
?
?
?
?MACRO DEMO V C   - enter a MACRO interactively. Be careful. If you find a mistake
 ENTER MACRO TEXT     after pressing carriage return, you will need to END and
?..MACRO DEMO has been called           start again (i.e. It is easier to put the
?..You may now issue SIM, DI and PR commands.         MACRO in bioeconB. and
?..If you want to do another run: CALL RESTART; then CALL DEMO;   call it from there).
?..then you may issue your own SET commands to override DEMO's
?..parameter values; then issue SIM, DI and PR commands
?SET VIRBIOM=V                  Characters following two dots will be
?AT 1988 SET CCON=C             printed out to the screen whenever
?SET MMEAN=.2                   the MACRO is called.
?SET ARMEAN=5
?SET AMMEAN=5
?SET KMEAN=.2
?SET LINFMEAN=50.
?SET TO=0.
?SET A=.1
?SET B=3.
?SET ROPT=3
?SET STEEP=.95
?SET PRICE=1000.                Set up parameter values
?SET PCOST=200.
?SET ICOST=3.
?SET COSTP=1.5
?SET REFB=50000.
?SET REFC=500.
?SET FIXCOST=0.
?SET IDISC=0
?AT 1987 SET IDISC=1
?SET D=.1
?SET IFISH=2
?SET WASTE=0.
?SET CCON=0.
?AT 1980 SET CCON=5000.
?AT 1981 SET CCON=10000.
?AT 1982 SET CCON=10000.        Catch history: Note: AT commands one
?AT 1983 SET CCON=10000.          step out of phase with time
?AT 1984 SET CCON=20000.          (e.g. AT 1980 will be executed
?AT 1985 SET CCON=20000.              at 1981).
?AT 1986 SET CCON=20000.
?AT 1987 SET CCON=20000.
?END          - end of interactive MACRO creation
 ENTER COMMAND
?
?
```

```
?
?
?DEMO 300000 30000
 MACRO DEMO has been called
 You may now issue SIM, DI and PR commands.
 If you want to do another run: CALL RESTART; then CALL DEMO,
 then you may issue your own SET commands to override DEMO's
 parameter values; then issue SIM, DI and PR commands
?
?
?
?
?SIM 1980 2000
?
?
?PR BEGBIO MIDBIO REMOVALS CATCH F R
  overl1: nymax   101
  ucomio994: index(irec+102)    0
```

- Call DEMO with virgin biomass = 300,000t and catch from 1989 onwards = 30,000t.

- For this demonstration, simulations must start at the year 1980 and end prior to the year 2079.
- Simulate from the year 1980 to the year 2000.
Note that at 1980, catch (CCON) = 0 (see DEMO). This acts as a check on whether the model is set up correctly (i.e. virgin biomass maintained).
← tabulate simulated values of variables of interest
- Spurious message
- spurious message

1 TIME	BEGBIO	MIDBIO	REMOVALS	CATCH	F	R	
0	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	- initial conditions
1980	.33155E+06	.30000E+06	.00000E+00	.00000E+00	.00000E+00	.19819E+08	- Virgin biomass (MIDBIO) correct
1981	.33155E+06	.29749E+06	5000.0	5000.0	.16774E-01	.19817E+08	
1982	.32650E+06	.29040E+06	10000.	10000.	.34356E-01	.19810E+08	
1983	.31693E+06	.28173E+06	10000.	10000.	.35412E-01	.19802E+08	
1984	.30839E+06	.27401E+06	10000.	10000.	.36410E-01	.19794E+08	
1985	.30088E+06	.26208E+06	20000.	20000.	.76069E-01	.19781E+08	
1986	.28422E+06	.24701E+06	20000.	20000.	.80704E-01	.19763E+08	
1987	.26944E+06	.23362E+06	20000.	20000.	.85319E-01	.19745E+08	
1988	.25644E+06	.22185E+06	20000.	20000.	.89837E-01	.19728E+08	
1989	.24509E+06	.20629E+06	30000.	30000.	0.14471	.19701E+08	← Constant catch of 30,000t begins in 1989.
1990	.22500E+06	.18806E+06	30000.	30000.	0.15867	.19665E+08	
1991	.20708E+06	.17179E+06	30000.	30000.	0.17362	.19626E+08	
1992	.19116E+06	.15734E+06	30000.	30000.	0.18947	.19585E+08	
1993	.17704E+06	.14450E+06	30000.	30000.	0.20619	.19542E+08	
1994	.16449E+06	.13309E+06	30000.	30000.	0.22374	.19497E+08	
1995	.15328E+06	.12287E+06	30000.	30000.	0.24217	.19450E+08	
1996	.14320E+06	.11369E+06	30000.	30000.	0.26156	.19401E+08	
1997	.13408E+06	.10536E+06	30000.	30000.	0.28199	.19349E+08	
1998	.12577E+06	97769.	30000.	30000.	0.30363	.19294E+08	
1999	.11813E+06	90785.	30000.	30000.	0.32666	.19236E+08	
2000	.11107E+06	84311.	30000.	30000.	0.35136	.19174E+08	

