A User's Guide to Fournier's Catch-at-age Model

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A USER'S GUIDE TO FOURNIER'S CATCH-AT-AGE MODEL

by

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ABSTRACT

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A user's guide to the operation of a new catch-at-age model developed by D. Fournier (Fournier and Archibald 1982) is presented. A detailed example using simulated data is described in stepwise fashion. The guide allows users to examine the influence of various parameters in the reconstruction of stock histories as well as to include additional information such as estimates of ageing errors, stock-recruit relations, or errors in input data. The influences of these elements are demonstrated through comparison of the model estimates of abundance at age with the known, simulated data. Computer code for the model is not included.

Key words: population model, user's guide, catch-at-age.

RESUME

Archibald, C. P., D. Fournier, and B. M. Leaman. 1983. A user's guide to Fournier's catch-at-age model. Can. MS Rep. Fish. Aquat. Sci. 1688: iii + 81 p.

On présente un guide pour l'utilisation d'un nouveau modèle de capture par groupe d'âge élaboré par D. Fournier (Fournier et Archibald 1982). Un exemple détaillé utilisant des données simulées est décrit étape par étape. Le guide permet aux utilisateurs d'étudier l'influence de divers paramètres dans la reconstitution de l'histoire des stocks ainsi que d'inclure d'autres renseignements, tels que les estimations des erreurs liées à la détermination de l'âge, les relations stock-recrutement ou les erreurs dans les données fournies. L'influence de ces éléments est démontrée en comparant les estimations fournies par le modèle de l'abondance par groupe d'âge avec les données connues et simulées. Le code informatique du modèle n'est pas fourni.

Mots-clés: modèle de population, guide de l'utilisateur, capture par groupe d'âge

INTRODUCTION

This user's guide to Fournier's catch-at-age model is intended primarily to enable a naive user to apply this analysis to a data set and to properly interpret the output. Before proceeding with this guide, the reader is strongly advised to become acquainted with the general theory behind the model by reading Fournier and Archibald (1982). Certain aspects of the theory will be dealt with in more detail in the sections dealing with individual options of the model.

The model is a general one and can be used to analyze any time-series of catch-at-age data for a fishery (i.e. where one might otherwise use a more common method of sequential analysis, such as cohort or virtual population analysis). The basic inputs to the model are catch at age and total catch data for each year of the time series, although information on fishing effort each year is also usually available. The model uses this information to reconstruct the population history and it provides estimates of the number of fish at age in the population each year, as well as estimates of the instantaneous fishing mortality at age in each year. The major strengths of this model are: it extracts additional information by analyzing all cohorts simultaneously; it correctly addresses the stochastic error in both the input data and the biological processes described; and, it utilizes the underlying regularities in the instantaneous mortality rates. There are no minimum size restrictions, but obviously the more years of data, the better the results. The model can presently handle up to 25 age classes and 100 years of data.

There is much additional information the program can incorporate to improve the solution obtained, such as fishing effort information, the existence of a stock-recruit relationship, time-dependent catchability, accuracy of ageing techniques, accuracy of estimates of total landings, and the effect of environmental factors on recruitment. The model described here is a method of combining such information in a systematic way with the catch-at-age data in order to provide an analysis of the past behaviour of an exploited fish population. However, it should be emphasized that when one attempts to apply an existing model to a new set of fisheries data, one often encounters some new contingency which calls for major or minor revisions of the model. For this reason a model should not be regarded as a final product, but rather as a flexible framework which can be modified should the situation require it.

The guide is organized as follows: first, the minimization procedure is described; second, the form of the input data is illustrated; third, the generation of simulated data for use in demonstrating the analyses is explained; fourth, the actual mechanics of doing a basic catch-at-age, reconstruction analysis are presented; fifth, the inclusion of various options into the basic model is discussed; and finally a section is presented on miscellaneous troubleshooting.

All logarithms dealt with in this guide are natural logarithms (to the base e). The program for the model is written in FORTRAN and the code is separated into 12 files (see Appendix B). The executable form of the model is stored in the file RECONS.EXE.

2. THE MINIMIZATION PROCEDURE

The basic task the model performs is a search for a solution (a particular set of estimates of numbers and F at age in each year) which can reproduce the input data as closely as possible. The model does this by constructing a log-likelihood function and then varying the parameters involved in this function in order to try to maximize the function value (see Fournier and Archibald 1982 for equation plus description of the parameters involved). According to maximum likelihood theory, the fit to the data is best when the function value is maximized. However, since this model works with the negative of the log-likelihood function, the model is actually trying to minimize the function value. Hence the term minimization procedure.

The model starts the minimization procedure with certain values for the parameters and evaluates the partial derivatives of the log-likelihood function with respect to each parameter. This is done to find out which parameters can be changed to decrease the function value: a high value for a certain partial derivative (either positive or negative) means that changing that particular parameter will result in a better solution (a lower function value) and the sign of the derivative indicates the direction in which the parameter should be changed. It may be helpful for the reader to compare this procedure to the situation in two dimensions where one is trying to find the minimum value on a curve: the partial derivatives correspond to the slope of the two-dimensional curve which gets smaller as the minimum is approached, eventually equalling zero at the minimum.

When the model calculates the value of the log-likelihood function for a given set of parameters, this is termed a function <u>evaluation</u>. Then the model calculates the partial derivatives to find out which parameters it can vary, and in which direction it should vary them, to improve the solution (to further approach the minimum value for the log-likelihood function). The model then makes changes in the parameter values according to the above, and calculates the function value (does a function evaluation) for this new set of parameters. If the function value does in fact decrease, then this new set of parameters becomes the starting point for the next step and this is termed an <u>iteration</u>. If the function does not decrease, then the model changes the parameters in a slightly different manner and again does a function evaluation to see if this different direction results in a function value decrease. Therefore, the minimization procedure is a long series of function evaluations and iterations. It should be evident that if the function is making good progress, then almost every function evaluation will result in an iteration. If it is not making much progress, then many evaluations will be done before an iteration is achieved and the number of evaluations will greatly exceed the number of iterations. Thus, for any run, the number of iterations will always be less than or equal to the number of function evaluations .

2. INPUT TO THE MODEL

Table 1 shows the form of the input presented to the model. The input data shown are simulated data and will be discussed later. The input is in free format and the first eight numbers are the GPAR values which represent the following:

GPAR(1) - number of years of data (20 in this case)

GPAR(2) - number of age classes in the catch (10)

GPAR(3) - number of age classes (starting with the oldest) that the model holds at the same instantaneous fishing mortality (F) for each year. That is, though the F for this group of age classes may vary among years, it is the same within this group of age classes in any one year. A zero or 1 here obviates this option so that the F values for the oldest age classes are not necessarily the same.

GPAR(4) - allows the user to hold this many of the last years (not age classes as in GPAR(3)) at the same overall level of F if such is deemed necessary. For example, one may wish to hold the overall level of F the same for the last 5 years of the data set; then GPAR(4) is set to 5. This option is not usually required and a zero or 1 here will obviate this option.

GPAR(5) - an F value to start with; should be approximately one's guess as to the average F experienced by fully recruited fish over the time series. The exact value is not too crucial as it is only used as an estimate.

GPAR(6) - user's estimate of instantaneous natural mortality (M). In most situations, M is not well determined by this model and so M is generally set by the user and assumed to be constant over age class and year.

GPAR(7) - value of F thought to be the maximum over the time series.

GPAR(8)- value of F thought to be the minimum over the time series. This and the previous number just provide bounds within which the model can work; if in doubt, make the limits broad. It should be noted that although the input is otherwise free format, these eight GPAR values must be read in as two lines of four numbers.

The next 28 input numbers shown in Table 1 are the 28 KPAR values which determine the options to be included in the particular run. The KPAR variables which are important for the basic catch-at-age analysis (section 4) are discussed here, while those involved with specific options such as the stock-recruit relation or time-dependent catchability are discussed in the sections dealing with those options. A complete description of all KPAR variables is shown in Appendix A.

KPAR(1) determines the maximum number of function evaluations before the run terminates. KPAR(2) determines the number of iterations of the function minimizer between displays of intermediate results. The smaller this number is, the more often intermediate results are displayed on the terminal screen and the user is able to keep very close track of the function minimizer's progress. KPAR(3) is the estimate of the initial amount of decrease in the log-likelihood function. It is generally sufficient to set this KPAR to 100, though smaller values may be necessary if one wishes to continue trying to minimize when already very close to the minimum (see description of KPAR(3) in Appendix A). KPAR(4) is the maximum number of function evaluations that can occur without resulting in an iteration; if this is exceeded the run terminates. This then is the second way for a run to terminate, the first being if KPAR(1) is exceeded. A run will also terminate if the function minimizer is not making enough progress; specifically, if the function value changes by less than 0.01 over a period of 10 evaluations. The various ways a run can terminate are summarized under KPAR(4) in Appendix A.

KPAR(5) simply determines which results from a run are printed into the output file. If zero, no results are printed out; if 1, only the final results are printed out (this is usually all one is interested in); and, if 2, both initial and final results are printed out in the output file, one after the other. KPAR(6) is the number of function evaluations after which the derivative checker will be invoked. This is only used for debugging purposes. KPAR(7) is set to zero for the initial run of any reconstruction, and then to 1 for further continuation of the minimization procedure. Data for the age structure of the catch must be presented as actual numbers and not proportions (see below), and if KPAR(8)=0 then sample sizes for catch age structure are taken exactly as supplied in the input data. If KPAR(8) is non-zero, then each age sample size for catch is scaled to equal 400/KPAR(8). The usual value here is 1 and for more details the reader is referred to Appendix A.

Setting KPAR(10)=1 means that the oldest age class is totally fished out, or in other words that the age range of the catch (set by GPAR(2)) is broad enough so that there are very few fish in the catch of the oldest age. For implications of KPAR(10) not being 1, see Appendix A under KPAR(10).

If KPAR(11)=1, then the model expects to be supplied with data on annual fishing effort. KPAR(20) determines whether the average level of F in each year can deviate from the level determined by effort. If zero, it cannot; and if non-zero, it can according to the calculation method described by Fournier and Archibald (1982). The amount of deviation permitted is inversely proportional to the value of KPAR(20) (see Appendix A).

KPARs (21) and (22) determine the type of fishing mortality parameterization used: if KPAR(21) is non-zero, then the so-called VB parameterization is used; and if KPAR(22) is non-zero then the Doubleday parameterization is used (see Fournier and Archibald 1982 for parameterization equations). Note that both KPARs cannot be made non-zero. For runs presented in this guide the VB parameterization will be used.

After the KPAR variables in Table 1, the estimates of total catch (by number) are entered for each year (110.6 through 66.5 in Table 1). Next one enters the age structure of the catch sample for each year. For example, referring to Table 1: 33 fish of the first age class were found in the age sample in the first year; 77 fish of the second age class in the first year; 57 of the first age class in the second year, etc. The numbers entered here should be actual numbers of fish found to be of that age in the catch sample, not proportions. If proportions are entered, the model cannot deal with the sample sizes properly (see KPAR(8) in Appendix A). Of course, the model eventually calculates proportions from the input catch at age in order to do the reconstruction analysis.

After the catch-at-age data, one enters the necesary information for the various options that are to be included. The most common is the inclusion of effort information for each year of the time series, and the effort data are entered immediately after the catch-at-age data. Any units can be used for the effort as a change in units will only result in a complementary change in the estimated catchability. The data for other options are entered following the effort data, and are discussed later. For now only their order of entry after the effort data will be noted:

- effort data
- relative fecundity values (if stock-recruit option included)
- ageing errors (if applicable)
- values of environmental factor (if applicable)

3. GENERATION OF SIMULATED DATA

Simulated data sets were generated on which to do the catch-at-age analyses and the results of the first basic simulation are shown in Table 2. The simulations were done in a stochastic fashion and four stochastic elements were dealt with: estimation of total catch, estimation of age structure, and the relationships between effort and fishing mortality, and between stock and recruitment.

The annual catch estimates differed from the true annual catch as follows:

$$O(i)=C(i)*\exp(Y(i)) \tag{3.1}$$

where O(i) is the estimated catch in year i, C(i) the true catch in year i, and Y(i) a normally distributed random variable with mean zero and variance 0.0025. This corresponds to approximately a 5% error in the estimate of total catch (standard deviation of about 0.05). The resulting values of true and estimated catch are shown in Table 2.

The true catch at age is shown in Table 2; these numbers can be calculated by putting the numbers at age and instantaneous mortalities at age into the standard catch equation (Ricker 1975; see equation 4.1.1). Each year's catch-at-age data were then scaled to correspond to a random sample of 400 fish, and this is shown in Table 2 under the heading "observed catch at age". Note that each year's sample size sums to 400 and that the ratio between ages closely approximates the ratios in the "true catch at age" section (only approximates the ratio because of the random sampling). A random sample of 400 means that if a true population percentage at a certain age is 0.2, then the observed value would lie between 0.16 and 0.24 96% of the time. Using properties of the binomial distribution (Li 1964, p. 445), this is calculated as follows:

$$\begin{aligned}
\text{standard error} &= \text{SQRT(variance/sample size)} \\
&= \text{SQRT}((0.2)(1-0.8)/400) \\
&= 0.02 \\
\text{approx. 96\% confidence limits} &= \text{mean} \pm 2*(\text{standard error}) \\
&= 0.2 \pm 0.04
\end{aligned}$$

The third stochastic element was introduced in the relationship between effort and fishing mortality (F). Log normal error was introduced in a fashion similar to that shown above for total catch:

$$Fa(i)=Fp(i)*exp(Y(i)) \quad 3.2$$

where Fa(i) is the average F actually experienced in year i, Fp is the average F predicted by effort in year i, and Y(i) is as before but with a variance of 0.01 now. The residuals (or deviations, or errors) in the effort-F relationship are shown near the bottom of Table 2. These numbers represent values of Y(i). For example, the residual -0.19 is equal to the natural log of the following ratio: Fa(2)/Fp(2). The importance of these residuals will be to see if the catch-at-age analysis can detect them, both in a qualitative and a quantitative sense.

The final stochastic element was included in the stock-recruit relationship (not included in Table 2, but see Table 4 for an example). Recruitment was assumed to follow the basic Ricker equation (Ricker 1975):

$$R(i+k)=A*P(i)*exp(-D*P(i))*exp(Y(i)) \quad 3.3$$

where R(i+k) is the recruitment to the fishery in year i+k (fish recruit at age k), P(i) is the stock fecundity in year i, A and D correspond to the alpha and beta parameters of Ricker, and Y(i) is as defined before (variance stated when this option is dealt with). Stock fecundity is calculated as the sum of the numbers at age times their respective relative fecundities (see section 5.1 for why it is not necessary to work with absolute fecundities). If the same relative fecundity value is used for all ages, then equation 3.3 is the same as Ricker's equation which is based on stock size in terms of numbers, not fecundity.

4. BASIC CATCH-AT-AGE ANALYSIS

4.1 Mechanics of the procedure

The sample basic catch-at-age (reconstruction) analysis will be done on the simulated data shown in Table 2 where we know the true values of N and F at age in each year (to enable us to see how well the analysis has reconstructed the fishery). In order to start the reconstruction analysis, we pass to the model the estimated values for total catch and age composition each year, and also the values for annual effort. These values taken from Table 2 can be seen in Table 1, which is the input to the model. Note that this most basic reconstruction includes effort information, and this is because the model makes little progress without such information. In the unlikely event that the user has no effort data whatsoever, one possible solution would be to provide the program with the same effort value for each year and allow F to be only loosely related to the effort (low value for KPAR(20)).

We are now ready to commence the catch-at-age analysis. The description of the procedure will follow in a stepwise fashion.

Step 1. Initial assignments

The raw data are read in on unit 10, the restart values to continue a run are read in on unit 13, the current parameter values are saved on unit 15, and the actual output is on unit 18. The use of the various units will become clear shortly, and for now simply note the following assignment statements that need to be done before the analysis can be started (file names are arbitrary; file INPUT.1 contains Table 1):

```
ASSIGN INPUT.1 FOR010
ASSIGN TT.1 FOR013
ASSIGN PP.1 FOR015
ASSIGN OO.1 FOR018
```

If these assign statements are not done, the following error message is displayed on the terminal screen:

```
    ERROR IN INPUT.  VALUE OF IERRX IS 1
  VALUE OF I INDEX IS     1
  VALUE OF J INDEX IS    -1
FORTRAN STOP
```

Step 2. Initial start

For the first series of iterations, the KPAR values are set as noted in Table 1. Note that KPAR(1) is set relatively low (20) for this initial run; KPAR(1) is not usually set higher until some progress has been made with the minimization. KPAR(2) is set at 30, higher than KPAR(1); there is no need to see intermediate results at this stage. KPAR(4) is set rather high (40) to ensure that the run will not be stopped prematurely by the function minimizer getting "temporarily stopped" (doing a small number of function evauations that do not result in an iteration). Since this is not a debugging run, KPAR(6) is set to -1 to omit the derivative checker. Note that KPAR(7)=0 since this is an initial start and KPAR(11) is non-zero (1) since we are supplying effort data to the model. KPAR(20) is set to zero for the initial start since the model cannot deal wih effort-F deviations until some progress has been made with the minimization procedure. All the other KPAR variables discussed in section 2 are assigned their usual values.