```
?
?
?
?
?PR MIDBIO IDISC ANREV DISREV UCOST
  overl1: nymax   101
  ucomio994: index(irec+102)    0
```

- tabulate simulated values of more variables
- spurious message
- spurious message

1 TIME	MIDBIO	IDISC	ANREV	DISREV	UCOST
0	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
1980	.30000E+06	.00000E+00	.00000E+00	.00000E+00	.00000E+00
1981	.29749E+06	.00000E+00	.22799E+07	.00000E+00	344.01
1982	.29040E+06	.00000E+00	.45522E+07	.00000E+00	344.78
1983	.28173E+06	.00000E+00	.45422E+07	.00000E+00	345.78
1984	.27401E+06	.00000E+00	.45329E+07	.00000E+00	346.71
1985	.26208E+06	.00000E+00	.90346E+07	.00000E+00	348.27
1986	.24701E+06	.00000E+00	.89909E+07	.00000E+00	350.45
1987	.23362E+06	.00000E+00	.89474E+07	.00000E+00	352.63
1988	.22185E+06	1.0000	.89048E+07	.89048E+07	354.76
1989	.20629E+06	1.0000	.13262E+08	.20904E+08	357.95
1990	.18806E+06	1.0000	.13129E+08	.31654E+08	362.35
1991	.17179E+06	1.0000	.12988E+08	.41276E+08	367.07
1992	.15734E+06	1.0000	.12837E+08	.49881E+08	372.09
1993	.14450E+06	1.0000	.12679E+08	.57571E+08	377.38
1994	.13309E+06	1.0000	.12512E+08	.64437E+08	382.94
1995	.12287E+06	1.0000	.12336E+08	.70563E+08	388.80
1996	.11369E+06	1.0000	.12151E+08	.76023E+08	394.96
1997	.10536E+06	1.0000	.11956E+08	.80884E+08	401.48
1998	97769.	1.0000	.11748E+08	.85206E+08	408.39
1999	90785.	1.0000	.11527E+08	.89043E+08	415.77
2000	84311.	1.0000	.11289E+08	.92443E+08	423.70

```
?
?
?RESTART     - Call RESTART (from bioeconB.) in prepartion for re-running the model
               with diffuent parameters
 MACRO RESTART has been called: reinitialises model -
 All AT commands cleared, TIME 0 recalled, random number generator
 reseeded, all random number indicators turned off, equilibrium
 recruitment and stable age distribution recalulated, discount
 rate indicator turned off, default maximum number of iterations
 reset to 100.
    If this is the first run of the session, an error message
       "NO SIMULATION RECORD FOUND FOR TIME 0" will appear -
        Ignore it.

?
?
?
?
?DEMO 300000 50000  - Call DEMO with a different catch level
 MACRO DEMO has been called
 You may now issue SIM, DI and PR commands.
 If you want to do another run: CALL RESTART; then CALL DEMO;
 then you may issue your own SET commands to override DEMO's
 parameter values; then issue SIM, DI and PR commands
?
?
?
?
?SET WASTE=.3      - Change the value of the parameter, WASTE
?DI PRICE          - Display current value of PRICE
?DI PRICE
 PRICE              =        1000.000
?
?SET PRICE=2000    - Change current value of PRICE
?
?DI PRICE          - Display new current value of PRICE
 PRICE              =        2000.000
?
?
?
?
?SIM 1980 2000     - Initiate a new simulation
?
?PR BEGBIO MIDBIO REMOVALS CATCH F R - Tabulate simulated values of variables of interest
  overl1: nymax   101  - Spurious message
  ucomio994:index(irec+102)    0 - spurious message
```

1 TIME	BEGBIO	MIDBIO	REMOVALS	CATCH	F	R
0	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
1980	.33155E+06	.30000E+06	.00000E+00	.00000E+00	.00000E+00	.19819E+08
1981	.33155E+06	.29674E+06	6500.0	5000.0	.21859E-01	.19816E+08
1982	.32499E+06	.28751E+06	13000.	10000.0	.45103E-01	.19808E+08
1983	.31254E+06	.27624E+06	13000.	10000.0	.46941E-01	.19797E+08
1984	.30144E+06	.26619E+06	13000.	10000.0	.48712E-01	.19786E+08
1985	.29166E+06	.25062E+06	26000.	20000.	0.10335	.19768E+08
1986	.26999E+06	.23098E+06	26000.	20000.	0.11211	.19741E+08
1987	.25071E+06	.21350E+06	26000.	20000.	0.12126	.19714E+08
1988	.23369E+06	.19808E+06	26000.	20000.	0.13066	.19686E+08
1989	.21875E+06	.16254E+06	65000.	50000.	0.39409	.19601E+08
1990	.16583E+06	.11344E+06	65000.	50000.	0.55946	.19399E+08
1991	.11755E+06	67191.	65000.	50000.	0.91873	.18955E+08
1992	73206.	16209.	65000.	50000.	2.8155	.16108E+08
1993	32311.	196.99	32311.	24855.	10.000	.94264E+06
1994	27808.	169.54	27808.	21391.	10.000	.81662E+06
1995	27522.	167.79	27522.	21171.	10.000	.80855E+06
1996	26892.	163.95	26892.	20686.	10.000	.79076E+06
1997	22853.	139.33	22853.	17579.	10.000	.67600E+06
1998	1338.4	8.1600	1338.4	1029.5	10.000	40886.
1999	1158.6	7.0635	1158.6	891.20	10.000	35402.
2000	1147.1	6.9936	1147.1	882.39	10.000	35052.

Removals cant be sustained

```
?-
?
?PR MIDBIO IDISC,ANREV DISREV UCOST - Tabulate simulated values of more variables
 overl1: nymax  101 - spurious message
 ucomio994: index(irec+102)  0 - spurious message
1   TIME MIDBIO       IDISC        ANREV        DISREV       UCOST
       0  .00000E+00  .00000E+00  .00000E+00  .00000E+00  .00000E+00
    1980  .30000E+06  .00000E+00  .00000E+00  .00000E+00  .00000E+00
    1981  .29674E+06  .00000E+00  .94634E+07  .00000E+00  344.09
    1982  .28751E+06  .00000E+00  .18914E+08  .00000E+00  345.11
    1983  .27624E+06  .00000E+00  .18896E+08  .00000E+00  346.44
    1984  .26619E+06  .00000E+00  .18880E+08  .00000E+00  347.72
    1985  .25062E+06  .00000E+00  .37702E+08  .00000E+00  349.91
    1986  .23098E+06  .00000E+00  .37620E+08  .00000E+00  353.09
    1987  .21350E+06  .00000E+00  .37533E+08  .00000E+00  356.41
    1988  .19808E+06  1.0000      .37444E+08  .37444E+08  359.83
    1989  .16254E+06  1.0000      .92938E+08  .12154E+09  370.18
    1990  .11344E+06  1.0000      .91316E+08  .19630E+09  395.14
    1991  67191.      1.0000      .87618E+08  .26121E+09  452.03
    1992  16209.      1.0000      .59092E+08  .30082E+09  890.89
    1993  196.99      1.0000     -.14896E+10 -.60269E+09  47904.
    1994  169.54      1.0000     -.14963E+10 -.14239E+10  55609.
    1995  167.79      1.0000     -.14968E+10 -.21672E+10  56184.
    1996  163.95      1.0000     -.14977E+10 -.28401E+10  57494.      Economic
    1997  139.33      1.0000     -.15037E+10 -.34515E+10  67599.      collapse
    1998  8.1600      1.0000     -.15357E+10 -.40165E+10  .11492E+07
    1999  7.0635      1.0000     -.15360E+10 -.45277E+10  .13276E+07
    2000  6.9936      1.0000     -.15360E+10 -.49904E+10  .13408E+07
?
?
?
?
?VIEW MIDBIO REMOVALS - Plot values of variables on line plotter
 overl1: nymax  101 - spurious message
 ucomio994: index(irec+102)  0 - spurious message
1
VARIABLE  1 IS MIDBIO               MAX =   .300E+06  Maximum values set individually
VARIABLE  2 IS REMOVALS             MAX =   .650E+05  by SIMCON
     +XXXXXXXXX+XXXXXXXXX+XXXXXXXXX+XXXXXXXXX+XXXXXXXXX+XXXXXXXXX+
   0I*
1980I2                                                           1
1981I      2                                                    1
1982I            2                                            1
1983I            2                                          1
1984I            2                                        1
1985I                        2                         1
1986I                        2                     1
1987I                        2                 1
1988I                        2              1
1989I                                1                           2
1990I                      1                                     2
1991I             1                                              2
1992I   1                                                        2
1993I1                            2
1994I1                        2
1995I1                        2
1996I1                       2
1997I1                    2
1998I12
1999I12                                       1 = MIDBIO
2000I12                                       2 = REMOVALS
?                                             * = both
?                                             TIME ↓
?
?
?Q  - quit and exit SIMCON
STOP: SIMCON HALTED
frc% ^D  - quit script
script done on Wed Jul 13 00:35:33 1988
```

APPENDIX III. ANNOTATED LISTING OF THE COMPUTER FILE bioeconB. INCLUDING MACRO LIBRARIES

bioeconB.

```
SET #IDUMP=ON     - not really necessary since ON = default
SET #NYMAX=101    - maximum number of iterations is #NYMAX-1

..Welcome to the generalised bioeconomic fish population dynamics
..simulation model constructed by Pamela Mace and Ian Doonan.
..  It is a good idea to CALL DEFAULTS at the start (only) of a
..  session so that parameters you're not using aren't left as
..  zeros in divisions
```

Any characters following two dots are printed out to the screen but otherwise ignored by SIMCON

```
..
--INITIALISATION AND DEFAULT VALUES FOR RANDOM NUMBER INDICATORS
--
```

Any characters following two hypens are ignored by SIMCO (treated as comments).

Use this first (non-MACRO) part of the file usermodel for documentation, since there is no limit on the size of this part of the file