The run is started by typing RUN RECONS and the input data will be shown on the terminal screen for the user to check. First the KPAR values are displayed, then the observed total catches, the observed age structure by year, the initial catchability (set to 0.001 by the model), and finally the effort values. This is followed by the initial statistics for the first function evaluation:

```
ITER. NO.  0          FUNCT. EVALUATIONS  1
FUNCTION VALUE =  1452.
CO-ORDINATES
          1.00       -0.700       -1.83        -8.16        -1.73
GRADIENT
         720.    -0.126E+04    0.000E+00     -175.          43.1
```

Since for this initial run KPAR(1) was set to 20, the model will continue until 20 function evaluations have been completed. Then the following is displayed on the terminal screen:

```
              *** MAXIMUM NUMBER OF FUNCTION EVALUATIONS EXCEEDED
                  -----------------------------------------------

ITER. NO. 17   FUNCT. EVALUATIONS = 20   EXIT CODE = 3
FUNCTION VALUE = 357.268
CO-ORDINATES
   1.23      -0.136      -1.83      -6.49      0.423
GRADIENT
   7.84      -18.3      0.000E+00   7.05      -9.48

 VALUE OF IEXIT IS    3        VALUE OF IHANG IS   0
```

The reader should not become too concerned about the actual values for the coordinates and gradients. The coordinates given are the model's current values for the various parameters; at this early stage the program is only dealing with 5 parameters (M, catchability, and 3 for F (see below)). For example, the value -1.83 is the model's value for M, calculated according to the way it is incorporated into the log-likelihood function (-1.83=log(0.4**2)). The gradient values are just the partial derivatives with respect to these five parameters. Large values for the gradients indicate that progress can still be made with the function minimizer, and as the function value approaches its minimum the gradients will be seen to approach zero. The gradient for M is 0 since it is not allowed to vary.

The exit code is the same as IEXIT, and IEXIT and IHANG are flag values which indicate how the run was terminated. If IEXIT=3 and IHANG=0, the run terminated because the number of function evaluations reached the number allowed by KPAR(1).

Step 3. Proceeding with the minimization

The initial start has been completed and we are now ready for a restart in order to continue with the minimization. This is done by editing the file INPUT.1 so that KPAR(7) is changed to 1. At this time we can also allow the fishing mortality to deviate from the effort, and so we change KPAR(20) to 25. The reader should be reminded that as long as KPAR(20) is non-zero, these deviations are allowed and the actual amount of deviation is determined by the size of KPAR(20), in an inverse fashion . A usual value here is 25, which corresponds to a variance of 0.02 in the log of the effort-F relationship (see Appendix A).

Since we now have all the options included that we wish to consider for now, we can allow the model to continue for more evaluations on this run (change KPAR(1) to 60). The final thing to be done before continuing on is to allow the model to begin from where it left off, and this is done by copying unit 15 into unit 13, or:

```
COPY PP.1 TT.1
```

Then we are set so we do another run: RUN RECONS. The first display on the terminal shows the initial statistics for this restart run:

```
ITER. NO.  0      FUNCT. EVALUATIONS  1
FUNCTION VALUE = 357.3
CO-ORDINATES
              (54 numbers here)

GRADIENT

  -15.3    19.0      40.1      24.3      -105.      12.3
  -42.     55.5     -27.2     -65.2      -72.5      296
              (42 more numbers here)
```

Note that the function value is the same from where we left off on the previous run. Also, there are many more parameters that the model is varying in its minimization procedure. There are 54 in this case: 1 for M, 1 for catchability, 3 for the curve of F over age (b1, b2, and s of Fournier and Archibald 1982), 29 (20 years + 10 age classes - 1) fundamental betas (Fournier and Archibald 1982), and 20 for the annual deviations of F from effort (added to the procedure by making KPAR(20) non-zero).

For this run KPAR(2)=30, so,after 30 iterations intermediate results will be displayed on the screen as follows:

```
INTERMEDIATE STATISTICS

ITER. NO.  30          FUNCT. EVALUATIONS  35
FUNCTION VALUE = 98.899
CO-ORDINATES

               (54 numbers here)

GRADIENT

               (54 numbers here)
```

And the run will stop once 60 evaluations have been done:

```
                   MAXIMUM NUMBER OF FUNCTION EVALUATIONS EXCEEDED
                   -----------------------------------------------

ITER. NO.  54    FUNCT. EVALUATIONS  60     EXIT CODE  3
FUNCTION VALUE = 82.2194
CO-ORDINATES

                (54 numbers here)

GRADIENT
  -0.571E-01     -.121      .921     -.629     -.664      .584
  -.705          -.485     -.206      .869      .204      1.08
                (42 more numbers here)

  VALUE OF IEXIT IS     3       VALUE OF IHANG IS      0
```

Note how the function value has dropped substantially and how the gradients are all closer to zero. To see if we are at the minimum, we copy unit 15 into unit 13 again and continue on:

```
COPY PP.1 TT.1
RUN RECONS
```

The following is displayed for the initial statistics of this additional restart run:

```
ITER. NO.  0        FUNCT. EVALUATIONS  1
FUNCTION VALUE = 86.22
CO-ORDINATES

          (54 numbers here)

GRADIENT

          (54 numbers here)
```

After 30 iterations, we see the intermediate statistics. Note the function value has decreased only slightly, indicating that we are near the minimum:

```
ITER. NO. 30        FUNCT. EVALUATIONS 39
FUNCTION VALUE = 86.10
CO-ORDINATES

          (54 numbers here)

GRADIENT

          (54 numbers here)
```

The next display on the terminal screen is as follows:

```
VALUE OF IEXIT IS      1            VALUE OF IHANG IS     1

FUNCTION MINIMIZER NOT MAKING ENOUGH PROGRESS
IS ANSWER ATTAINED?  (model doesn't expect an answer to this question)
```

The values of IEXIT and IHANG are now both 1 whereas previously they were 3 and 0, respectively. This indicates that the model has failed to decrease the function value by more than 0.01 over a period of 10 function evaluations. Another message that may be displayed when the function minimizer isn't making enough progress is:

```
VALUE OF IEXIT IS    1          VALUE OF IHANG IS  0
PROGRAM CAME TO NORMAL TERMINATION
FORTRAN STOP
```

These flag values indicate the manner in which the run terminated, and for more details the reader is referred to the discussion of KPAR(4) in Appendix A. Either way the program stops, the progress of the minimizer can be checked by referring to the output.

Step 4. Examining the output

The output (in file 00.1 from unit 18) for this final run of the basic analysis is shown in Table 3. This ouput will now be dicussed in detail, section by section.

The first part of the output is the series of function evaluations calculated during the run; every fifth evaluation is printed out. The value 86.2085 is the 5th evaluation, 86.1088 the 35th, 86.1000 is the 40th, and 86.1 is somwhere between the 41st and 45th evaluation. This final run did not reach the maximum number of evaluations allowed by KPAR(1) because it was stopped between the 41st and 45th evaluation because of insufficient progress.

Next in the output shown in Table 3 are the 8 GPAR and 28 KPAR values. Note that these are the same as the values supplied to the model's last run, with the exception that GPARs (3) and (4) are now 1 (were zero before). This is because a value of zero for these two GPARs is reset to 1 by the program.

The KPAR values are followed by the estimated number of fish at age in each year of the time series; the years are presented in order, each starting with the youngest age class. These numbers are in the same units as the input catch data. The total number of fish in the population each year is presented below this.

The estimated age structure of the catch each year can be compared with the observed age structure of the catch to see how well the model was able to fit the input data. It is this comparison that the model makes as it tries to find a better solution, and a lower function value indicates a closer comparison.

Between the above two sets of age structure information are the multiplicative factors for the total catch. These are estimates of the error involved in the observed total catch data supplied to the model. The model will vary the annual catch data if it finds that this will improve the overall fit to the input catch at age data, and these new numbers are then the model's estimates of the true annual catch. These new numbers can be calculated by the user by multiplying the observed catch for each year by the corresponding multiplicative factor. For example, in year 1, the observed catch was 110.6 while the true catch was 117 (Table 2). The model's estimate of the true catch in year one is 110.6*1.003=111.0. Thus, to some extent, the model is able to estimate the stochastic error involved in the input annual catch data and make the appropriate corrections. This is discussed in more detail in section 4.3.

The relative fishing vulnerability is presented to show the relative change in F over age; this is assumed to be the same for each year. The fishing vulnerability is set to 1.0 at the age where F is a maximum.

The actual estimated value of F over age for each year is then presented. Of course, each year is the same in a relative sense as the fishing vulnerability, but the overall level in each year is different (determined to some extent by the effort in that year). The estimated value for natural mortality is simply that supplied to the model. The estimates of average fishing mortality are given for each year, in this case averaged over all age classes starting with the first one. For example, in year 1 the average of the 10 F values 0.045 through 0.390 is 0.285, which is the value given for average fishing mortality in that year. If the user wishes to calculate the average fishing mortality based on only the older age classes, then KPAR(18) is set equal to the first age class that is to be used in the calculation. KPAR(18)=0 is interpreted as a 1 and all age classes are used in the calculation.

The observed effort is printed out next, followed by the model's estimate of catchability. Note that the model's estimates of the effort-F residuals compare well with the true residuals shown in Table 2. Thus the model was able to detect the errors involved in the effort-F relationship; this type of error detection is discussed more fully in section 4.3. The variance estimate of the effort-F relationship is simply the standard variance of the residuals. This equals 0.0085 which rounds off to 0.01.

A sample calculation will be done to assure the reader that the ouput is consistent. For example, given numbers (N) and instantaneous fishing mortality (F) in each year, we can check the calculation of catch by hand. Using the catch of age class 3 fish in year 1, we proceed as follows, starting with the standard catch equation (equation and symbols after Ricker, 1975):

$$\text{catch} = (F*A/Z)*N \qquad 4.1.1$$

$$= (F*(1-\exp(-Z))/Z)*N$$

$$= [(.212*(1-\exp(-.212-0.4)))/(.212+0.4)]*130$$

$$= 20.6$$

This number is to be compared with the model's estimate of the catch of age class 3 fish in year 1:

catch = (model's est. of total catch in year 1)*(est. proportion that were of age class 3)

= (1.003*observed catch)*(0.186)

= (1.003*110.6)*(0.186)

= 20.6

In this sample catch at age analysis, the model has done very well in reconstructing the numbers at age and the F at age in each year of the data set.

This can be seen by comparing Tables 2 and 3.

The basic analysis has now been completed, and before proceeding on to the addition of various options we shall examine the effects on these results of varying M and the amount of stochastic variation.

4.2 Effect of varying natural mortality (M)

Natural mortality was fixed at the true value for the preceding analysis, and the reader may wonder what would happen to the overall fit to the data (as indicated by the function value) if M were fixed at a different value. The value of M can be changed in two ways. One can simply start all over again from an initial start and use a different input value of M. However, it is easier to change the value of M in the restart file (TT.1, on unit 13). As long as the change in M is not too great, one can then simply continue with the minimization. For example , let's see what happens to the minimum function value when M is changed to 0.5. Looking at file TT.1 from where we finished off our last run, we see the following (as an aside, note that the 80 variables after the number 54 are the 80 IPAR variables discussed in Appendix C; these are in part determined by the KPAR variables and the model works with these IPAR variables, not the KPAR variables):

```
54

60    30   100   40    1   -1    1    0    2    0
 0     1     0    1    0    0    0    0    0    0
 1     1     0    0    0    0    0    0    1    0
 0     0     0    0    0    0    0    0    0    1
 0     0     0    0    0    1    0    0   25    0
 0     0     0    0    1    0    0    0    0    1
 0     0     0    0    0    0    0    0    0    0
 0     0     0    0    0    0    0    0    0    0

-2.3148        -2.0025        -2.3732        -2.3558        -2.3229
-2.0885        -2.3346        -2.4221        -3.1734        -2.9260
-2.6565        -2.7381        -2.6007        -2.8292        -2.7386
-2.3164        -2.3586        -2.5811        -3.5497        -2.7910

-2.0185        -1.0166        -1.2510        -2.0867        -2.4149
-2.3622        -3.5831        -3.9885        -5.9524

 1.2479        -0.17364

-0.14659E-01   -0.15608        0.16484       0.29944E-02   -0.27888E-01
-0.38639E-01    0.64442E-01   -0.78699E-01   0.56362E-02   -0.37666E-01
-0.10996        0.16419       -0.51743E-01   0.14028        0.18653E-01
-0.71784E-01    0.14929       -0.11638      -0.12848E-01    0.47365E-02

-1.8326

-6.4101

 0

0.65240
```

The only number which need concern us here is -1.8326 which corresponds to M=0.4, as noted earlier. This number is now changed to -1.3863 for M=0.5 (-1.3863=log(0.5**2)). Note that there is no need to change the M value in the input file INPUT.1 since after the initial run the M value is read from TT.1. Now we are ready to proceed as before with the minimization, and in this case the function value levelled off at 86.8. Doing this for other values of M produced the following results:

FUNCTION VALUE (F) FOR DIFFERENT VALUES OF M:

M -	0.1	0.2	0.3	0.4	0.5	0.6	0.7
F -	88.2	87.0	86.3	86.1	86.8	88.5	91.4

It is evident that the function value is indeed a minimum at M=0.4, the true value of M. However, the function value changes only slightly from M=0.2 to M=0.5 and this is because M is not well determined by the model. It is recommended that the user start off with the best estimate of M that can be obtained from other information, and later alter the value of M to see if the initial value of M is close to the M giving the lowest function value. See Fournier and Archibald (1982) and Archibald et al. (1983) for additional discussions of this point.

4.3 Effect of increasing the stochastic variation

In the analyses presented above, there were three sources of stochastic error or variation and the model was given an estimate of the extent of each one: the error in the estimate of total catch (determined by KPAR(27));the error in the effort-F relationship (KPAR(20)); and the error in the samples taken for the determination of age structure (KPAR(8)). KPARs 8 and 20 have already been discussed, and when KPAR(27)=0 (as in our case) the variance in the total catch estimates is set by default to 0.0025. If non-zero, this variance is set equal to 0.5/KPAR(27). Let us now examine how the model performs when we increase the variation in one of the stochastic elements, for example the estimate of total catch.

The same input data will be used here as were used initially, but with the variance in the total catch estimate increased from 0.0025 (approx. 5% error) to 0.09 (approx. 30%). The reconstruction model was told of the increased variance (KPAR(27) set to 6) and the function value minimized at 90.8. Note that this represents a poorer fit than was obtained before (function value of 86.1) and this is because the input total catch data are less accurate. A more interesting question to ask is how well did the model estimate the errors in the total catch. This can be answered by comparing the true error in the catch data with the model's estimates of the error in the catch data. Remembering from section 3 that the residuals (Y(i) in equation 3.1) represent these errors, note that the two sets of residuals are as follows:

THE MODEL'S ESTIMATES OF THE RESIDUALS (ONE FOR EACH YEAR)

.351	.178	-.368	-.350	.248	-.145	-.284	.264	.151	.110
.291	-.309	.141	-.265	-.252	.243	-.361	.272	.019	.070

THE TRUE SIMULATED RESIDUALS

0.348	-0.087	-0.440	-0.696	0.244	-0.328	-0.344	0.310	0.287	0.177
0.362	-0.197	0.165	-0.233	-0.396	0.225	-0.354	0.255	0.052	0.153

To compare the two sets of residuals it is perhaps easiest to think of each set as a vector in 20-dimensional space (with 20 coordinates which are the values of the residuals). Then one can ask whether the two vectors point in the same direction (are similar in a qualitative sense) and whether they are of comparable length (similar in a quantitative sense). A correlation coefficient tests similarity of direction and r here is 0.93 ($p<0.01$ with 18 degrees of freedom). To test vector length, one calculates the norm which is the square root of the sum of the squares of the residuals (the equivalent of the Pythagorean theorem in 20-D space). The norm of the model's residual vector is 1.13 which is 80% of the true residual norm of 1.41.

Therefore, the model is able to estimate the errors fairly well when one of the stochastic elements has a large amount of variation. Of course, the model would do less well as the variance in the other stochastic elements increases in addition to the above. This is unavoidable and it is a simple fact that if the errors in the input data are very large, there is essentially no basis on which to do any analysis.

At present, the model is not set up to estimate the variance in the various stochastic elements and so they are set by the user. Also, it is not appropriate to vary the variances by hand in an attempt to find the best fit (as was done with M). The model can be modified so that these procedures are possible, but this is beyond the scope of the present work.

The user must therefore use other sources of information in order to decide on the variance estimates. If in doubt, the user is advised to choose a conservative value to avoid having the model pick up too much spurious noise in the data. The choice of a particular variance is usually not too critical since the most important point is that the stochastic elements are included. Most other catch-at-age models assume the data to be without error, and the fact that this model is told there is stochastic error in the data is more important than the precise magnitude of this error.

5. ADDITIONAL OPTIONS FOR THE CATCH-AT-AGE ANALYSIS

5.1 The stock-recruit option

This section examines the inclusion of the stock-recruit option. The model uses the same Ricker equation for the stock-recruit relationship as the simulator (equation 3.3). The same input to the simulator was used with fish first entering the fishery at 3 yr old and the variance of the stock-recruit relationship set fairly high at 0.09. The number of recruits from year 4 on was calculated using the stock-recruit equation. The resulting simulated data set is shown in Table 4.