```
SET INIT=1  --if 1, calculates virgin. rec. & eq. nos. at age
--            if 0, doesnt; i.e. proceeds from current values
--            (default is 1 at time 0; 0 thereafter)
SET ISEED=1  --if 1, seeds the random no. generator
--             if 0, doesnt; i.e. proceeds from current point
--             (default is 1 at time 0; 0 thereafter)
--note: to re-run with vir. bio. & same rand. no. sequence:
--        use TIME 0;SIM 1 100 (or CALL RESTART)
--       to re-run with vir. bio. & continuing rand. no.
--        sequence, use TIME 0;SET ISEED=0;SIM 1 100
--       to re-run with current bio. & continuing rand. no.
--        sequence, use SIM 101 200
--IRANDx is the random number indicator for virgin biomass,
--        natural mortality, ages of recruitment and maturity,
--        growth parameters and recruitment
--          if 1, generates params from prob. dists.
--          if 0, doesnt
SET IRANDBIO=0  -- Random no. indicator for virgin biomass
SET IRANDM=0    -- Random no. indicator for nat. mort.
SET IRANDA=0    -- Random no. indicator for age rec. & maturity
SET IRANDG=0    -- Random no. indicator for growth (K & LINF)
SET IRANDR=0    -- Random no. indicator for recruitment
--
--BIOLOGICAL PARAMETERS
--Note: Mean values (expected values) MUST be given in appropriate
--       MACROs. The variables associated with random number
--       indicators (prefaced below by five dashes)
--       are set to default (nonsense) values in MACRO
--       DUMMYRAND. Any SET command will override the defaults.
SET MAXAGE=70  --maximum age considered in the model (must not be
--              greater than 70)
--Biomass
--VIRBIOM  --mean value of virgin biomass
-----VIRBIOL  --lower limit of mean value as multiplier of mean
-----VIRBIOH  --upper limit of mean value as multiplier of mean
-----VIRMIN   --lower bound on biomass
-----VIRMAX   --upper bound on biomass
-----VIRSD    --standard deviation of biomass
--Natural mortality
--MMEAN  --mean value of natural mortality
-----MMIN  --lower bound
-----MMAX  --upper bound
--Ages of recruitment and maturity
--ARMEAN  --mean value of age of recruitment
-----ARL  --lower bound
-----ARH  --upper bound
--AMMEAN  --mean value of age of maturity
-----AML  --lower bound
-----AMH  --upper bound
--Growth
--KMEAN  --mean value of Brody growth coeff of vonBert equation
-----KMIN  --lower bound
-----KMAX  --upper bound
--LINFMEAN  --mean value of maximum length in vonBert equation
-----LMIN  --lower bound
-----LMAX  --upper bound
-----CORRLK  --covariance LINF and K
-----CORRKK  --variance K
-----CORRLL  --variance LINF
--T0  --x-intercept of vonBert equation
```

```
--Length-weight parameters
--A  --weight=a*l**b where weight is in grams
--B  --power constant of length-weight relationship
--Population length
SET ILENAGE=0  --indicator for length calculations
--                  0=no calculations
--                  1=select by length
--                  2=select by age
-----ILENL  --lower limit of length
-----ILENH  --upper limit of length
-----IAGEL  --lower limit of age
-----IAGEH  --upper limit of age
--Recruitment
SET ROPT=1  --  0 gives zero, 1 gives constant, 2 gives knife-edge,
--              3 gives Beverton-Holt
--STEEP  -- Steepness of the Beverton-Holt relationship:
--            Rec = (STEEP*RVIRG) when MATWT = .2*VIRSPAWN
-----RMIN  --minimum recruitment in numbers
-----RMAX  --maximum recruitment in numbers
-----RSD   --standard dev. of log(rec)
--
--FISHING PARAMETERS
--
SET IFISH=0  --fishing indicator:
--                  0=no fishing (FCON, CCON & BIOCON ignored)
--                  1=constant F (CCON & BIOCON ignored)
--                  2=constant catch (FCON & BIOCON ignored)
--                  3=constant biomass (FCON & CCON ignored)
--FCON  --fishing mortality (used when ifish=1)
--CCON  --catch in tonnes (used when ifish=2)
--BIOCON  --biomass in tonnes (used when ifish=3)
SET WASTE=0.  --prop.of catch not landed or reported
--
--ECONOMIC PARAMETERS
--
SET IECON=1  --if 0, econ variables not calc
--              if 1, they are
--              MACRO DUMMYECON has dummy (nonsense) values for
--              economic parameters, which can be overridden
--              by any SET command
SET IDISC=0  --if 1, applies discount rate to revenue
--              if 0, doesnt
SET D=.1  --discount rate for profits
--PRICE  --fob price per tonne in $
--PCOST  --cost of processing per tonne ($)
SET ICOST=0   --which cost function to use:
--            0 = zero cost
--            1 = constant cost
--            2 = cost prop to F
--            3 = cost inversely related to stock size
--COSTCC    --current cost of catching per tonne
--COSTC     --cost-of-catching constant for cost prop to F
--COSTP     --cost=COSTP*COSTBo when MIDBIO=.2 VIRBIO
--REFC      --reference cost corresponding to REFB
--REFB      --reference biomass corresponding to REFC
--FIXCOST   --fixed costs in $ per fishing year
```

This is the end of the non-MACRO part of bioeconB.
Do not use an END statement here.
All commands contained in the above part of the file will be executed immediately when the model is loaded.
The remainder of the file contains a library of MACROs that are executed only if they are called.