The initial run to start the analysis of the simulated data was done with the following KPAR values:

20	30	100	40	1	-1	0	1	0	1
1	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0		

Note we do not include the stock-recruit option during the initial run (KPAR(13)=0) since the model will usually not run if it is included at this stage. After 20 function evaluations, the function value is 319.5. We then copy PP.1 into TT.1 and edit INPUT.1 before proceeding:

- change KPAR(7) to 1 as this will now be a restart run.

- the stock-recruit option can now be included and so KPAR(13)=1 to invoke the option, KPAR(14)=3 (third age class is first one contributing to reproduction), KPAR(15)=4 (implying a relatively weak stock-recruit relationship, see Appendix A), and KPAR(16)=3 (fish are 3 yr old at recruitment, so age of first age class is 3 yr). The model also wants to read in the user's estimates of relative fecundity of different age classes, starting with the first reproductive age class (age class 3 in our case). The numbers put in are only important in a relative sense. These data are added to INPUT.1 after the effort data, and in this case we told it the true relative fecundities (from Table 4).

- two other KPAR changes can be made now since we are ready for the final run to the minimum: increase KPAR(1), say to 60, to allow for more function evaluations, and change KPAR(20) to 25 to allow fishing mortality to vary from the level determined by effort.

Type RUN RECONS and the model displays the relative fecundity values and then the initial statistics with a function value of 340.8. This is not the same function value as where we left off (319.5) because the stock-recruit relation has now been included.

After 30 iterations (and 36 function evaluations) the model displays the intermediate results, and the function value is now 96.2. The run terminates when 60 evaluations have been done and the function value is 88.9. We then copy PP.1 into TT.1 and continue with the minimization. At a function value of 88.8 the model is unable to make any further progress. The final reconstruction results are shown in Table 5 and may be compared with Table 4 to check how well the model did in reconstructing the fishery. In particular, the model detected the errors about the stock-recruit relationship quite well: the true and estimated residuals were correlated with $r=0.97$ ($p<0.01$ with 15 degrees of freedom) and the vector lengths were 1.36 (true) and 1.40 (estimated).

The form of the output in Table 5 is similar to Table 3 except that estimates of the stock-recruit option are included (printed out following the estimated number at age). The first age class entering into the stock-recruit relationship is shown, and then the relative fecundities are printed. The maximum reproduction occurred at 2.1 times the average population fecundity of 599.7. This average fecundity is averaged over the first 17 years; the last three years do not contribute to the stock-recruit relation since their young do not enter the fishery until after the time series for the data set stops. This "maximum reproduction" statistic gives the user some idea of where the population is relative to the peak in the Ricker stock-recruit curve. In our case, the stock-recruit curve peaks at a population fecundity of 2.1*599.7=1259.4, and the average population level over the time series (as measured by population fecundity) is substantially lower than this.

The estimated coefficients for the Ricker curve are shown next, first alpha and then delta. The predicted recruitment for the last 17 years is shown, followed by the associated residuals. For example, for year 20:

Rp = predicted recruitment = 324

Re = actual estimated recruitment = 294

since Re=Rp*exp(Y(i)), the residual=Y(i)=ln(Re/Rp)=0.097 which rounds off to 0.10.

The estimated fecundities are calculated as follows (using year 1 as an example):

$$\text{est. fecundity} = \sum_{j=3}^{10} f(j)*N(1,j)$$

$$= (1*128) + (3*107) + (4*48) + \ldots\ldots + (5*1)$$

$$= 1146$$

where f(j) is the relative fecundity of age class j and N(1,j) is the number of fish of age class j in year 1. Taking into account the round-off error (which is greatest for the older age classes due to the small numbers involved), 1146 is close enough to 1142. Since we are using relative fecundity values, it is unnecessary to assume a specific sex ratio and so the fecudity values were applied to all fish of reproductive age in the population. All that is assumed is that the sex ratio (whatever it is) and the relative fecundity do not change over time, and that the sex ratio is constant over all age classes.

The variance estimate for stock-recruitment is just the variance of the residuals for the stock-recruit relation. This works out to 0.1149 (rounded to 0.11) and the total variation of the residuals is this number multiplied by the sample size (0.1149 * 17 = 1.95). To calculate the total variation for recruitment, one takes the logarithm of the estimated recruitment in each of the last 17 years and calculates the standard sum of squares of deviations from the mean for this set of numbers. This number is 2.55, the total variation for recruitment. (This number can also be obtained by calculating the standard variance of the above set of numbers and multiplying by 16, which is the sample size-1.) The difference between 2.55 and 1.95 is the amount of variance in recruitment explained by the stock-recruit relationship, and in this case equals 24% [(2.55-1.95)/2.55=0.24].

The straight sum of the residuals for the stock-recruit relationship is 0. 05 (the sum of the 17 numbers -0.19 through -0.10, taking into account roundoff error). This number should be close to zero and if its absolute value is much in excess of 0.1, then the model has been unable to do the proper minimization. Should this happen, the user is advised to do the minimization procedure again with more weight given to the stock-recruit relationship (use a higher value for KPAR(15)). Once a minimum has been reached (hopefully with the absolute value of the sum of residuals less than

0.1), then KPAR(15) can be changed back to its original value and the minimization procedure continued. This problem is most likely to be encountered when little weight is given to the stock-recruit relationship (KPAR(15) values of 2 or 3).

The following example shows how the predicted recruitment for year 20 was calculated:

R(20) = ALPHA*P(17)*exp[-DELTA*P(17)]

= (0.9404)*(521.8)*[exp(-0.000793*521.8)]

= 324.4

where the variables are defined as before.

Finally, it should be noted that on a given data set the inclusion of the stock-recruit option will increase the function value slightly compared with the same run without the option. However, the user may wish to include it in order to estimate future recruitment to do forward simulations (for example, see Archibald et al. 1983).

5.2 Inclusion of an environmental factor affecting recruitment

This option allows the user to account for the influence of an environmental factor on recruitment in addition to the influence of stock fecundity. This option is active when KPAR(24) is non-zero and since this is only operative in conjunction with the stock-recruit option, KPAR(13) must be set to 1. When these two KPARs are set in this way, the new equation for recruitment becomes:

R(i+k)= A * P(i) * exp(-D*P(i)) * exp(-G*E(i)) * exp(Y(i))   5.2.1

where E(i) is the value of the environmental factor in year i, G is the parameter associated with the environmental factor, and the other symbols are as defined for equation 3.3. The model now has to estimate 3 parameters for the recruitment equation: A, D, and G. Note that with this option active (KPAR(24) non-zero and KPAR(13)=1), the model can still choose a recruitment relation that depends only on stock fecundity. That is, if it finds the best fit with G=0 then equation 5.2.1 reduces to equation 3.3. Note, however, that the model cannot make recruitment dependent only on the environmental factor since it cannot reduce the term "A*P(i)*exp(-D*(P(i))" to a constant. The inclusion of this option basically allows the user to see if the given environmental factor enables the model to explain more of the variation in recruitment, over and above that explained by stock fecundity.

To illustrate the performance of this option the simulated results shown in Table 4 will again be used for reconstruction. In addition, however, it is assumed that the residuals for the stock-recruit relation shown in Table 4 are explained by an environmental factor. Therefore the inclusion of this option should explain almost all of the variation in recruitment. The values of the hypothetical environmental factor given to the model were as follows (for years 1 through 17 respectively) :

1000 950 1400 1600 800 900 600 700 1700 1400
1200 800 850 1000 500 850 1000

The correlation between these values and the stock-recruit residuals shown in Table 4 is 0.93 ($p<0.01$ with 15 degrees of freedom).

The initial run to start the analysis is done exactly as the initial run described in section 5.1. Once finished, we then copy unit 15 (PP.1) into unit 13 (TT.1) and edit the input file (INPUT.1 or unit 10) as follows:

- change KPAR(7) to 1 for a restart run

- to include stock effects on recruitment we proceed exactly as before and set KPAR(13) to 1, KPAR(14) to 3, KPAR(15) to 4, and KPAR(16) to 3 (see section 5.1 for fuller explanation of these changes). To include the effect of the environmental factor on recruitment, KPAR(24) is set to 1 (any non-zero integer will do).

- as before, the relative fecundity data must be included after the effort data in INPUT.1, and now the 17 environmental values are included after the relative fecundity data.

- as before, KPAR(1) is changed to 60 to allow more function evaluations for this run and KPAR(20) to 25 to allow the fishing mortality to vary from the level determined by effort.

The model is now run again and this time each year's recruitment is related not only to stock fecundity three years previous, but also to the value of the hypothetical environmental variable three years previous, all according to equation 5.2.1. The minimum function value reached was 81.9 and only the first part of the output from this reconstruction is shown in Table 6 to illustrate the differences compared with Table 5. The estimated value of G is -0.34 and after this the standardized environmental values are printed out. These standardized values are what are actually used for E(i) in equation 5.2.1 and are calculated as follows:

$$E(i) = (EO(i)-Em)/\mathrm{sqrt}((\sum_{i=1}^{17}(EO(i)-Em)^{**}2)/17) \qquad 5.2.2$$

where E(i) is the standardized environmental value for year i, EO(i) the original environmental value supplied to the model for year i, and Em the mean of EO(i) values.

The calculations of predicted and estimated recruitment will now be demonstrated. Predicted recruitment is calculated using equation 5.2.1 minus the stochastic element and for year 4 one proceeds as follows:

$$\text{predicted } R(4) = A * P(i) * \exp(-D*P(i)) * \exp(-G*E(i))$$

$$= 1.23 * 1139 * \exp(-.00125*1139) * \exp(0.34*(-.04465))$$

$$= 332$$

The actual recruitment that the model estimates for year 4 will be close to this number, but not exactly equal to it due to the fact that stochastic error is being accounted for. As an aside here, note that the higher the value of KPAR(15), the less stochastic error allowed and the closer will be the values for predicted and actual estimated recruitmnet. Since KPAR(15)=4 in this case, the stock-recruit relationship is assumed to be fairly weak and there will be a fair amount of difference between these two numbers. Indeed, the actual recruitment for year 4 estimated by the model is 357, calculated as follows:

estimated R(4) = predicted R(4) * exp(Y(i)) (from equation 5.2.1)

= 332 * exp(0.07)

= 357

Thus the model estimates the recruitment for year 4 to be 357 and the true value from Table 4 is 353.

Since the environmental factor in this case is well correlated with the stock-recruit residuals from Table 4 (i.e. the factor explains the residual variation in recruitment), the overall fit to the data is better with this option included (compare F=81.9 of Table 6 with F=88.8 of Table 5). The residuals for the stock/envir.-recruit relation are generally smaller than before since a greater amount of the variation in recruitment has now been explained (compare 89% in Table 6 with 24% in Table 5).

Of course, if the included environmental factor does not explain much of the residual variation in recruitment, then the fit to the data will not substantially improve. For example, the following environmental values are not correlated with the stock-recruit residuals in Table 4 (r=0.03):

1000 800 750 1100 1100 1200 950 800 1000 1250
950 1150 1300 900 1100 900 800

When these values are supplied to the model, the final reconstruction occurred at an F value of 88.5, an estimated G of -0.06 for the environmental factor, and with 26% of the variation in recruitment explained by the stock/envir. -recruit equation. These are essentially the same results as in Table 5 and so this particular environmental factor can be assumed to play no noticeable role in influencing recruitment.

5.3 Time-dependent catchability

In all runs so far, the model has estimated one value for catchability; that is, catchability has been assumed to be constant for all years in the data set (time-independent). If the user wishes to allow the model to vary catchability over time in its search for the best fit, then KPAR(17) is made non-zero to include time-dependent catchability. If KPAR(17)=1, then the log of catchability is assumed to change in a linear fashion with time; if KPAR(17)=2, then log catchability is assumed to change in a sigmoid fashion over time with the inflection point occurring halfway through the time series. The actual equations for time-dependent catchability will now be discussed in more detail.

If KPAR(17)=0, then the log of catchability is a single parameter(P1) that the model estimates:

$$\log Q = P1 \qquad 5.3.1$$

where Q is catchability. If KPAR(17)=1, then the model estimates two parameters for catchability and the following equation applies:

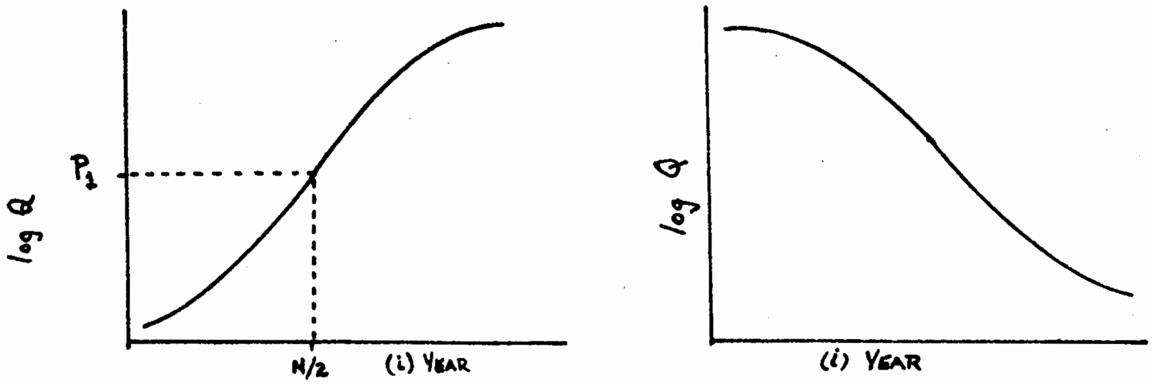
$$\log Q(i) = P1 + P2(i-N/2) \qquad 5.3.2$$

where i is the year and N is the total number of years in the data. From equation 5.3.2 it is clear that the log of catchability either increases (P2>0) or decreases (P2<0) linearly with time. If the model cannot improve the fit by allowing catchability to vary in this fashion over time, then the estimate of P2 will be zero or very close to zero.

If KPAR(17)=2, then the model again estimates two parameters for catchability, but uses a different equation:

$$\log Q(i) = P1 + P2*\mathrm{sqrt}(\mathrm{abs}(i-N/2))*f(i-N/2) \qquad 5.3.3$$

where the function f(i-N/2) is -1 when (i-n/2)<0, and +1 when (i-N/2)>0. This equation gives a sigmoid curve with the inflection point at i=N/2 and log Q = p1:



P2>0 P2<0

In order to demonstrate the use of this option, a simulated data set involving time-dependent catchability was generated. This was easily done by using exactly the same input data as used in section 5.1, but with the effort modified according to the time-dependent catchability trend desired. That is, if we wish to include a linear increase in log catchability over time in the input data, this can be done by making the log of the effort data decrease linearly over time. Since fishing mortality in the input data has not changed, this decrease in effort implies a corresponding increase in catchability. Therefore, the data supplied to the reconstruction model were the same as in section 5.1 with the exception that the effort data were replaced as follows:

year	old effort data	new effort data	ratio (old/new)	log ratio
1	100	100	1.000	0.000
2	100	94.9	1.054	.0523
3	120	108	1.110	.105
4	120	102.5	1.171	.158
5	140	113.4	1.235	.211
6	80	61.5	1.301	.263
7	140	102.1	1.371	.316
8	150	103.8	1.445	.368
9	130	85.3	1.524	.421
10	150	93.4	1.606	.474
11	200	118.2	1.692	.526
12	240	134.5	1.784	.579
13	180	95.7	1.881	.632
14	200	100.9	1.982	.684
15	200	95.7	2.090	.737
16	150	68.1	2.203	.790
17	180	77.5	2.323	.843
18	140	57.2	2.448	.895
19	100	38.8	2.577	.947
20	100	36.8	2.717	1.000

Since the effort values change over time, the difference between the old and new effort values can best be seen by examining the ratio of the two. It is the log of this ratio that changes linearly with time (increasing in this case because of the way the ratio was formed). This implies a similar increase in the log of catchability, in fact since the fishing mortality does not change the catchability must increase by the degree that the effort decreases, and so catchability increases by a fact or of 2.717 over the time series of the data.

We are now ready to do the reconstruction on the same input data as in section 5.1 but with the input effort data changed as noted above. The time-dependent catchability option can be included right from the start and so the KPAR values for the initial run are as follows:

20	30	100	40	1	-1	0	1	0	1
1	0	0	0	0	0	1	0	0	0
1	0	0	0	0	0	0	0		

Note that the only difference with the KPAR array in section 5.1 is that KPAR(17)=1 since we want to tell the model it can vary the log of catchability in a linear fashion over time if such a change will improve the fit to the data.

After the initial run we modify the input file exactly as was done in section 5.1 and continue with the minimization procedure. At the minimum, the function value is 88.7 and the ouput is shown in Table 7. This fit is essentially the same as that shown in Table 5 and so the model was able to detect the change in catchability. The model's estimates of catchability (presented near the end of the Table) range from 0.001613 in year 1 to 0.00435 in year 20, a change of 2.70 which compares well with the true change of 2.717 times.

If the model is not allowed to vary catchability over time (same reconstruction with KPAR(17)=0), the fit to the data is much worse (F=103.8). If the function value drops substantially with the inclusion of time-dependent catchability, this indicates that catchability has indeed changed over the time course of the data.

5.4 The incorporation of ageing errors

Given that this model is so dependent on catch-at-age data, the reader may wonder how ageing errors might be dealt with. As long as they are not too great (see later) and as long as the user can supply the model with estimates of these errors, the model can deal with them using KPARs 9 and 12.