```
MACRO DEFAULTS

...MACRO DEFAULTS has been called: all params given default values
--THESE ARE ALL THE PARAMS THAT MUST BE RESET FOR THE
--DETERMINISTIC VERSION OF THE MODEL, IF YOU WANT TO
--OVERRIDE THEM
SET #NYMAX=101
SET IRANDBIO=0
SET IRANDM=0
SET IRANDA=0
SET IRANDG=0
SET IRANDR=0
SET MAXAGE=70
SET VIRBIOM=100000.
SET MMEAN=.2
SET ARMEAN=5
SET AMMEAN=5
SET KMEAN=.2
SET LINFMEAN=40.
SET T0=0.
SET A=.1
SET B=3.0
SET ILENAGE=0
SET ILENL=0
SET ILENH=100
SET IAGEL=0
SET IAGEH=100
SET ROPT=1
SET STEEP=.95
SET RSD=0.
SET IFISH=0
SET FCON=.2
SET CCON=0.
SET BIOCON=50000.
SET WASTE=0.
CALL DUMMYRAND
CALL DUMMYECON
END
--
--
```

MACRO DEFAULTS assigns default values to the biological parameters. Use SET commands or call another MACRO to override these defaults.

This MACRO also provides a list of the parameters that need to be set in customised MACROs

} MACRO DEFAULTS calls MACROS DUMMYRAND and DUMMYECON

```
MACRO DUMMYRAND
.......MACRO DUMMYRAND has been called
--UPPER AND LOWER LIMITS AND STANDARD DEVIATIONS FOR
--RANDOM NUMBER GENERATION
SET VIRBIOL=.4
SET VIRBIOH=1.6
SET VIRMIN=5000.
SET VIRMAX=1000000.
SET VIRSD=50000.
SET MMIN=.1
SET MMAX=.3
SET ARL=4
SET ARH=6
SET AML=4
SET AMH=6
SET KMIN=.01
SET KMAX=.99
SET LMIN=20.
SET LMAX=100.
SET CORRLK=.015
SET CORRKK=.00015
SET CORRLL=1.6
SET ROPT=1
SET RMIN=1.0
SET RMAX=1.E12
SET RSD=1.
END
--
--
```

MACRO DUMMYRAND assigns default values to the parameters used in random number distributions. They will not be used unless biomass, natural mortality, ages of recruitment and maturity, or growth parameters are to be drawn from probability distributions.

```
MACRO DUMMYECON
......MACRO DUMMYECON has been called

SET IECON=1
SET IDISC=0
SET D=.1
SET PRICE=1000.
SET PCOST=200.
SET ICOST=0
SET COSTCC=500.
SET COSTC=5000000.
SET COSTP=1.5
SET REFB=50000.
SET REFC=500.
SET FIXCOST=0.
END
--
```

MACRO DUMMYECON assigns default values to the parameters used in the economics submodel.
Use SET commands or another MACRO to override one or more of the defaults.

```
MACRO RESTART
...
..MACRO RESTART has been called: reinitialises model -
..All AT commands cleared, TIME 0 recalled, random number generator
..reseeded, all random number indicators turned off, equilibrium
..recruitment and stable age distribution recalulated, discount
..rate indicator turned off, default maximum number of iterations
...reset to 100.
..     If this is the first run of the session, an error message
          "NO SIMULATION RECORD FOUND FOR TIME 0" will appear -
          Ignore it.

AT CLEAR
TIME 0
SET #NYMAX=101
SET ISEED=1   - Set ISEED=0 to choose a
SET IRANDBIO=0    new combination of
SET IRANDM=0      demographic parameters
SET IRANDA=0
SET IRANDG=0
SET IRANDR=0
SET N(ALL)=0
SET INIT=1
SET IDISC=0
END
--
--
```

MACRO RESTART reinitialises the model.

```
MACRO VIRGIN VTRY
--HELPS DETERMINE BACK-CALCULATED VIRGIN BIOMASS
..MACRO VIRGIN has been called with
SET VIRBIOM=VTRY
DI VIRBIOM
...
..Note that you must call RESTART and at least one MACRO
..containing all necessary biological parameters before
..accessing this macro
...
SIM 1 20 - This command may need to be changed
           depending on the time units used.
...
PR BEGBIO MIDBIO REMOVALS F
...
...
...
END
--
--
```

MACRO VIRGIN facilitates trial and error calculation of the virgin biomass that will produce a known biomass level at some later date

```
MACRO MSY CTRY
--HELPS DETERMINE MSY FOR CONSTANT CATCH POLICY
..MACRO MSY has been called with
SET CCON=CTRY
DI CCON
...
..note: TIME 0 recalled at beg of each run, but not at end.
        Time horizon = 500 years.
...
RESTART
SET #NYMAX=501 - increases the allowable number
SET WASTE=0.       of iterations, since constant
SET IFISH=2        catch policies take a long
SET CCON=CTRY      time to converge
SIM 1 500 - This command may need to be changed
            depending on the time units used
...
DI BEGBIO MIDBIO F REMOVALS
ST BEGBIO MIDBIO F REMOVALS
...
..BIOMASS AFTER 500 YEARS AS % OF Bo:
DI PBIO
...
...
...
END
--
--
```

MACRO MSY facilitates trial and error calculation of the maximum constant catch that can be sustained

```
MACRO REPEATMSY CTRY1 CTRY2 CTRY3 CTRY4 CTRY5
CALL MSY CTRY1
CALL MSY CTRY2
CALL MSY CTRY3
CALL MSY CTRY4
CALL MSY CTRY5
END
--
--
```

MACRO REPEATMSY allows five trial values of catch to be used in MACRO MSY at once

```
MACRO FMSY FTRY
--HELPS DETERMINE MSY FOR CONSTANT CATCH POLICY
..MACRO FMSY has been called with
SET FCON=FTRY
DI FCON
...
..note: TIME 0 recalled at beg of each run, but not at end.
..      Time horizon = 500 years.
...
RESTART
SET #NYMAX=501  - increase the allowable number
SET WASTE=0.      of interations
SET IFISH=1
SET FCON=FTRY
SIM 1 500  - this command may need to be changed
             depending on the time units used
...
DI BEGBIO MIDBIO F REMOVALS
ST BEGBIO MIDBIO F REMOVALS
...
..BIOMASS AFTER 500 YEARS AS % OF Bo:
DI PBIO
...
...
...
END
--
--
```

MACRO FMSY facilitates trial and error calculation of the maximum constant fishing mortality that can be sustained

```
MACRO REPEATFMSY FTRY1 FTRY2 FTRY3 FTRY4 FTRY5
CALL FMSY FTRY1
CALL FMSY FTRY2
CALL FMSY FTRY3
CALL FMSY FTRY4
CALL FMSY FTRY5
END
--
--
```

MACRO REPEATFMSY allows five trial values of fishing mortality to be used in MACRO FMSY at once

```
MACRO RESULT
...
PR BEGBIO MIDBIO REMOVALS ANREV DISREV UCOST
...
...
END
--
--
MACRO RESBIO
...
PR MIDBIO REMOVALS CATCH F R PBIO
...
...
END
--
--
MACRO RESBIOEC
...
PR MIDBIO REMOVALS CATCH F ANREV DISREV
...
...
END
--
--
```

These three result MACROs reduce the necessity for continually typing long PRINT commands. Numerous similar MACROs could be defined.

```
MACRO CHATHAM
..MACRO CHATHAM has been called: basic ORH params set
SET VIRBIOM=500000.
SET MMEAN=.1
SET ARMEAN=6
SET AMMEAN=6
SET KMEAN=.26
SET LINFMEAN=41.2
SET TO=.65
SET A=.0963
SET B=2.68
SET IFISH=2
SET CCON=0.
--SET PRICE=3288.
SET PRICE=2567.    --price has decreased
SET PCOST=432.
SET ICOST=3
SET COSTCC=1517.
SET COSTC=180000000.
SET COSTP=1.5
SET REFB=96800.
SET REFC=1050.
SET FIXCOST=0.
AT 1979 SET CCON=11800.
AT 1980 SET CCON=31100.
AT 1981 SET CCON=28200.
AT 1982 SET CCON=32605.
AT 1983 SET CCON=32535.
AT 1984 SET CCON=29340.
AT 1985 SET CCON=23420.
AT 1986 SET CCON=34000.
--AT 1987 SET IDISC=1
END
--
--
```

Parameter values for CHATHAM Rise orange roughy used in 1988 Fishery Assessment Meetings

CHATHAM Rise orange roughy catch history

```
MACRO CHAL
..MACRO CHAL has been called: basic ORH params set
SET VIRBIOM=117000.
SET MMEAN=.10
SET ARMEAN=5
SET AMMEAN=5
SET KMEAN=.215
SET LINFMEAN=39.18
SET TO=2.17
SET A=.0963
SET B=2.68
SET IFISH=2
SET CCON=0.
SET PRICE=3288.
SET PCOST=432.
SET ICOST=3
SET COSTCC=1517.
SET COSTC=180000000.
SET COSTP=1.5
SET REFB=3263.
SET REFC=718.
SET FIXCOST=0.
AT 1981 SET CCON=4072.
AT 1982 SET CCON=11947.
AT 1983 SET CCON=9475.
AT 1984 SET CCON=5117.
AT 1985 SET CCON=7753.
AT 1986 SET CCON=10000.
--AT 1990 SET CCON=6000.
--AT 1987 SET IDISC=1
END
--
--
```

Parameter values for CHALLENGER Plateau orange roughy used in 1988 Fishery Assessment Meetings

CHALLENGER Plateau orange roughy catch history

```
MACRO RITCHIE
..MACRO RITCHIE has been called: basic ORH params set
SET VIRBIOM=127000.
SET MMEAN=.40
SET ARMEAN=6
SET AMMEAN=6
SET KMEAN=0.26
SET LINFMEAN=41.2
SET T0=0.65
SET A=.0963
SET B=2.68
SET IFISH=2
SET CCON=0.
SET PRICE=3288.
SET PCOST=432.
SET ICOST=3
SET COSTCC=2229.
SET COSTC=10320270.
SET COSTP=1.5
SET REFB=3263.
SET REFC=718.
SET FIXCOST=0.
AT 1981 SET CCON=554.
AT 1982 SET CCON=3510.
AT 1983 SET CCON=7200.
AT 1984 SET CCON=8151.
AT 1985 SET CCON=5939.
AT 1986 SET CCON=9042.
--AT 1987 SET IDISC=1
END
--
--
```

Parameter values for RITCHIE Bank orange roughy used in 1988 Fishery Assessment Meetings

RITCHIE Bank orange roughy catch history

```
MACRO WAIRA
..MACRO WAIRA has been called: basic ORH params set
SET VIRBIOM=18679.
SET MMEAN=.1
SET ARMEAN=6
SET AMMEAN=6
SET KMEAN=.26
SET LINFMEAN=41.2
SET T0=.65
SET A=.0963
SET B=2.68
SET IFISH=2
SET CCON=0.
SET PRICE=2567.
SET PCOST=432.
SET ICOST=3
SET COSTCC=718.
SET COSTC=15000000.
SET COSTP=1.5
SET REFB=3263.
SET REFC=718.
SET FIXCOST=0.
AT 1981 SET CCON=554.
AT 1982 SET CCON=3510.
AT 1983 SET CCON=6685.
AT 1984 SET CCON=3310.
AT 1985 SET CCON=867.
--AT 1986 SET CCON=787.
--AT 1987 SET IDISC=1
END
--
--
```

Parameter values for WAIRARAPA orange roughy used in 1988 Fishery Assessment Meetings

WAIRARAPA orange roughy catch history