First, let us examine the data set upon which the reconstuction will be done. The set was generated in a fashion similar to that already described for the generation of Table 4, but with three differences:

i. whereas a variance of 0.09 about the stock-recruit relation was used in section 5.1, here a variance of 0.01 was used to reduce overall stochastic variation in order to more clearly demonstrate the detection of ageing errors.

ii. the input effort data was changed according to section 5.3 so that the time-dependent catchability option was needed.

iii. the observed catch-at-age data (later to be supplied as input data to the model) was generated by sampling not the true age distribution, but the expected age distribution given certain ageing errors. This process simulates sampling fish for age determination and then having certain errors inherent in that age determination. The resulting simulated data set is shown in Table 8 along with the actual ageing errors used.

Let us now do the reconstruction on this data set with the ageing error option operative and the model informed of the true ageing errors. To do this, we include the ageing error option right from the initial run: KPAR(12) is set to 1 to invoke this option and KPAR(9) is set to 5 to indicate that the ageing error is spread over 5 years (true age $\pm$ 2 years). Therefore, the KPAR array for the initial run is:

20	30	100	40	1	-1	0	1	5	1
1	1	0	0	0	0	1	0	0	0
1	0	0	0	0	0	0	0		

It should be noted that since KPAR(12) is changed to 1, the model will expect to read in as part of the input the user's estimates of the ageing errors. This information is added to the input file after the effort data, and is put in starting with the proportion of each age class that is underaged by two years, then the proportion of each age class underaged by one year, etc. That is, the ageing errors shown in Table 8 will be added to the input file as follows:

0	0	0	0	.1	.2	.2	.2	.3	.3
0	0	.1	.2	.2	.2	.2	.3	.3	.3
.8	.8	.7	.7	.6	.6	.6	.5	.4	.4
.1	.1	.2	.1	.1	0	0	0	0	0
.1	.1	0	0	0	0	0	0	0	0

It is important to note how the ageing error information is added to the input file as it is ordered differently than one might expect.

Once the initial run has been completed, we do the usual routine of copying PP.1 into TT.1 and modifying INPUT.1 as follows:

- change KPAR(7) to 1 for a restart run

- the stock-recruit option can now be included, so KPAR(13) is changed to 1, KPAR(14) to 3, KPAR(15) to 5 (was 4 before but now we want to tell the model that the stock-recruit relation is a bit tighter), and KPAR(16) to 3. See section 5.1 for more details on these changes. The relative fecundity values are now added after the effort data but BEFORE the ageing error data. The order of data in the input file

INPUT.1 is now as follows:

8 GPAR values
28 KPAR vlaues
total catch by year
catch at age by year
effort data by year
relative fecundity
ageing errors

Obviously it is important to put each data group in its proper place.

- change KPAR(1) to 60 to allow more function evaluations and KPAR(20) to 25 to allow fishing mortality to vary from the level determined by effort.

We then proceed with this run by typing RUN RECONS. Before displaying the initial statistics, the model displays on the terminal screen the relative fecundity values and then the ageing error data. This is useful for checking that this information is being read in properly. The function value minimized at 82.4 and the full output is shown in Table 9. The only new item in the output is the predicted, apparent age structure of the catch which is presented near the bottom of Table 9. This age structure is generated by applying the given ageing error probabilities to the model's estimates of the true age structure of the catch, the latter being presented after the stock-recruit information under the heading "estimated age structure of the catch". This predicted, apparent age structure information is what the model compares with the observed age structure in its attempt to find a suitable solution. The observed age structure is presented just before the fishing mortality estimates and it is simply the catch-at-age data that are supplied to the model in the input.

When the model is not told of the systematic errors in the catch-at-age data it naturally cannot fit the input data very well. In our case, the function value minimized at 112.3 when KPARs (12) and (9) were set to zero.

Fournier and Archibald (1982) present a similar but more detailed example of the effect on the reconstruction of accounting for versus ignoring ageing errors. The reader is referred to this paper for additional discussion on this matter.

The reader may feel that the restrictions placed on KPAR(9) (maximum spread of five years in the ageing error, see Appendix A) are too restictive since this option cannot deal with ageing errors that deviate by more than two years from the true age. Unfortunately, little can be done to rectify this due to the fact that once the spread of ageing error becomes too large (>5 years) it is not possible to find a unique solution to the question of what true age distribution, with the given ageing errors, generated the observed age distribution. (Strictly speaking, a unique solution can be found, but only if one ignores the stochastic error present in the data.)

For errors greater than two years, the reader may wish to consider grouping some of the older age classes where the error is usually the greatest. This is discussed in the next section.

5.5 Grouping older age classes

In situations where ageing of older fish is inaccurate or very time consuming, the user may wish to group the ageing data for these older age classes. Note that this option is not compatible with the just-discussed ageing error option; the user either groups the older ages together or estimates the ageing errors in the raw data, not both. Fournier and Archibald (1982) present a well-worked example which compares the reconstruction obtained using this grouping option to those obtained by ignoring ageing errors and by supplying the model the true ageing errors. Archibald et al. (1983) present an analysis of Pacific ocean perch data using grouping of older ages. The reader is encouraged to refer to these two papers as only the mechanics of using this option will be presented here.

In order to run this option on the data set described in section 5.4, one does the initial run with the same KPAR array shown in section 5.4 but with KPARs (12) and (9) set to zero (we are not supplying the model with estimates of the ageing errors), KPAR(26) set to 1 (discussed shortly), and KPAR(19) set to a number greater than 1, for example 7. If KPAR(19) is zero or 1, this grouping option is not invoked and the catch at age data is dealt with exactly as presented in the input file. If KPAR(19)>1, then the model groups together the ageing data for this number of last age classes. In our case, the catch-at-age data for the last 7 age classes in each year will be grouped together in the input data.

With the initial run done, the continuation runs are done in the usual manner. The function value minimized at 26.0; note that this value cannot be compared with the function values in section 5.4 since the likelihood function involved in the minimization here is different. From the ouput file only the estimated numbers at age in the population are shown, and this is presented in

Table 10. Note that in the first year, 289 is the estimated number of age 3 fish (fish recruit at age 3), 212 of age 4, 148 of age 5, and 236 of age 6 or greater. In year 2, this 236 has become 114 fish of age 7 or greater, and so on. A more complete description of the output from this type of reconstruction is shown in Fournier and Archibald (1982) and Archibald et al. (1983).

It should be noted that in cases where the user has the data already grouped before input to the model (such as where one uses a >20 yr. category while ageing fish), one must proceed slightly differently with respect to the input catch-at-age data. For example, let us assume we have aged a fish species into 10 categories: ages 2 through 10 plus the category of fish older than 10 years. If the oldest fish likely to be found in the catch is 20, then for each year of the input catch at age data, 19 values must be presented: the actual numbers found to be of ages 2 through 10 (the first 9 vaues),the grouped number for ages >11 will be the tenth value, and zeros for the 11th to 19th values (corresponding to, but not representing, ages 12 to 20). Since there are 19 age classes being considered, GPAR(2) must be set to 19, not 10, in the input file. Also, KPAR(19) is set to 10 since there are 10 age classes in the grouped category (ages 11-20).

To complete this section, only the use of KPAR(26) remains to be discussed. It is used in conjunction with the grouping of older age classes and is basically a penalty weight to prevent a large number of fish from reaching the oldest age class in the data set. A value of 1 is usually sufficient and if the user wishes to check this, then the final run of the reconstruction is repeated with KPAR(28) set to 1. This simply results in an output that is the same as if KPAR(28) was zero except that the estimated numbers at age in the population are spread out for the grouped age class (Table 11). In year 1 for example, the 232 fish in the ≥6 yr. category are spread out over the ages 6 through 12 (170+59+3+1=233, not 232 due to roundoff error). It should be made clear that the model has not estimated that there are 59 fish of age 7 in year 1; it has only estimated that there are 232 fish of age 6 or greater. These spread-out numbers of the grouped age class are simply adjusted by the model to satisfy other requirements such as the stock-recruit relation or the total annual catch. These numbers are of no consequence are far as model fit is concerned, and are only of importance to the user if there turns out to be large numbers of fish in the oldest age class since these fish will disappear entirely from the population the next year. In order to avoid this, a weight is included (KPAR(26)) which penalizes the likelihood function for putting too many fish in the oldest age class. The user can check this by setting KPAR(28) to 1 and printing out how the model has spread out the grouped age class. If the user should desire to increase the penalty weight (accepting the word of caution noted in Appendix A for KPAR(26)), one must increase the value of KPAR(26) and start the reconstruction all over again right from the initial run .

The reader will note that the results presented in Archibald et al. (1983) are with KPAR(28)=0, while those in Fournier and Archibald (1982) are with KPAR(28) = 1.

5.6 Density-dependent catchability

Time-dependent trends in catchability have already been discussed (section 5.3), and this is usually sufficient to account for changes in gear type, vessel size, etc. However, changes in catchability may also come about due to changes in stock density. For example, as density declines for a schooling species, school size may not change and thus fishing success on schools will remain constant. Catchability, as defined by the time actually spent fishing (excluding search time), will increase. To account for these density-dependent changes in catchability, KPAR(25) is used.

A simulated data set was generated in the same manner as Table 2, except that for each year catchability was made dependent on stock biomass in that year. Since catchability in turn affects stock biomass through fishing mortality, the simulation was done in an iterative fashion until the results converged. Catchability was related to biomass in the following way:

$$\log(Q(i)) = Q1 + Q2*BIO(i) \qquad 5.6.1$$

where Q1 and Q2 are parameters estimated by the model and

$$BIO(i) = (BIOMASS(i)-BMEAN)/BMEAN \qquad 5.6.2$$

with BIOMASS(i) the relative stock biomass in year i and BMEAN the average of BIOMASS(i) over all years in the data set. The relative stock biomass is the sum of the numbers at age times the relative weights at age. Note that if this option is not included (KPAR(25)=0), then only Q1 is estimated by the model (model uses following equation where catchability is the same each year: log(Q(i))=Q1).

Table 12 shows the resulting simulated data set, plus the relative weights at age used in the simulator. The values for density-dependent catchability are shown followed by the relative stock biomass values for each year (calculated according to equation 5.6.2).

To do the reconstruction on this data set, one first does a normal analysis assuming constant catchability (KPAR(25)=0). Therefore, one starts the initial run with this KPAR array (same as in Table 1):

20	30	100	40	1	-1	0	1	0	1
1	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0		

Once the initial run is finished, one carries on with the minimization as before (KPAR(25) still set to zero). Once the minimum function value is reached (106. 3 in this case), unit 15 (PP.1) is copied into unit 13 (TT.1) and KPAR(25) is changed to 1 in the input file (unit 10 or INPUT.1). KPAR(1) is lowered to 10 since the model will now progress in iterative cycles as it first determines catchability from biomass, performs some function evaluations to determine the biomass resulting from the new catchability, and then repeats the cycle over again. The relative weights at age must also be supplied to the model; these weights are read in from unit 9 (not unit 10). Thus a file WEIGHT.1 can be created that contains the relative weight-at-age data (starting with the youngest age class, as shown in Table 12), and this file assigned to unit 9: ASSIGN WEIGHT.1 FOR009.

To continue with the minimization, one types the usual RUN RECONS. The relative weights are shown on the screen before the initial statistics so one can check that they are being read in correctly. The model starts at a function value of 106.3 with the first evaluation, and finishes at 93.8 after 10 evaluations. After copying PP. into TT.1 and running again, the function value at the first evaluation is 97.9 which is not where the model left off on the previous run (function value of 93.8). This is because the model is now doing repetitive cycles, adjusting the biomass and catchability alternately. After 10 evaluations the function value is 86.0. PP.1 is again copied into TT.1 and the run repeated. This process is continued until the model converges on a solution; that is, until there is essentially no difference between the function values of the first and tenth evaluations of a run. In our case the model converged at a function value of 85.2. It should be noted that there may be some instability seen during this period of iterative cycles. For example, the function value at the start of a run may be slightly higher than that at the start of the previous run. Usually, however, the function value will eventually converge to a stable value. If not, the user can try shorter cycles (smaller value of KPAR(1)).

The output from this reconstruction is shown in Table 13. The estimated density-dependent catchability is shown for each year, as is the relative stock biomass. The value of 0.001552 given for the single "estimate for the catchability" is raised to the power of Q1 (0.001552=exp(Q1)). The parameter Q2 can be calculated by making the appropriate substitutions into equation 5.6.1.

Comparing Tables 12 and 13, it can be seen that although the model's estimate of the change in catchability was rather conservative, the model was able to detect the qualitative variation in catchability.

6. MISCELLANEOUS TROUBLESHOOTING

This section describes some of the more common problems encountered during runs of the catch-at-age model. Remember also that all of the options described can be included in the initial run except the stock-recruit option (KPARs 13, 14, 15, and 16) and the KPAR allowing deviation of fishing mortality from the level determined by effort (KPAR(20)); these can only be added to the restart run once the initial run has been completed.

6.1 Improper ASSIGN statements

The reader is reminded that unless the assign statements are done before the initial run is started, an error message will be displayed on the terminal screen as discussed in Step 1, section 4.1.

6.2 Initial step size too large

KPAR(3) determines the initial step size or the estimate of the amount of decrease in the log-likelihood function. This is usually set to 100, but maybe lowered if the model has trouble making progress right from the start of a run. This problem is sometimes encountered in the following situation: a certain run of evaluations finishes with the function value close to the minimum (function value changing very little as seen in the output file). Then, when one tries to carry on the minimization, the model prints out the initial estimates and then bombs with an "arithmetic fault, floating overflow" message. The problem here is that the initial step size (KPAR(3)) is too large, and the run will usually continue on if one lowers the value of KPAR(3), say to 10 or even 1.

6.3 Output numbers too large

If the values for number of fish at age are too large to be printed in the output file according to the given format (F6.0, see subroutine DATPRI), then an "output conversion error" message is displayed on the screen along with some other diagnostic information. Since the error occurs while printing into the output file (after all the calculations are done), this error message is displayed after the final statistics for the run are displayed. To correct this, one can either change the units of the input total catch data (say, from tons to thousands of tons) or, more simply, increase the value of KPAR(23). This KPAR has a default value of 1 and it is the number that the total catches are divided by before use by the model. This has the same effect as changing the units of the input total catch data and the only difference in the output (compared with KPAR(23)=1) is that the estimated numbers at age have been divided by KPAR(23). Hence, to correct this "output conversion error", one simply increases KPAR(23) until the numbers fit into the given format.

6.4 Division by zero

An "arithmetic fault, division by zero" error message occurring in subroutine FMIN will sometimes result when the function minimizer has almost reached the minimum. In such cases, all the user can do is to carry out a run of fewer function evaluations (lower KPAR(1)) in order to get as close as possible to the point where the program bombs. For example, if a run with KPAR(1)=60 bombs between the 30th and 35th function evaluation (can be checked by seeing how many function values are printed out in the output file - see Step 4, section 4.1), then the run can be redone with KPAR(1)=30. This run will terminate normally and provide a complete output in the output file. This error message usually only occurs near the minimum function value, and so the output achieved via the above method is usually satisfactory.

6.5 Stock-recruit problems

Since one cannot include the stock-recruit option during the initial run of a minimization, one must remember to not only change the appropriate KPAR values (13, 14, 15, and 16) to include this in the restart run, but also to supply the model with relative fecundity data. It is easy to check if the model is reading the relative fecundities properly since these values are displayed on the terminal screen before the initial statistics for a run.

Another item to remember when running the stock-recruit option is to check that the sum of the residuals for the stock-recruit relationship is fairly close to zero. This matter has already been discussed in section 5.1.

REFERENCES

Archibald, C. P., D. Fournier, and B. M. Leaman. 1983. Reconstruction of stock history and development of rehabilitation strategies for Pacific ocean perch in Queen Charlotte Sound. North American Journal of Fisheries Management (in press).

Fournier, D., and C. P. Archibald. 1982. A general theory for analyzing catch at age data. Can. J. Fish. Aquat. Sci. 39: 1195-1207.

Li, J. C. R. 1964. Statistical inference. I. Edward Bros. Inc., Ann Arbor, Michigan. 658 p.

Table 1. This table illustrates the form of the input to Fournier's catch-at-age model. This is a copy of a sample input file to the model and the various numbers are explained in the text.

```
 20      10      1      1
.2    .4    5.0    0.001

20   30  100   40    1   -1    0    1    0    1
 1    0    0    0    0    0    0    0    0    0
 1    0    0    0    0    0    0    0

110.6      83.7      123.1      88.3      84.7
 43.8      84.9       80.0      88.5     106.6
127.2     181.4       99.3     128.1      91.0
 54.2      80.8       53.7      56.8      66.5
        33        77        85        71        32        35
        41        14        11         1

        57        78        70        54        66        25
        23        18         5         4

        47        93        80        73        36        25
        20         9        14         3

        48        77       101        81        41        17
        16         8         6         5

        35       104       116        78        28        15
         8        10         3         3

        57        62       110        72        53        21
        11         8         5         1

        89        97        65        62        32        29
        16         5         4         1

        79       130        79        40        43        13
        11         2         2         1

        92       121        97        50        14        17
         2         2         3         2

        66       149        91        56        17         9
        10         1         0         1

        54       120       124        54        24        14
         6         2         1         1
        94        92       103        62        37         5
         4         1         2         0
```

Table 1 (con't)

79	133	105	35	28	12
4	3	1	0		
66	114	122	52	31	14
1	0	0	0		
39	118	137	61	31	8
4	1	1	0		
72	63	135	74	36	13
3	3	1	0		
78	142	51	72	32	17
4	3	1	0		
105	126	95	23	29	16
4	2	0	0		
95	142	89	43	10	11
7	3	0	0		
53	147	116	40	27	7
5	2	2	1		

100.0000	100.0000	120.0000	120.0000	140.0000
80.0000	140.0000	150.0000	130.0000	150.0000
200.0000	240.0000	180.0000	200.0000	200.0000
150.0000	180.0000	140.0000	100.0000	100.0000

Table 2. The basic simulated data set is shown below. The simulator is explained in the text and this is the data set upon which the basic catch-at-age analysis is done.

THE NUMBER OF FISH AT AGE IS

300.	200.	130.	110.	60.	40.	50.	20.	10.	4.
320.	192.	118.	70.	56.	29.	19.	24.	9.	5.
250.	206.	115.	66.	38.	29.	15.	10.	12.	5.
260.	157.	116.	58.	31.	17.	12.	6.	4.	5.
150.	166.	92.	62.	29.	15.	8.	6.	3.	2.
240.	94.	92.	45.	28.	12.	6.	3.	2.	1.
300.	155.	57.	53.	25.	15.	6.	3.	2.	1.
330.	188.	87.	28.	24.	11.	6.	3.	1.	1.
430.	207.	105.	43.	13.	10.	4.	3.	1.	1.
360.	270.	116.	53.	20.	6.	4.	2.	1.	0.
300.	225.	150.	57.	24.	8.	2.	2.	1.	0.
330.	184.	119.	67.	23.	9.	3.	1.	1.	0.
300.	193.	86.	43.	21.	6.	2.	1.	0.	0.
250.	185.	103.	39.	18.	8.	2.	1.	0.	0.
100.	150.	92.	42.	14.	6.	2.	1.	0.	0.
200.	61.	78.	40.	16.	5.	2.	1.	0.	0.
200.	125.	34.	38.	18.	7.	2.	1.	0.	0.
300.	121.	64.	15.	14.	6.	2.	1.	0.	0.
350.	189.	68.	32.	7.	6.	3.	1.	0.	0.
250.	223.	110.	36.	16.	3.	3.	1.	0.	0.

THE TRUE TOTAL CATCH EACH YEAR IS

117	82	114	78	88	41	80	84	92	109	135	175	102
123	85	56	76	56	57	68						

THE ESTIMATED CATCH EACH YEAR IS

110.6	83.7	123.1	88.3	84.7	43.8	84.9	80.0	88.5	106.6	127.2	181.4	99.3
128.1	91.0	54.2	80.8	53.7	56.8	66.5						

THE TRUE CATCH AT AGE IS

11.	20.	21.	22.	13.	9.	12.	5.	2.	1.
10.	16.	16.	12.	11.	6.	4.	5.	2.	1.
13.	28.	24.	17.	11.	9.	5.	3.	4.	2.
11.	17.	20.	12.	7.	4.	3.	2.	1.	1.
8.	23.	20.	17.	9.	5.	3.	2.	1.	1.
7.	7.	11.	7.	5.	2.	1.	1.	0.	0.
16.	22.	12.	14.	7.	5.	2.	1.	1.	0.
18.	26.	19.	8.	7.	3.	2.	1.	0.	0.
22.	28.	22.	11.	4.	3.	1.	1.	0.	0.
20.	39.	26.	15.	6.	2.	1.	1.	0.	0.
21.	40.	41.	19.	9.	3.	1.	1.	0.	0.
34.	47.	45.	31.	11.	5.	2.	0.	0.	0.
20.	33.	23.	14.	8.	2.	1.	0.	0.	0.

Table 2 (cont'd)

22.	40.	34.	15.	8.	4.	1.	0.	0.	0.
7.	28.	26.	15.	5.	2.	1.	0.	0.	0.
11.	9.	17.	11.	5.	2.	1.	0.	0.	0.
16.	25.	10.	14.	7.	3.	1.	0.	0.	0.
15.	16.	13.	4.	4.	2.	1.	0.	0.	0.
14.	20.	12.	7.	2.	2.	1.	0.	0.	0.
11.	25.	19.	8.	4.	1.	1.	0.	0.	0.

THE OBSERVED CATCH AT AGE IS

33.000	77.000	85.000	71.000	32.000	35.000	41.000	14.000	11.000	1.000
57.000	78.000	70.000	54.000	66.000	25.000	23.000	18.000	5.000	4.000
47.000	93.000	80.000	73.000	36.000	25.000	20.000	9.000	14.000	3.000
48.000	77.000	101.000	81.000	41.000	17.000	16.000	8.000	6.000	5.000
35.000	104.000	116.000	78.000	28.000	15.000	8.000	10.000	3.000	3.000
57.000	62.000	110.000	72.000	53.000	21.000	11.000	8.000	5.000	1.000
89.000	97.000	65.000	62.000	32.000	29.000	16.000	5.000	4.000	1.000
79.000	130.000	79.000	40.000	43.000	13.000	11.000	2.000	2.000	1.000
92.000	121.000	97.000	50.000	14.000	17.000	2.000	2.000	3.000	2.000
66.000	149.000	91.000	56.000	17.000	9.000	10.000	1.000	0.000	1.000
54.000	120.000	124.000	54.000	24.000	14.000	6.000	2.000	1.000	1.000
94.000	92.000	103.000	62.000	37.000	5.000	4.000	1.000	2.000	0.000
79.000	133.000	105.000	35.000	28.000	12.000	4.000	3.000	1.000	0.000
66.000	114.000	122.000	52.000	31.000	14.000	1.000	0.000	0.000	0.000
39.000	118.000	137.000	61.000	31.000	8.000	4.000	1.000	1.000	0.000
72.000	63.000	135.000	74.000	36.000	13.000	3.000	3.000	1.000	0.000
78.000	142.000	51.000	72.000	32.000	17.000	4.000	3.000	1.000	0.000
105.000	126.000	95.000	23.000	29.000	16.000	4.000	2.000	0.000	0.000
95.000	142.000	89.000	43.000	10.000	11.000	7.000	3.000	0.000	0.000
53.000	147.000	116.000	40.000	27.000	7.000	5.000	2.000	2.000	1.000

THE RELATIVE FISHING VULNERABILITY IS

0.135	0.369	0.608	0.781	0.886	0.943	0.973	0.988	0.996	1.000

THE INST. FISHING MORT IS

0.05	0.13	0.21	0.27	0.31	0.33	0.34	0.35	0.35	0.35
0.04	0.11	0.18	0.23	0.26	0.27	0.28	0.29	0.29	0.29
0.06	0.18	0.29	0.37	0.42	0.45	0.46	0.47	0.48	0.48
0.05	0.14	0.23	0.30	0.34	0.36	0.37	0.38	0.38	0.38
0.07	0.19	0.31	0.40	0.45	0.48	0.49	0.50	0.51	0.51
0.04	0.10	0.16	0.20	0.23	0.25	0.25	0.26	0.26	0.26
0.07	0.18	0.30	0.39	0.44	0.47	0.48	0.49	0.49	0.50
0.07	0.18	0.30	0.39	0.44	0.47	0.48	0.49	0.50	0.50
0.06	0.18	0.29	0.37	0.42	0.45	0.47	0.47	0.48	0.48
0.07	0.19	0.31	0.40	0.46	0.49	0.50	0.51	0.51	0.52

Table 2 (cont'd)

0.09	0.24	0.40	0.51	0.58	0.62	0.64	0.65	0.65	0.65
0.13	0.37	0.60	0.77	0.88	0.93	0.96	0.98	0.99	0.99
0.09	0.23	0.39	0.49	0.56	0.60	0.62	0.63	0.63	0.63
0.11	0.30	0.49	0.63	0.72	0.77	0.79	0.80	0.81	0.81
0.09	0.25	0.42	0.54	0.61	0.65	0.67	0.68	0.68	0.69
0.07	0.19	0.31	0.40	0.46	0.49	0.50	0.51	0.51	0.51
0.10	0.27	0.45	0.57	0.65	0.69	0.71	0.73	0.73	0.73
0.06	0.18	0.29	0.37	0.42	0.45	0.46	0.47	0.48	0.48
0.05	0.14	0.23	0.29	0.33	0.36	0.37	0.37	0.38	0.38
0.05	0.14	0.24	0.30	0.34	0.37	0.38	0.38	0.39	0.39

THE CATCHABILITY IS 0.0013

THE DEVIATIONS IN EFF-FISH MORT ARE

-0.01	-0.19	0.12	-0.11	0.03	-0.08	0.00	-0.06	0.04	-0.03
-0.08	0.16	0.00	0.14	-0.03	-0.03	0.14	-0.04	0.07	0.09

THE EFFORT DATA ARE

100.0000	100.0000	120.0000	120.0000	140.0000
80.0000	140.0000	150.0000	130.0000	150.0000
200.0000	240.0000	180.0000	200.0000	200.0000
150.0000	180.0000	140.0000	100.0000	100.0000

Table 3. The results of the first basic catch-at-age analysis are shown below. This is an exact copy of the output file 00.1 (from unit 18). Parameters for the run are discussed in the text.

```
VALUE OF F IS    86.2085
VALUE OF F IS    86.1664
VALUE OF F IS    86.1554
VALUE OF F IS    86.1385
VALUE OF F IS    86.1299
VALUE OF F IS    86.1193
VALUE OF F IS    86.1088
VALUE OF F IS    86.1000

THE VALUE OF THE OBJECTIVE FUNCTION WAS    86.1

THE GPAR VALUES ARE
 20.00 10.00  1.00  1.00  0.20  0.40  5.00  0.0010

 THE KPAR VALUES ARE

   60   30  100   40    1   -1    1    1    0    1
    1    0    0    0    0    0    0    0    0   25
    1    0    0    0    0    0    0    0

 THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

  302.   208.   130.   109.    47.    40.    40.    12.     8.     1.
  339.   194.   123.    70.    55.    23.    19.    19.     5.     3.
  259.   219.   116.    68.    37.    28.    11.     9.     9.     3.
  261.   163.   122.    57.    31.    16.    11.     5.     4.     3.
  150.   166.    93.    63.    27.    14.     7.     5.     2.     1.
  219.    95.    93.    47.    29.    12.     6.     3.     2.     1.
  302.   141.    58.    53.    25.    15.     6.     3.     1.     1.
  323.   189.    78.    28.    23.    10.     6.     2.     1.     1.
  422.   203.   106.    39.    13.    10.     4.     2.     1.     0.
  336.   267.   115.    54.    18.     6.     4.     2.     1.     0.
  304.   211.   148.    57.    24.     8.     2.     2.     1.     0.
  356.   188.   112.    68.    23.     9.     3.     1.     1.     0.
```

Table 3 (cont'd)

300.	209.	87.	41.	20.	6.	2.	1.	0.	0.
250.	186.	113.	41.	17.	8.	2.	1.	0.	0.
102.	151.	93.	46.	14.	5.	2.	1.	0.	0.
207.	62.	78.	40.	17.	5.	2.	1.	0.	0.
212.	130.	35.	39.	18.	7.	2.	1.	0.	0.
314.	129.	67.	15.	14.	6.	2.	1.	0.	0.
372.	198.	74.	34.	7.	6.	3.	1.	0.	0.
235.	238.	117.	40.	17.	3.	3.	1.	0.	0.

TOTAL NUMBERS OF FISH IN EACH YEAR ARE

896.	850.	759.	673.	529.	505.	606.	662.	801.	802.
756.	759.	668.	617.	414.	412.	445.	548.	696.	656.

THE ESTIMATED AGE STRUCTURE OF THE CATCH IS

0.100	0.185	0.186	0.199	0.098	0.089	0.094	0.028	0.018	0.002
0.127	0.197	0.201	0.147	0.132	0.059	0.051	0.052	0.015	0.019
0.112	0.251	0.211	0.156	0.095	0.077	0.033	0.027	0.027	0.012
0.131	0.218	0.261	0.155	0.094	0.051	0.039	0.016	0.013	0.021
0.089	0.262	0.234	0.199	0.098	0.053	0.027	0.020	0.008	0.010
0.145	0.171	0.273	0.175	0.123	0.054	0.028	0.014	0.010	0.008
0.199	0.247	0.158	0.183	0.098	0.063	0.026	0.013	0.006	0.007
0.205	0.319	0.209	0.094	0.088	0.042	0.025	0.010	0.005	0.004
0.232	0.298	0.247	0.114	0.042	0.035	0.016	0.009	0.003	0.003
0.168	0.354	0.241	0.141	0.054	0.018	0.014	0.006	0.003	0.002
0.155	0.281	0.309	0.146	0.070	0.023	0.007	0.005	0.002	0.002
0.203	0.270	0.243	0.178	0.066	0.027	0.008	0.002	0.002	0.001
0.188	0.345	0.225	0.131	0.074	0.023	0.009	0.003	0.001	0.001
0.164	0.314	0.291	0.129	0.060	0.029	0.009	0.003	0.001	0.000

Table 3 (cont'd)

0.083	0.320	0.304	0.187	0.064	0.026	0.012	0.003	0.001	0.000
0.195	0.155	0.307	0.199	0.097	0.029	0.011	0.005	0.001	0.001
0.204	0.324	0.134	0.183	0.096	0.042	0.012	0.004	0.002	0.001
0.267	0.294	0.242	0.068	0.074	0.034	0.014	0.004	0.001	0.001
0.243	0.349	0.209	0.123	0.029	0.028	0.012	0.005	0.001	0.001
0.133	0.363	0.286	0.124	0.061	0.013	0.012	0.005	0.002	0.001

THE MULTIPLICATIVE FACTORS FOR THE TOTAL CATCHES ARE

1.003	1.021	0.978	1.006	1.003	1.005	0.988	1.004	0.994	1.000
1.009	0.978	1.004	0.988	1.005	1.012	0.985	1.016	1.001	0.999

THE OBSERVED AGE STRUCTURE OF THE CATCH IS

0.083	0.192	0.213	0.177	0.080	0.087	0.102	0.035	0.027	0.002
0.142	0.195	0.175	0.135	0.165	0.063	0.058	0.045	0.013	0.010
0.117	0.233	0.200	0.183	0.090	0.063	0.050	0.023	0.035	0.007
0.120	0.192	0.252	0.203	0.102	0.043	0.040	0.020	0.015	0.013
0.087	0.260	0.290	0.195	0.070	0.038	0.020	0.025	0.007	0.007
0.142	0.155	0.275	0.180	0.132	0.052	0.027	0.020	0.013	0.002
0.222	0.243	0.162	0.155	0.080	0.072	0.040	0.013	0.010	0.002
0.198	0.325	0.198	0.100	0.108	0.032	0.027	0.005	0.005	0.002
0.230	0.303	0.243	0.125	0.035	0.043	0.005	0.005	0.007	0.005
0.165	0.373	0.228	0.140	0.043	0.023	0.025	0.002	0.000	0.002
0.135	0.300	0.310	0.135	0.060	0.035	0.015	0.005	0.002	0.002
0.235	0.230	0.257	0.155	0.093	0.013	0.010	0.002	0.005	0.000
0.198	0.333	0.262	0.087	0.070	0.030	0.010	0.007	0.002	0.000
0.165	0.285	0.305	0.130	0.078	0.035	0.002	0.000	0.000	0.000
0.097	0.295	0.343	0.153	0.078	0.020	0.010	0.002	0.002	0.000
0.180	0.157	0.338	0.185	0.090	0.032	0.007	0.007	0.002	0.000

Table 3 (cont'd)

0.195	0.355	0.127	0.180	0.080	0.043	0.010	0.007	0.002	0.000
0.262	0.315	0.237	0.058	0.072	0.040	0.010	0.005	0.000	0.000
0.237	0.355	0.222	0.108	0.025	0.027	0.018	0.007	0.000	0.000
0.132	0.368	0.290	0.100	0.068	0.018	0.013	0.005	0.005	0.002

THE RELATIVE FISHING VULNERABILITY IS

0.116	0.325	0.542	0.710	0.823	0.895	0.941	0.970	0.989	1.000

THE ESTIMATES OF INSTANTANEOUS FISHING MORTALITY ARE

0.045	0.127	0.212	0.277	0.321	0.350	0.367	0.379	0.386	0.390
0.039	0.110	0.184	0.240	0.279	0.303	0.319	0.329	0.335	0.339
0.065	0.182	0.304	0.398	0.461	0.502	0.527	0.544	0.554	0.560
0.055	0.155	0.258	0.338	0.392	0.427	0.449	0.462	0.471	0.477
0.063	0.175	0.292	0.383	0.444	0.483	0.508	0.523	0.533	0.539
0.035	0.099	0.165	0.216	0.251	0.273	0.287	0.296	0.301	0.305
0.069	0.192	0.321	0.420	0.486	0.529	0.557	0.574	0.584	0.591
0.064	0.178	0.298	0.390	0.452	0.491	0.517	0.533	0.543	0.549
0.060	0.168	0.281	0.367	0.426	0.464	0.487	0.502	0.512	0.518
0.066	0.186	0.310	0.406	0.470	0.512	0.538	0.555	0.565	0.572
0.082	0.230	0.385	0.503	0.584	0.635	0.668	0.688	0.701	0.709
0.130	0.364	0.608	0.795	0.922	1.003	1.055	1.087	1.108	1.120
0.078	0.220	0.367	0.480	0.557	0.606	0.637	0.657	0.669	0.677
0.106	0.296	0.494	0.647	0.750	0.816	0.858	0.884	0.901	0.911
0.094	0.262	0.438	0.573	0.664	0.723	0.760	0.783	0.798	0.807
0.064	0.180	0.300	0.392	0.455	0.495	0.520	0.536	0.547	0.553
0.096	0.269	0.449	0.587	0.681	0.741	0.779	0.803	0.818	0.828
0.057	0.160	0.268	0.350	0.406	0.442	0.465	0.479	0.488	0.493
0.045	0.127	0.212	0.278	0.322	0.350	0.368	0.379	0.387	0.391
0.046	0.129	0.216	0.282	0.327	0.356	0.374	0.386	0.393	0.398

Table 4 (cont'd)

THE ESTIMATE OF INSTANTANEOUS NATURAL MORTALITY IS 0.400

THE ESTIMATES OF AVERAGE FISHING MORTALITY EACH YEAR ARE

0.285	0.248	0.410	0.348	0.394	0.223	0.432	0.401	0.378	0.418
0.519	0.819	0.495	0.666	0.590	0.404	0.605	0.361	0.286	0.291

THE OBSERVED EFFORT WAS

100.	100.	120.	120.	140.	80.
140.	150.	130.	150.	200.	240.
180.	200.	200.	150.	180.	140.
100.	100.				