```
MACRO KAIKOURA
.. MACRO KAIKOURA has been called: basic ORH params set
SET VIRBIOM=10512.
SET MMEAN=.1
SET ARMEAN=6
SET AMMEAN=6
SET KMEAN=.26
SET LINFMEAN=41.2
SET T0=.65
SET A=.0963
SET B=2.68
SET IFISH=2
SET CCON=0.
SET PRICE=2567.
SET PCOST=432.
SET ICOST=3
SET COSTCC=718.
SET COSTC=15000000.
SET COSTP=1.5
SET REFB=3263.
SET REFC=718.
SET FIXCOST=0.
AT 1982 SET CCON=253.
AT 1983 SET CCON=353.
AT 1984 SET CCON=2987.
AT 1985 SET CCON=2285.
--AT 1986 SET CCON=2532.
--AT 1987 SET IDISC=1
END
--
--
```

Kaikoura catch history

Parameter values for KAIKOURA orange roughy used in 1988 Fishery Assessment Meetings

```
MACRO WCSI
..MACRO WCSI has been called: basic ORH params set
SET VIRBIOM=10000.
SET MMEAN=.10
SET ARMEAN=6
SET AMMEAN=6
SET KMEAN=0.26
SET LINFMEAN=41.2
SET T0=0.65
SET A=.0963
SET B=2.68
SET IFISH=2
SET CCON=0.
SET PRICE=3288.
SET PCOST=432.
SET ICOST=3
SET COSTCC=2229.
SET COSTC=10000000.
SET COSTP=1.5
SET REFB=3263.
SET REFC=718.
SET FIXCOST=0.
AT 1983 SET CCON=2.
AT 1984 SET CCON=282.
AT 1985 SET CCON=1763.
AT 1986 SET CCON=1691.
--AT 1987 SET IDISC=1
END
--
--
```

West Coast South Island catch history

Parameter values for West Coast South Island orange roughy used in 1988 Fishery Assessment Meetings

```
MACRO HAKE
.. MACRO HAKE has been called: basic HAK params set
SET VIRBIOM=30000.
SET MMEAN=.2
SET ARMEAN=10
SET AMMEAN=10
SET KMEAN=.18
SET LINFMEAN=87.1
SET TO=.026
SET A=.00438
SET B=3.067
SET IFISH=2
SET CCON=0.
SET PRICE=2567.
SET PCOST=432.
SET ICOST=3
SET COSTCC=500.
SET COSTC=10000000.
SET COSTP=1.5
SET REFB=3263.
SET REFC=718.
AT 1975 SET CCON=71.
AT 1976 SET CCON=5005.
AT 1977 SET CCON=17806.
AT 1978 SET CCON=498.
AT 1979 SET CCON=4839.
AT 1980 SET CCON=2000.
AT 1981 SET CCON=2776.
AT 1982 SET CCON=1924.
AT 1983 SET CCON=1156.
AT 1984 SET CCON=667.
AT 1985 SET CCON=1431.
--AT 1986 SET IDISC=1
END
--
--
```

Some preliminary HAKE parameter estimates

HAKE catch history

```
--
--
MACRO CHAT88 C1 C2 C3 C4 C5 C6 C7 C8 C9 C10
RESTART
CHATHAM
...
SET VIRBIOM=C1
SET REFB=96800.
SET REFC=1050.
SET FIXCOST=0.
SET PCOST=320.
AT 1979 SET N(1)=0.
AT 1979 SET N(2)=0.
AT 1980 SET N(1)=0.
AT 1981 SET N(1)=0.
AT 1979 SET ROPT=C2
AT 1982 SET ROPT=C3
AT 1984 SET ROPT=C4
AT 1986 SET ROPT=C5
SET WASTE=.3
--AT 1987 SET WASTE=C6
AT 1988 SET WASTE=C6
AT 1987 SET D=C7
AT 1987 SET IFISH=C8
AT 1988 SET IFISH=C9
AT 1987 SET CCON=C10
SET FCON=.18
SET STEEP=0.95
--SIM 1979 2000
--PR MIDBIO CATCH F ANREV DISREV UCOST
--PR MIDBIO CATCH F R PBIO
..
END
--
--
```

MACROs RESTART and CHATHAM called

A MACRO to simulate CHATHAM rise orange roughy population dynamics for various levels of virgin biomass, catch overruns and discount rates, using different combinations of stock-recruitment relationships and constant catch or constant fishing mortality strategies.