THE ESTIMATE FOR THE CATCHABILITY IS 0.1596E-02

THE ESTIMATE FOR THE VARIANCE OF THE EFFORT-FISHING MORTALITY RELATIONSHIP IS 0.01

THE RESIDUALS FOR THE EFFORT -FISHING MORTALITY RELATIONSHIP ARE

-0.014	-0.156	0.165	0.003	-0.028	-0.038	0.064	-0.079	0.006	-0.038
-0.110	0.165	-0.052	0.141	0.020	-0.072	0.150	-0.116	-0.012	0.005

Table 4. The results of the simulation with a stock-recruit relationship are shown below. See section 5.1 for more details.

THE NUMBER OF FISH AT AGE IS

300.	200.	130.	110.	60.	40.	50.	20.	10.	4.
320.	192.	118.	70.	56.	29.	19.	24.	9.	5.
250.	206.	115.	66.	38.	29.	15.	10.	12.	5.
353.	157.	116.	58.	31.	17.	12.	6.	4.	5.
358.	225.	92.	62.	29.	15.	8.	6.	3.	2.
526.	224.	125.	45.	28.	12.	6.	3.	2.	1.
591.	341.	136.	71.	25.	15.	6.	3.	2.	1.
264.	371.	190.	68.	32.	11.	6.	3.	1.	1.
273.	166.	207.	94.	31.	14.	4.	3.	1.	1.
214.	172.	93.	104.	43.	13.	6.	2.	1.	0.
246.	134.	95.	46.	46.	18.	6.	2.	1.	0.
748.	151.	70.	43.	18.	17.	7.	2.	1.	0.
496.	438.	70.	26.	13.	5.	5.	2.	0.	0.
402.	305.	233.	32.	11.	5.	2.	2.	1.	0.
335.	242.	151.	95.	11.	3.	2.	1.	0.	0.
173.	205.	126.	67.	37.	4.	1.	1.	0.	0.
268.	108.	114.	62.	30.	16.	2.	0.	0.	0.
191.	163.	55.	49.	23.	10.	5.	1.	0.	0.
356.	120.	91.	28.	22.	10.	4.	2.	0.	0.
286.	227.	70.	49.	14.	11.	5.	2.	1.	0.

THE TRUE TOTAL CATCH EACH YEAR IS

117 82 114 82 108 63 143 141 120 106 110 185 146
197 152 99 118 67 58 68

THE ESTIMATED CATCH EACH YEAR IS

110.6 83.7 123.1 92.6 103.8 67.1 152.2 134.6 114.6 103.7 103.8 192.0 142.0
205.7 163.3 95.3 126.0 64.8 58.2 66.4

THE RELATIVE FISHING VULNERABILITY IS

0.135 0.369 0.608 0.781 0.886 0.943 0.973 0.988 0.996 1.000

THE INST. FISHING MORT IS

0.05	0.13	0.21	0.27	0.31	0.33	0.34	0.35	0.35	0.35
0.04	0.11	0.18	0.23	0.26	0.27	0.28	0.29	0.29	0.29
0.06	0.18	0.29	0.37	0.42	0.45	0.46	0.47	0.48	0.48
0.05	0.14	0.23	0.30	0.34	0.36	0.37	0.38	0.38	0.38
0.07	0.19	0.31	0.40	0.45	0.48	0.49	0.50	0.51	0.51
0.04	0.10	0.16	0.20	0.23	0.25	0.25	0.26	0.26	0.26
0.07	0.18	0.30	0.39	0.44	0.47	0.48	0.49	0.49	0.50
0.07	0.18	0.30	0.39	0.44	0.47	0.48	0.49	0.50	0.50
0.06	0.18	0.29	0.37	0.42	0.45	0.47	0.47	0.48	0.48
0.07	0.19	0.31	0.40	0.46	0.49	0.50	0.51	0.51	0.52
0.09	0.24	0.40	0.51	0.58	0.62	0.64	0.65	0.65	0.65
0.13	0.37	0.60	0.77	0.88	0.93	0.96	0.98	0.99	0.99
0.09	0.23	0.39	0.49	0.56	0.60	0.62	0.63	0.63	0.63
0.11	0.30	0.49	0.63	0.72	0.77	0.79	0.80	0.81	0.81
0.09	0.25	0.42	0.54	0.61	0.65	0.67	0.68	0.68	0.69

Table 4 (cont'd)

0.07	0.19	0.31	0.40	0.46	0.49	0.50	0.51	0.51	0.51
0.10	0.27	0.45	0.57	0.65	0.69	0.71	0.73	0.73	0.73
0.06	0.18	0.29	0.37	0.42	0.45	0.46	0.47	0.48	0.48
0.05	0.14	0.23	0.29	0.33	0.36	0.37	0.37	0.38	0.38
0.05	0.14	0.24	0.30	0.34	0.37	0.38	0.38	0.39	0.39

THE DEVIATIONS IN EFF-FISH MORT ARE

-0.01 -0.19 0.12 -0.11 0.03 -0.08 0.00 -0.06 0.04 -0.03
-0.08 0.16 0.00 0.14 -0.03 -0.03 0.14 -0.04 0.07 0.09

THE COEFFS FOR THE RICKER CURVE ARE (ALPHA AND THEN DELTA)

1.000 0.1000E-02

THE RELATIVE FECUNDITIES ARE

0.0000E+00	0.0000E+00	1.000	3.000	4.000	5.000
5.000	5.000	5.000	5.000		

THE MAXIMUM REPRODUCTION IS AT 1.60 TIMES THE AVERAGE FECUNDITY OF 624.

THE REPRODUCTIVE POTENTIALS ARE

1320.	987.3	816.7	633.2	556.1	496.2
584.8	629.7	725.0	691.1	555.1	408.3
261.4	418.2	513.9	506.7	509.9	0.0000E+00
0.0000E+00	0.0000E+00				

THE PREDICTED RECRUITMENT IS

352.6	367.8	360.9	336.2	318.9	302.1
325.9	335.5	351.1	346.3	318.6	271.4
201.3	275.3	307.4	305.3	306.2	

THE ERRORS IN THE STOCK-RECRUITMENT RELATIONSHIP ARE

0.001 -0.027 0.377 0.565 -0.187 -0.100 -0.420 -0.308 0.756 0.358
0.233 0.211 -0.153 -0.027 -0.473 0.155 -0.067

THE EFFORT DATA ARE

100.0000	100.0000	120.0000	120.0000	140.0000
80.0000	140.0000	150.0000	130.0000	150.0000
200.0000	240.0000	180.0000	200.0000	200.0000
150.0000	180.0000	140.0000	100.0000	100.0000

Table 5. Shown below are the relevant portions of the output file for the catch-at-age analysis of the simulated data shown in Table 4.

VALUE OF F IS 88.7774

THE VALUE OF THE OBJECTIVE FUNCTION WAS 88.8

THE GPAR VALUES ARE
20.00 10.00 1.00 1.00 0.20 0.40 5.00 0.0010

THE KPAR VALUES ARE

60	30	100	40	1	-1	1	1	0	1
1	0	1	3	4	3	0	0	0	25
1	0	0	0	0	0	0	0		

THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

301.	209.	128.	107.	48.	40.	40.	12.	8.	1.
332.	193.	123.	69.	54.	23.	19.	18.	5.	3.
258.	214.	116.	69.	36.	27.	12.	9.	9.	3.
359.	162.	119.	57.	31.	15.	11.	5.	4.	3.
369.	227.	93.	62.	27.	14.	7.	5.	2.	1.
484.	232.	128.	46.	28.	12.	6.	3.	2.	1.
588.	313.	141.	72.	25.	15.	6.	3.	1.	1.
253.	368.	173.	68.	32.	10.	6.	2.	1.	0.
277.	159.	206.	86.	31.	14.	4.	2.	1.	0.
213.	175.	90.	105.	40.	14.	6.	2.	1.	0.
220.	134.	98.	45.	47.	17.	5.	2.	1.	0.
803.	136.	71.	45.	18.	18.	6.	2.	1.	0.
490.	473.	63.	26.	14.	5.	4.	1.	0.	0.
416.	303.	254.	29.	11.	5.	2.	2.	0.	0.
334.	251.	151.	104.	10.	3.	2.	0.	0.	0.
201.	204.	129.	65.	39.	4.	1.	0.	0.	0.
282.	126.	114.	64.	30.	17.	1.	0.	0.	0.
192.	172.	65.	49.	24.	10.	5.	0.	0.	0.
374.	122.	98.	34.	23.	11.	4.	2.	0.	0.
294.	240.	72.	53.	17.	11.	5.	2.	1.	0.

THE FIRST AGE CLASS ENTERING INTO THE STOCK-RECRUITMENT RELATIONSHIP IS 3

THE RELATIVE REPRODUCTIVE POTENTIALS ARE
1.000 3.000 4.000 5.000 5.000 5.000
5.000 5.000

THE MAXIMUM REPRODUCTION IS AT 2.10 TIMES THE AVERAGE POPULATION FECUNDITY OF 599.7

THE COEFFS FOR THE RICKER CURVE ARE 0.9404 0.7930E-03

THE PREDICTED RECRUITMENT IS

434.	414.	392.	352.	327.	313.	346.	351.	377.	372.
334.	279.	194.	287.	329.	320.	324.			

Table 5 (cont'd)

THE RESIDUALS FOR THE STOCK-RECRUITMENT RELATION ARE

-0.19	-0.11	0.21	0.51	-0.26	-0.12	-0.49	-0.47	0.76	0.28
0.22	0.18	0.04	-0.02	-0.54	0.16	-0.10			

THE ESTIMATED FECUNDITIES ARE

1142.	895.8	765.8	603.8	530.3	492.5
585.4	602.7	694.7	675.1	548.1	412.1
251.3	429.7	534.2	509.7	521.8	391.2
382.3	398.8				

THE VARIANCE ESTIMATE FOR STOCK-RECRUITMENT IS 0.12

THE TOTAL VARIATION FOR RECRUITMENT IS 2.55
THE TOTAL VARIATION OF THE RESIDUALS IS 1.95
THE PROPORTION OF THE VARIATION EXPLAINED IS 0.24

THE SUM OF THE RESIDUALS IS 0.05

THE MULTIPLICATIVE FACTORS FOR THE TOTAL CATCHES ARE

1.006	1.019	0.976	1.007	1.005	0.999	0.985	1.003	0.996	1.007
1.017	0.981	1.008	0.988	0.998	1.014	0.984	1.019	0.999	0.998

THE RELATIVE FISHING VULNERABILITY IS

0.116	0.323	0.540	0.708	0.821	0.894	0.940	0.969	0.988	1.000

THE ESTIMATES OF INSTANTANEOUS FISHING MORTALITY ARE

0.046	0.127	0.213	0.279	0.324	0.352	0.371	0.382	0.389	0.394
0.040	0.110	0.185	0.242	0.280	0.305	0.321	0.331	0.337	0.342
0.066	0.183	0.306	0.401	0.465	0.507	0.533	0.549	0.560	0.567
0.056	0.156	0.260	0.341	0.396	0.431	0.453	0.467	0.476	0.482
0.063	0.176	0.295	0.386	0.448	0.488	0.513	0.529	0.539	0.546
0.036	0.101	0.169	0.221	0.256	0.279	0.294	0.303	0.309	0.312
0.070	0.194	0.325	0.426	0.494	0.538	0.565	0.583	0.594	0.601
0.064	0.178	0.297	0.390	0.452	0.492	0.517	0.534	0.544	0.550
0.060	0.168	0.280	0.367	0.425	0.463	0.487	0.502	0.512	0.518
0.065	0.182	0.304	0.399	0.462	0.503	0.529	0.546	0.556	0.563
0.081	0.227	0.379	0.497	0.576	0.627	0.660	0.680	0.694	0.702
0.131	0.365	0.609	0.798	0.926	1.008	1.060	1.093	1.114	1.127
0.080	0.222	0.371	0.486	0.563	0.613	0.645	0.665	0.678	0.686
0.106	0.295	0.493	0.645	0.748	0.815	0.857	0.884	0.901	0.912
0.094	0.262	0.438	0.574	0.666	0.725	0.762	0.786	0.801	0.811
0.063	0.177	0.296	0.387	0.449	0.489	0.514	0.530	0.540	0.547
0.095	0.264	0.442	0.578	0.671	0.730	0.768	0.792	0.807	0.817
0.056	0.157	0.262	0.343	0.398	0.433	0.456	0.470	0.479	0.485
0.045	0.127	0.212	0.277	0.322	0.350	0.369	0.380	0.387	0.392
0.046	0.128	0.213	0.280	0.324	0.353	0.371	0.383	0.390	0.395

Table 5 (cont'd)

THE ESTIMATE OF INSTANTANEOUS NATURAL MORTALITY IS 0.400

THE ESTIMATES OF AVERAGE FISHING MORTALITY EACH YEAR ARE

0.288	0.249	0.414	0.352	0.398	0.228	0.439	0.402	0.378	0.411
0.512	0.823	0.501	0.665	0.592	0.399	0.597	0.354	0.286	0.288

THE OBSERVED EFFORT WAS

100.0	100.0	120.0	120.0	140.0	80.00
140.0	150.0	130.0	150.0	200.0	240.0
180.0	200.0	200.0	150.0	180.0	140.0
100.0	100.0				

THE ESTIMATE FOR THE CATCHABILITY IS 0.1632E-02

THE ESTIMATE FOR THE VARIANCE OF THE EFFORT-FISHING MORTALITY RELATIONSHIP IS 0.01

THE RESIDUALS FOR THE EFFORT -FISHING MORTALITY RELATIONSHIP ARE

-0.007	-0.150	0.174	0.012	-0.018	-0.016	0.079	-0.078	0.004	-0.056
-0.123	0.169	-0.040	0.138	0.021	-0.085	0.134	-0.137	-0.012	-0.005

Table 6. The following is the relevant portion of the output file from the reconstruction done on the data shown in Table 4 with a hypothetical environmental factor included in the recruitment equation. See section 5.2.

```
VALUE OF F IS     81.8963
VALUE OF F IS     81.8906

THE VALUE OF THE OBJECTIVE FUNCTION WAS     81.9

THE GPAR VALUES ARE
 20.00 10.00  1.00  1.00  0.20  0.40  5.00  0.0010

 THE KPAR VALUES ARE

   80   30  100   40    1   -1    1    1    0    1
    1    0    1    3    4    3    0    0    0   25
    1    0    0    1    0    0    0    0

 THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

  302.   208.   128.   107.    48.    40.    40.    11.     8.     1.
  332.   193.   123.    69.    54.    23.    19.    19.     5.     3.
  258.   214.   116.    68.    36.    27.    12.     9.     9.     3.
  357.   162.   119.    57.    31.    15.    11.     5.     4.     3.
  368.   226.    93.    62.    27.    14.     7.     5.     2.     1.
  485.   232.   127.    46.    28.    12.     6.     3.     2.     1.
  591.   314.   140.    72.    25.    15.     6.     3.     1.     1.
  250.   370.   173.    68.    32.    10.     6.     2.     1.     0.
  276.   157.   207.    86.    31.    13.     4.     2.     1.     0.
  209.   174.    89.   105.    40.    13.     6.     2.     1.     0.
  217.   131.    97.    44.    47.    17.     5.     2.     1.     0.
  811.   134.    70.    45.    18.    18.     6.     2.     1.     0.
  493.   477.    62.    26.    13.     5.     4.     1.     0.     0.
  416.   305.   256.    29.    11.     5.     2.     2.     0.     0.
  331.   251.   152.   105.    10.     3.     2.     0.     0.     0.
  199.   202.   129.    66.    40.     4.     1.     0.     0.     0.
  278.   125.   113.    64.    30.    17.     1.     0.     0.     0.
```

Table 6 (cont'd)

185.	170.	64.	49.	24.	10.	5.	0.	0.	0.
365.	117.	97.	33.	23.	11.	4.	2.	0.	0.
287.	233.	69.	52.	17.	11.	5.	2.	1.	0.

TOTAL NUMBERS OF FISH IN EACH YEAR ARE

892.	841.	753.	764.	805.	941.	1168.	912.	778.	640.
562.	1104.	1082.	1026.	855.	641.	631.	509.	653.	678.

THE FIRST AGE CLASS ENTERING INTO THE STOCK-RECRUITMENT RELATIONSHIP IS 3

THE RELATIVE REPRODUCTIVE POTENTIALS ARE

1.000	3.000	4.000	5.000	5.000	5.000
5.000	5.000				

THE MAXIMUM REPRODUCTION IS AT 1.34 TIMES THE AVERAGE POPULATION FECUNDITY OF 599.0

THE COEFFS FOR THE RICKER CURVE ARE 1.230 0.1250E-02

THE VALUE OF THE ENVIRONMENTAL PARAMETER INFLUENCING RECRUITMENT IS -0.34

THE ENVIRONMENTAL FACTORS AFFECTING RECRUITMENT ARE

-0.4465E-01	-0.1965	1.170	1.777	-0.6519	-0.3483
-1.259	-0.9556	2.081	1.170	0.5626	-0.6519
-0.5001	-0.4465E-01	-1.563	-0.5001	-0.4465E-01	

THE PREDICTED RECRUITMENT IS

332.	337.	536.	634.	270.	291.	227.	253.	721.	529.
410.	242.	189.	305.	200.	281.	329.			

THE RESIDUALS FOR THE STOCK/ENVIR.-RECRUITMENT RELATION ARE

0.07	0.09	-0.10	-0.07	-0.08	-0.05	-0.08	-0.15	0.12	-0.07
0.01	0.31	0.05	-0.09	-0.08	0.26	-0.14			

THE ESTIMATED FECUNDITIES ARE

1139.	894.3	764.3	602.9	530.0	492.2
583.9	601.5	694.7	674.2	545.4	408.6
248.4	430.4	538.1	512.2	522.1	389.1
377.9	390.3				

Table 6 (cont'd)

THE VARIANCE ESTIMATE FOR STOCK/ENVIR.-RECRUITMENT IS 0.18E-01

THE TOTAL VARIATION FOR RECRUITMENT IS 2.67
THE TOTAL VARIATION OF THE RESIDUALS IS 0.29
THE PROPORTION OF THE VARIATION EXPLAINED IS 0.89

THE SUM OF THE RESIDUALS IS 0.01

Table 7. Relevant part of the output file from reconstruction done on data in Table 4 except that the effort data was changed to include time-dependent catchability. See section 5.3.

```
VALUE OF F IS    88.7556
VALUE OF F IS    88.7521
VALUE OF F IS    88.7477

THE VALUE OF THE OBJECTIVE FUNCTION WAS    88.7

THE GPAR VALUES ARE
 20.00 10.00  1.00  1.00  0.20  0.40  5.00  0.0010

 THE KPAR VALUES ARE

   90   30  100   40    1   -1    1    1    0    1
    1    0    1    3    4    3    1    0    0   25
    1    0    0    0    0    0    0    0

 THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

  302.   208.   128.   107.    48.    40.    40.    12.     8.     1.
  332.   193.   123.    69.    54.    24.    19.    19.     5.     3.
  258.   214.   116.    69.    36.    27.    12.     9.     9.     3.
  358.   162.   119.    57.    31.    15.    11.     5.     4.     3.
  370.   227.    93.    62.    27.    14.     7.     5.     2.     1.
  484.   233.   128.    46.    28.    12.     6.     3.     2.     1.
  589.   313.   141.    72.    25.    15.     6.     3.     1.     1.
  252.   368.   173.    68.    32.    10.     6.     2.     1.     0.
  277.   159.   207.    86.    31.    14.     4.     2.     1.     0.
  213.   175.    90.   105.    40.    14.     6.     2.     1.     0.
  220.   134.    98.    45.    47.    17.     6.     2.     1.     0.
  805.   136.    72.    45.    18.    18.     6.     2.     1.     0.
  490.   473.    63.    26.    14.     5.     4.     1.     0.     0.
  416.   303.   254.    29.    11.     5.     2.     2.     0.     0.
  334.   251.   151.   104.    10.     3.     2.     1.     0.     0.
  202.   204.   129.    66.    39.     4.     1.     0.     0.     0.
  283.   127.   115.    65.    30.    17.     1.     0.     0.     0.
  193.   172.    65.    50.    24.    10.     5.     0.     0.     0.
  377.   123.    99.    34.    24.    11.     4.     2.     0.     0.
  296.   241.    72.    54.    17.    12.     5.     2.     1.     0.

 TOTAL NUMBERS OF FISH IN EACH YEAR ARE

    894.    842.    753.    766.    807.    942.   1166.    913.    781.
645.
    569.   1102.   1077.   1023.    857.    646.    638.    522.    674.
701.

  THE FIRST AGE CLASS ENTERING INTO THE STOCK-RECRUITMENT RELATIONSHIP IS    3

  THE RELATIVE REPRODUCTIVE POTENTIALS ARE
  1.000       3.000       4.000       5.000       5.000       5.000
  5.000       5.000
```

Table 7 (cont'd)

THE MAXIMUM REPRODUCTION IS AT 2.12 TIMES THE AVERAGE POPULATION FECUNDITY OF 600.5

THE COFFS FOR THE RICKER CURVE ARE 0.9405 0.7864E-03

THE PREDICTED RECRUITMENT IS

438.	417.	395.	354.	329.	315.	347.	353.	379.	374.
335.	281.	194.	289.	331.	321.	326.			

THE RESIDUALS FOR THE STOCK-RECRUITMENT RELATION ARE

-0.20	-0.12	0.20	0.51	-0.26	-0.13	-0.49	-0.47	0.75	0.27
0.22	0.17	0.04	-0.02	-0.54	0.16	-0.10			

THE ESTIMATED FECUNDITIES ARE

1143.	897.1	766.8	604.7	530.7	492.9
585.5	602.9	695.6	675.8	548.5	413.0
251.8	430.7	535.4	510.8	523.6	394.0
385.5	402.5				

THE VARIANCE ESTIMATE FOR STOCK-RECRUITMENT IS 0.12

THE TOTAL VARIATION FOR RECRUITMENT IS 2.54
THE TOTAL VARIATION OF THE RESIDUALS IS 1.95
THE PROPORTION OF THE VARIATION EXPLAINED IS 0.23

THE SUM OF THE RESIDUALS IS 0.00

THE ESTIMATED AGE STRUCTURE OF THE CATCH IS

0.101	0.187	0.184	0.195	0.101	0.090	0.094	0.028	0.018	0.003
0.126	0.198	0.203	0.146	0.130	0.061	0.051	0.051	0.015	0.019
0.113	0.247	0.212	0.157	0.094	0.076	0.033	0.027	0.027	0.012
0.174	0.209	0.246	0.149	0.091	0.048	0.036	0.015	0.012	0.020
0.181	0.294	0.190	0.159	0.080	0.043	0.022	0.016	0.006	0.008
0.212	0.276	0.245	0.114	0.079	0.035	0.018	0.009	0.006	0.005
0.219	0.307	0.218	0.140	0.054	0.034	0.014	0.007	0.003	0.004
0.096	0.370	0.275	0.137	0.072	0.025	0.014	0.006	0.003	0.002
0.118	0.179	0.370	0.194	0.079	0.037	0.012	0.007	0.003	0.002
0.107	0.233	0.190	0.277	0.119	0.043	0.019	0.006	0.003	0.002
0.135	0.215	0.246	0.139	0.165	0.063	0.021	0.009	0.003	0.002

Table 7 (cont'd)

0.433	0.184	0.146	0.111	0.049	0.051	0.018	0.006	0.002	0.001
0.216	0.546	0.114	0.059	0.034	0.013	0.012	0.004	0.001	0.001
0.170	0.318	0.409	0.058	0.024	0.012	0.004	0.004	0.001	0.001
0.152	0.295	0.276	0.234	0.026	0.009	0.004	0.001	0.001	0.001
0.106	0.284	0.286	0.182	0.123	0.012	0.004	0.002	0.001	0.001
0.170	0.197	0.275	0.192	0.099	0.059	0.005	0.002	0.001	0.000
0.133	0.316	0.191	0.183	0.102	0.046	0.026	0.002	0.001	0.000
0.237	0.207	0.269	0.117	0.093	0.047	0.020	0.011	0.001	0.000
0.165	0.361	0.174	0.164	0.060	0.043	0.020	0.008	0.004	0.001

THE MULTIPLICATIVE FACTORS FOR THE TOTAL CATCHES ARE

1.003	1.020	0.977	1.008	1.004	1.001	0.984	1.000	0.995	1.006
1.014	0.982	1.008	0.988	0.999	1.011	0.982	1.018	1.000	0.999

THE OBSERVED AGE STRUCTURE OF THE CATCH IS

0.083	0.192	0.213	0.177	0.080	0.087	0.102	0.035	0.027	0.002
0.142	0.195	0.175	0.135	0.165	0.063	0.058	0.045	0.013	0.010
0.117	0.233	0.200	0.183	0.090	0.063	0.050	0.023	0.035	0.007
0.155	0.180	0.252	0.195	0.097	0.032	0.043	0.018	0.018	0.010
0.185	0.315	0.207	0.160	0.052	0.032	0.020	0.013	0.010	0.005
0.198	0.275	0.252	0.130	0.063	0.045	0.020	0.010	0.005	0.002
0.250	0.320	0.177	0.112	0.060	0.050	0.015	0.007	0.007	0.000
0.090	0.373	0.268	0.155	0.072	0.023	0.013	0.005	0.000	0.002
0.123	0.160	0.370	0.215	0.075	0.038	0.005	0.002	0.007	0.005
0.095	0.252	0.192	0.273	0.108	0.047	0.027	0.002	0.000	0.002
0.135	0.220	0.243	0.147	0.142	0.060	0.032	0.015	0.002	0.002
0.435	0.185	0.142	0.102	0.058	0.052	0.013	0.007	0.005	0.000
0.225	0.567	0.080	0.052	0.030	0.018	0.013	0.010	0.005	0.000
0.165	0.303	0.412	0.083	0.030	0.005	0.000	0.002	0.000	0.000

Table 7 (cont'd)

0.157	0.280	0.315	0.213	0.020	0.010	0.002	0.000	0.000	0.002
0.097	0.278	0.310	0.177	0.117	0.010	0.005	0.002	0.002	0.000
0.170	0.210	0.273	0.198	0.080	0.060	0.007	0.002	0.000	0.000
0.138	0.287	0.213	0.192	0.093	0.047	0.025	0.005	0.000	0.000
0.237	0.213	0.290	0.095	0.087	0.040	0.020	0.018	0.000	0.000
0.162	0.363	0.155	0.172	0.058	0.047	0.030	0.002	0.007	0.002

THE RELATIVE FISHING VULNERABILITY IS

0.116	0.324	0.541	0.708	0.821	0.894	0.941	0.970	0.988	1.000

THE ESTIMATES OF INSTANTANEOUS FISHING MORTALITY ARE

0.046	0.127	0.212	0.278	0.322	0.351	0.369	0.381	0.388	0.392
0.040	0.110	0.185	0.242	0.280	0.305	0.321	0.331	0.337	0.341
0.066	0.183	0.306	0.401	0.465	0.506	0.532	0.549	0.559	0.566
0.056	0.156	0.261	0.341	0.396	0.431	0.453	0.467	0.476	0.482
0.063	0.176	0.294	0.385	0.447	0.487	0.512	0.528	0.538	0.544
0.036	0.101	0.169	0.221	0.257	0.279	0.294	0.303	0.309	0.312
0.070	0.195	0.325	0.425	0.493	0.537	0.565	0.582	0.594	0.601
0.064	0.178	0.296	0.388	0.450	0.490	0.515	0.531	0.542	0.548
0.060	0.167	0.280	0.366	0.425	0.462	0.486	0.501	0.511	0.517
0.065	0.182	0.304	0.398	0.462	0.502	0.528	0.545	0.555	0.562
0.081	0.226	0.378	0.495	0.574	0.625	0.657	0.677	0.690	0.699
0.131	0.365	0.609	0.797	0.925	1.007	1.059	1.092	1.113	1.126
0.079	0.222	0.370	0.485	0.562	0.612	0.644	0.664	0.676	0.684
0.106	0.295	0.492	0.644	0.747	0.813	0.855	0.882	0.899	0.909
0.094	0.262	0.438	0.573	0.664	0.723	0.761	0.784	0.799	0.809
0.063	0.176	0.294	0.385	0.446	0.486	0.511	0.527	0.537	0.543
0.094	0.263	0.439	0.574	0.666	0.725	0.763	0.786	0.801	0.811

Table 7 (cont'd)

0.056	0.156	0.260	0.340	0.395	0.430	0.452	0.466	0.475	0.480
0.045	0.126	0.210	0.275	0.319	0.348	0.366	0.377	0.384	0.389
0.045	0.127	0.212	0.277	0.322	0.350	0.368	0.380	0.387	0.391

THE ESTIMATE OF INSTANTANEOUS NATURAL MORTALITY IS 0.400

THE ESTIMATES OF AVERAGE MORTALITY EACH YEAR ARE

0.287	0.249	0.413	0.352	0.397	0.228	0.439	0.400	0.378	0.410
0.510	0.822	0.500	0.664	0.591	0.397	0.592	0.351	0.284	0.286

THE OBSERVED EFFORT WAS

100.0	94.87	108.0	102.5	113.4	61.49
102.1	103.8	85.33	93.41	118.2	134.5
95.72	100.9	95.72	68.11	77.54	57.22
38.78	36.79				

THE ESTIMATED TIME DEPENDENT CATCHABILITY IS

0.1613E-02	0.1699E-02	0.1790E-02	0.1886E-02	0.1987E-02	0.2094E-02
0.2206E-02	0.2325E-02	0.2449E-02	0.2580E-02	0.2719E-02	0.2865E-02
0.3018E-02	0.3180E-02	0.3350E-02	0.3530E-02	0.3719E-02	0.3919E-02
0.4129E-02	0.4350E-02				

THE ESTIMATE FOR THE VARIANCE OF THE EFFORT-FISHING MORTALITY RELATIONSHIP IS 0.01

THE RESIDUALS FOR THE EFFORT -FISHING MORTALITY RELATIONSHIP ARE

-0.012	-0.152	0.173	0.012	-0.020	-0.015	0.080	-0.081	0.005	-0.055
-0.124	0.171	-0.039	0.140	0.024	-0.086	0.133	-0.139	-0.014	-0.007

Table 8. These are the simulated data which include ageing errors.

THE NUMBER OF FISH AT AGE IS

300.	200.	130.	110.	60.	40.	50.	20.	10.	4.
320.	192.	118.	70.	56.	29.	19.	24.	9.	5.
250.	206.	115.	66.	38.	29.	15.	10.	12.	5.
353.	157.	116.	58.	31.	17.	12.	6.	4.	5.
365.	225.	92.	62.	29.	15.	8.	6.	3.	2.
409.	228.	125.	45.	28.	12.	6.	3.	2.	1.
406.	265.	139.	71.	25.	15.	6.	3.	2.	1.
300.	254.	148.	69.	32.	11.	6.	3.	1.	1.
292.	188.	142.	73.	31.	14.	4.	3.	1.	1.
284.	184.	105.	71.	34.	14.	6.	2.	1.	0.
295.	177.	102.	52.	32.	14.	6.	2.	1.	0.
424.	181.	93.	46.	21.	12.	5.	2.	1.	0.
363.	248.	84.	34.	14.	6.	3.	1.	1.	0.
328.	223.	132.	38.	14.	5.	2.	1.	0.	0.
294.	197.	111.	54.	14.	5.	2.	1.	0.	0.
210.	180.	103.	49.	21.	5.	2.	1.	0.	0.
244.	132.	100.	50.	22.	9.	2.	1.	0.	0.
216.	148.	67.	43.	19.	8.	3.	1.	0.	0.
270.	136.	83.	34.	20.	8.	3.	1.	0.	0.
261.	172.	79.	44.	17.	9.	4.	2.	1.	0.