```
MACRO CHAL88 CH1 CH2 CH3 CH4 CH5 CH6 CH7 CH8 CH9 CH10
RESTART } MACROS RESTART and CHAL
CHAL    }        called
...
SET VIRBIOM=CH1
SET STEEP=0.95
SET ROPT=CH2
AT 1988 SET ROPT=CH3
AT 1987 SET CCON=CH4
AT 1988 SET CCON=CH5
AT 1989 SET CCON=CH6
SET WASTE=CH7
AT 1989 SET WASTE=CH8
AT 1989 SET IFISH=CH9
AT 1989 SET FCON=CH10
SIM 1981 2000
PR MIDBIO CATCH F R PBIO
...
END
--
--
```

A MACRO to simulate CHALLENGER Plateau orange roughy population dynamics for various levels of virgin biomass and catch overruns, using different combinations of stock-recruitment relationships and constant catch or constant fishing mortality strategies.

```
MACRO RITCH88 RT1 RT2 RT3 RT4 RT5 RT6 RT7 RT8 RT9 RT10
RESTART } MACROS RESTART and RITCHIE
RITCHIE }        called
...
SET VIRBIOM=RT1
AT 1987 SET CCON=RT2
SET ROPT=RT3
SET STEEP=RT4
AT 1988 SET ROPT=RT5
SET WASTE=RT6
AT 1988 SET WASTE=RT7
AT 1988 SET IFISH=RT8
AT 1988 SET CCON=RT9
AT 1988 SET FCON=RT10
SIM 1981 2000
PR MIDBIO CATCH F R PBIO
...
END
--
--
```

A MACRO to simulate RITCHIE Bank orange roughy population dynamics for various levels of virgin biomass and catch overruns, using different combinations of stock-recruitment relationships and constant catch or constant fishing mortality strategies.

```
MACRO WAIRA88 WW1 WW2 WW3 WW4 WW5 WW6 WW7 WW8 WW9 WW10
RESTART } MACROS RESTART and WAIRA
WAIRA   }        called
...
SET VIRBIOM=WW1
AT 1987 SET CCON=WW2
SET ROPT=WW3
AT 1986 SET CCON=WW4
SET STEEP=0.95
AT 1988 SET ROPT=WW5
SET WASTE=WW6
AT 1988 SET WASTE=WW7
AT 1988 SET IFISH=WW8
AT 1988 SET CCON=WW9
AT 1988 SET FCON=WW10
SIM 1981 2000
PR MIDBIO CATCH F R PBIO
...
END
--
--
```

A MACRO to simulate WAIRARAPA orange roughy population dynamics for various levels of virgin biomass and catch overruns, using different combinations of stock-recruitment relationships and constant catch or constant fishing mortality strategies.

```
MACRO KAIK88 KK1 KK2 KK3 KK4 KK5 KK6 KK7 KK8 KK9 KK10
RESTART  } MACROS RESTART and KAIKOURA
KAIKOURA }        called
...
SET VIRBIOM=KK1
AT 1987 SET CCON=KK2
SET ROPT=KK3
AT 1986 SET CCON=KK4
SET STEEP=0.95
AT 1988 SET ROPT=KK5
SET WASTE=KK6
AT 1988 SET WASTE=KK7
AT 1988 SET IFISH=KK8
AT 1988 SET CCON=KK9
AT 1988 SET FCON=KK10
SIM 1982 2000
PR MIDBIO CATCH F R PBIO
...
END
--
--
```

A MACRO to simulate KAIKOURA orange roughy population dynamics for various levels of virgin biomass and catch overruns, using different combinations of stock-recruitment relationships and constant catch or constant fishing mortality strategies.

```
MACRO WCSI88 W1 W2 W3 W4 W5 W6 W7 W8 W9 W10
RESTART } MACROS RESTART and WCSI
WCSI    }        called
...
SET VIRBIOM=W1
AT 1987 SET CCON=W2
SET ROPT=W3
SET STEEP=W4
AT 1988 SET ROPT=W5
SET WASTE=W6
AT 1988 SET WASTE=W7
AT 1988 SET IFISH=W8
AT 1988 SET CCON=W9
AT 1988 SET FCON=W10
SIM 1983 2000
PR MIDBIO CATCH F R PBIO
...
END
--
--
```

A MACRO to simulate West Coast South Island orange roughy population dynamics for various levels of virgin biomass and catch overruns, using different combinations of stock-recruitment relationships and constant catch or constant fishing mortality strategies.

```
MACRO DEMO V C
..MACRO DEMO has been called
..You may now issue SIM, DI and PR commands.
..If you want to do another run: CALL RESTART; then CALL DEMO;
..then you may issue your own SET commands to override DEMO's
..parameter values; then issue SIM, DI and PR commands
SET VIRBIOM=V
AT 1988 SET CCON=C
SET MMEAN=.2
SET ARMEAN=5
SET AMMEAN=5
SET KMEAN=.2
SET LINFMEAN=50.
SET T0=0.
SET A=.1
SET B=3.
SET ROPT=3
SET STEEP=.95
SET PRICE=1000.
SET PCOST=200.
SET ICOST=3
SET COSTP=1.5
SET REFB=50000.
SET REFC=500.
SET FIXCOST=0.
SET IDISC=0
AT 1987 SET IDISC=1
SET D=.1
SET IFISH=2
SET WASTE=0.
SET CCON=0.
AT 1980 SET CCON=5000.
AT 1981 SET CCON=10000.
AT 1982 SET CCON=10000
AT 1983 SET CCON=10000.
AT 1984 SET CCON=20000.
AT 1985 SET CCON=20000.
AT 1986 SET CCON=20000.
AT 1987 SET CCON=20000.
END
--
```

A demonstration MACRO for the novice user (see Appendix II).