THE TRUE TOTAL CATCH EACH YEAR IS

117 82 114 82 108 60 123 118 105 103 118 167 110

144 116 82 107 65 55 61

THE ESTIMATED CATCH EACH YEAR IS

110.6 83.7 123.1 92.6 104.1 63.9 131.1 112.6 100.3 100.3 111.4 173.1 107.5
150.7 124.9 79.8 113.9 62.5 54.6 60.0

THE TRUE PROPORTIONS AT AGE IN THE CATCH ARE

0.098	0.171	0.177	0.187	0.114	0.080	0.103	0.042	0.021	0.008
0.124	0.196	0.192	0.144	0.128	0.071	0.048	0.060	0.024	0.012
0.113	0.241	0.211	0.150	0.095	0.077	0.041	0.027	0.033	0.013
0.177	0.206	0.241	0.150	0.088	0.050	0.039	0.020	0.013	0.016
0.185	0.294	0.187	0.156	0.081	0.043	0.023	0.018	0.009	0.006
0.194	0.286	0.251	0.114	0.079	0.037	0.019	0.010	0.007	0.004
0.176	0.297	0.243	0.155	0.059	0.037	0.017	0.008	0.004	0.003
0.136	0.298	0.271	0.156	0.082	0.028	0.017	0.007	0.004	0.002
0.144	0.239	0.284	0.181	0.086	0.040	0.013	0.008	0.003	0.002
0.153	0.255	0.229	0.190	0.100	0.043	0.019	0.006	0.003	0.001
0.175	0.267	0.235	0.146	0.099	0.047	0.019	0.008	0.003	0.001
0.263	0.276	0.212	0.125	0.061	0.037	0.016	0.006	0.003	0.001
0.223	0.388	0.203	0.101	0.046	0.020	0.011	0.005	0.002	0.001
0.195	0.332	0.297	0.105	0.042	0.017	0.007	0.004	0.002	0.001
0.185	0.314	0.271	0.161	0.045	0.016	0.006	0.002	0.001	0.001

Table 8 (cont'd)

0.141	0.311	0.277	0.163	0.078	0.019	0.006	0.002	0.001	0.000
0.178	0.242	0.279	0.172	0.082	0.035	0.008	0.003	0.001	0.000
0.171	0.304	0.216	0.170	0.084	0.036	0.014	0.003	0.001	0.000
0.201	0.265	0.258	0.130	0.085	0.038	0.015	0.006	0.001	0.000
0.179	0.308	0.224	0.157	0.066	0.039	0.017	0.007	0.003	0.001

THE EXPECTED OBSERVED PROPORTIONS AT AGE IN THE CATCH ARE (INCLUDING AGEING ERRORS):

0.078	0.164	0.199	0.222	0.123	0.088	0.080	0.030	0.011	0.003
0.099	0.188	0.208	0.199	0.115	0.077	0.054	0.041	0.013	0.005
0.090	0.225	0.223	0.206	0.095	0.069	0.042	0.027	0.017	0.005
0.142	0.207	0.246	0.201	0.086	0.051	0.033	0.019	0.010	0.006
0.148	0.272	0.218	0.200	0.077	0.042	0.022	0.013	0.005	0.002
0.155	0.273	0.254	0.182	0.070	0.036	0.016	0.008	0.004	0.001
0.141	0.279	0.255	0.206	0.062	0.033	0.014	0.006	0.003	0.001
0.109	0.279	0.272	0.215	0.073	0.030	0.013	0.005	0.002	0.001
0.115	0.234	0.282	0.233	0.080	0.037	0.011	0.005	0.002	0.001
0.122	0.242	0.249	0.233	0.091	0.041	0.014	0.005	0.002	0.001
0.140	0.254	0.248	0.205	0.087	0.043	0.015	0.005	0.001	0.001
0.210	0.268	0.234	0.177	0.060	0.033	0.012	0.004	0.001	0.000
0.178	0.353	0.228	0.164	0.044	0.020	0.009	0.003	0.001	0.000
0.156	0.315	0.286	0.178	0.040	0.016	0.006	0.002	0.001	0.000
0.148	0.296	0.276	0.210	0.047	0.016	0.005	0.002	0.001	0.000
0.113	0.290	0.280	0.220	0.068	0.021	0.005	0.002	0.000	0.000
0.142	0.239	0.280	0.224	0.075	0.031	0.006	0.002	0.000	0.000
0.137	0.282	0.241	0.217	0.077	0.033	0.010	0.002	0.001	0.000
0.161	0.258	0.262	0.194	0.075	0.035	0.011	0.004	0.001	0.000
0.143	0.286	0.244	0.207	0.067	0.035	0.013	0.004	0.001	0.000

THE AGEING ERROR PROBABILITIES FOR THE 10 AGE CLASSES ARE

AGE	UNDERAGE		TRUE	OVERAGE	
CLASS	-2	-1	AGE	+1	+2
1	0.000	0.000	0.800	0.100	0.100
2	0.000	0.000	0.800	0.100	0.100
3	0.000	0.100	0.700	0.200	0.000
4	0.000	0.200	0.700	0.100	0.000
5	0.100	0.200	0.600	0.100	0.000
6	0.200	0.200	0.600	0.000	0.000
7	0.200	0.200	0.600	0.000	0.000
8	0.200	0.300	0.500	0.000	0.000
9	0.300	0.300	0.400	0.000	0.000
10	0.300	0.300	0.400	0.000	0.000

THE OBSERVED CATCH AT AGE IS (OBTAINED BY TAKING A RANDOM SAMPLE OF THE EXPECTED OBSERVED PROPORTIONS AND ADJUSTING TO A SIZE OF 400):

25.000	77.000	91.000	79.000	41.000	34.000	36.000	13.000	3.000	1.000
50.000	74.000	77.000	76.000	56.000	30.000	19.000	13.000	3.000	2.000
40.000	89.000	82.000	95.000	33.000	24.000	19.000	9.000	9.000	0.000
48.000	76.000	98.000	103.000	33.000	14.000	17.000	7.000	2.000	2.000
59.000	112.000	104.000	78.000	18.000	12.000	10.000	3.000	4.000	0.000

Table 8 (cont'd)

53.000	105.000	110.000	78.000	23.000	18.000	8.000	4.000	1.000	0.000
68.000	95.000	110.000	69.000	26.000	22.000	5.000	5.000	0.000	0.000
40.000	117.000	104.000	87.000	33.000	11.000	5.000	2.000	0.000	1.000
49.000	83.000	113.000	98.000	34.000	15.000	3.000	2.000	3.000	0.000
46.000	104.000	90.000	100.000	31.000	21.000	7.000	0.000	1.000	0.000
48.000	101.000	101.000	84.000	35.000	18.000	9.000	3.000	1.000	0.000
96.000	96.000	95.000	62.000	34.000	9.000	5.000	1.000	2.000	0.000
74.000	140.000	107.000	47.000	14.000	10.000	4.000	4.000	0.000	0.000
59.000	112.000	128.000	77.000	18.000	5.000	1.000	0.000	0.000	0.000
58.000	115.000	121.000	82.000	16.000	6.000	1.000	0.000	1.000	0.000
43.000	108.000	124.000	86.000	24.000	11.000	3.000	1.000	0.000	0.000
53.000	109.000	108.000	85.000	27.000	14.000	4.000	0.000	0.000	0.000
51.000	104.000	107.000	89.000	30.000	14.000	4.000	1.000	0.000	0.000
65.000	100.000	109.000	75.000	28.000	14.000	6.000	3.000	0.000	0.000
49.000	118.000	83.000	91.000	30.000	19.000	6.000	2.000	2.000	0.000

THE RELATIVE FISHING VULNERABILITY IS

0.135	0.369	0.608	0.781	0.886	0.943	0.973	0.988	0.996	1.000

THE INST. FISHING MORT IS

0.05	0.13	0.21	0.27	0.31	0.33	0.34	0.35	0.35	0.35
0.04	0.11	0.18	0.23	0.26	0.27	0.28	0.29	0.29	0.29
0.06	0.18	0.29	0.37	0.42	0.45	0.46	0.47	0.48	0.48
0.05	0.14	0.23	0.30	0.34	0.36	0.37	0.38	0.38	0.38
0.07	0.19	0.31	0.40	0.45	0.48	0.49	0.50	0.51	0.51
0.04	0.10	0.16	0.20	0.23	0.25	0.25	0.26	0.26	0.26
0.07	0.18	0.30	0.39	0.44	0.47	0.48	0.49	0.49	0.50
0.07	0.18	0.30	0.39	0.44	0.47	0.48	0.49	0.50	0.50
0.06	0.18	0.29	0.37	0.42	0.45	0.47	0.47	0.48	0.48
0.07	0.19	0.31	0.40	0.46	0.49	0.50	0.51	0.51	0.52
0.09	0.24	0.40	0.51	0.58	0.62	0.64	0.65	0.65	0.65
0.13	0.37	0.60	0.77	0.88	0.93	0.96	0.98	0.99	0.99
0.09	0.23	0.39	0.49	0.56	0.60	0.62	0.63	0.63	0.63
0.11	0.30	0.49	0.63	0.72	0.77	0.79	0.80	0.81	0.81
0.09	0.25	0.42	0.54	0.61	0.65	0.67	0.68	0.68	0.69
0.07	0.19	0.31	0.40	0.46	0.49	0.50	0.51	0.51	0.51
0.10	0.27	0.45	0.57	0.65	0.69	0.71	0.73	0.73	0.73
0.06	0.18	0.29	0.37	0.42	0.45	0.46	0.47	0.48	0.48
0.05	0.14	0.23	0.29	0.33	0.36	0.37	0.37	0.38	0.38
0.05	0.14	0.24	0.30	0.34	0.37	0.38	0.38	0.39	0.39

THE DEVIATIONS IN EFF-FISH MORT ARE

-0.01	-0.19	0.12	-0.11	0.03	-0.08	0.00	-0.06	0.04	-0.03
-0.08	0.16	0.00	0.14	-0.03	-0.03	0.14	-0.04	0.07	0.09

THE COEFFS FOR THE RICKER CURVE ARE (ALPHA AND THEN DELTA) 1.000 0.1000E-02

THE RELATIVE FECUNDITIES ARE

0.0000E+00	0.0000E+00	1.000	3.000	4.000	5.000
5.000	5.000	5.000	5.000		

THE MAXIMUM REPRODUCTION IS AT 1.72 TIMES THE AVERAGE FECUNDITY OF 580.

Table 8 (cont'd)

THE REPRODUCTIVE POTENTIALS ARE

1320.	987.3	816.7	633.2	556.1	496.1
587.2	591.1	599.5	568.7	501.7	415.3
298.6	349.9	364.2	371.4	398.2	0.0000E+00
0.0000E+00	0.0000E+00				

THE PREDICTED RECRUITMENT IS

352.6	367.8	360.9	336.2	318.9	302.1
326.4	327.3	329.2	322.0	303.8	274.2
221.5	246.6	253.0	256.2	267.4	

THE ERRORS IN THE STOCK-RECRUITMENT RELATIONSHIP ARE

0.000 -0.009 0.126 0.188 -0.062 -0.033 -0.140 -0.103 0.252 0.119
0.078 0.070 -0.051 -0.009 -0.158 0.052 -0.022

Table 9. Shown below is the entire output file for the reconstruction done on the simulated data in Table 8. The ageing error option is included here.

THE VALUE OF THE OBJECTIVE FUNCTION WAS 82.4

THE GPAR VALUES ARE
20.00 10.00 1.00 1.00 0.20 0.40 5.00 0.0010

THE KPAR VALUES ARE

90	30	100	40	1	-1	1	1	5	1
1	1	1	3	5	3	1	0	0	25
1	0	0	0	0	0	0	0		

THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

281.	212.	124.	106.	52.	30.	46.	14.	5.	2.
350.	180.	125.	67.	54.	25.	14.	21.	7.	2.
272.	225.	108.	70.	35.	27.	12.	7.	10.	3.
351.	171.	126.	53.	31.	15.	11.	5.	3.	4.
381.	222.	98.	65.	26.	14.	6.	5.	2.	1.
358.	240.	125.	49.	30.	11.	6.	3.	2.	1.
430.	231.	146.	71.	27.	16.	6.	3.	1.	1.
271.	269.	128.	71.	31.	11.	6.	2.	1.	0.
301.	170.	151.	64.	32.	13.	4.	2.	1.	0.
268.	190.	97.	77.	30.	14.	6.	2.	1.	0.
286.	168.	106.	48.	34.	12.	6.	2.	1.	0.
463.	176.	90.	49.	19.	13.	4.	2.	1.	0.
369.	272.	82.	33.	15.	5.	3.	1.	0.	0.
336.	228.	147.	39.	14.	6.	2.	1.	0.	0.
292.	202.	115.	61.	14.	4.	2.	1.	0.	0.
242.	178.	105.	50.	23.	5.	1.	1.	0.	0.
251.	152.	100.	53.	23.	10.	2.	1.	0.	0.
214.	153.	79.	44.	20.	8.	3.	1.	0.	0.
301.	135.	88.	41.	21.	9.	3.	1.	0.	0.
247.	193.	80.	48.	21.	10.	4.	2.	1.	0.

TOTAL NUMBERS OF FISH IN EACH YEAR ARE

871. 844. 769. 769. 821. 824. 931. 791. 740.
684.
664. 818. 781. 772. 691. 605. 592. 521. 600.
605.

THE FIRST AGE CLASS ENTERING INTO THE STOCK-RECRUITMENT RELATIONSHIP IS 3

THE RELATIVE REPRODUCTIVE POTENTIALS ARE
1.000 3.000 4.000 5.000 5.000 5.000
5.000 5.000

THE MAXIMUM REPRODUCTION IS AT 1.77 TIMES THE AVERAGE POPULATION FECUNDITY OF 556.6

THE COEFFS FOR THE RICKER CURVE ARE 1.034 0.1017E-02

Table 9 (cont'd)

THE PREDICTED RECRUITMENT IS

370.	372.	362.	336.	322.	312.	336.	330.	332.	328.
309.	281.	223.	260.	270.	268.	281.			

THE RESIDUALS FOR THE STOCK-RECRUITMENT RELATION ARE

-0.05	0.03	-0.01	0.25	-0.17	-0.04	-0.23	-0.14	0.33	0.12
0.08	0.04	0.08	-0.03	-0.23	0.12	-0.13			

THE ESTIMATED FECUNDITIES ARE

1132.	884.8	753.9	596.2	538.8	502.6
596.7	569.6	580.1	560.6	494.1	414.5
290.2	363.2	387.5	383.2	414.7	350.5
363.8	390.7				

THE VARIANCE ESTIMATE FOR STOCK-RECRUITMENT IS 0.24E-01

THE TOTAL VARIATION FOR RECRUITMENT IS 0.73
THE TOTAL VARIATION OF THE RESIDUALS IS 0.39
THE PROPORTION OF THE VARIATION EXPLAINED IS 0.46

THE SUM OF THE RESIDUALS IS 0.00

THE ESTIMATED AGE STRUCTURE OF THE CATCH IS

0.096	0.189	0.178	0.194	0.109	0.068	0.109	0.035	0.012	0.009
0.137	0.185	0.208	0.143	0.131	0.066	0.039	0.060	0.019	0.012
0.121	0.257	0.195	0.159	0.091	0.075	0.036	0.020	0.031	0.015
0.171	0.216	0.254	0.137	0.092	0.047	0.036	0.016	0.009	0.023
0.188	0.281	0.197	0.166	0.074	0.044	0.021	0.015	0.007	0.006
0.167	0.294	0.249	0.126	0.088	0.035	0.020	0.009	0.006	0.005
0.187	0.258	0.256	0.158	0.067	0.042	0.016	0.008	0.004	0.004
0.125	0.318	0.241	0.169	0.085	0.032	0.018	0.007	0.003	0.002
0.148	0.217	0.306	0.164	0.094	0.042	0.015	0.008	0.003	0.002
0.144	0.261	0.211	0.211	0.093	0.047	0.020	0.007	0.004	0.002
0.169	0.252	0.248	0.140	0.114	0.044	0.021	0.008	0.003	0.002
0.281	0.261	0.201	0.132	0.059	0.041	0.015	0.007	0.002	0.001
0.217	0.407	0.193	0.097	0.049	0.018	0.012	0.004	0.002	0.001

Table 9 (cont'd)

0.189	0.321	0.317	0.103	0.041	0.018	0.006	0.004	0.001	0.001
0.176	0.306	0.270	0.178	0.045	0.015	0.006	0.002	0.001	0.001
0.154	0.292	0.273	0.165	0.087	0.019	0.006	0.002	0.001	0.001
0.170	0.258	0.264	0.173	0.084	0.039	0.008	0.002	0.001	0.000
0.157	0.290	0.239	0.168	0.088	0.038	0.016	0.003	0.001	0.001
0.206	0.241	0.251	0.149	0.087	0.041	0.016	0.007	0.001	0.001
0.156	0.318	0.212	0.162	0.081	0.042	0.019	0.007	0.003	0.001

THE MULTIPLICATIVE FACTORS FOR THE TOTAL CATCHES ARE

1.001	1.016	0.978	1.008	1.004	1.003	0.988	1.004	0.996	1.003
1.013	0.982	1.008	0.987	1.000	1.013	0.984	1.015	1.000	0.998

THE OBSERVED AGE STRUCTURE OF THE CATCH IS

0.063	0.192	0.228	0.198	0.102	0.085	0.090	0.032	0.007	0.002
0.125	0.185	0.192	0.190	0.140	0.075	0.047	0.032	0.007	0.005
0.100	0.222	0.205	0.237	0.083	0.060	0.047	0.023	0.023	0.000
0.120	0.190	0.245	0.257	0.083	0.035	0.043	0.018	0.005	0.005
0.147	0.280	0.260	0.195	0.045	0.030	0.025	0.007	0.010	0.000
0.132	0.262	0.275	0.195	0.058	0.045	0.020	0.010	0.002	0.000
0.170	0.237	0.275	0.172	0.065	0.055	0.013	0.013	0.000	0.000
0.100	0.292	0.260	0.218	0.083	0.027	0.013	0.005	0.000	0.002
0.123	0.207	0.282	0.245	0.085	0.038	0.007	0.005	0.007	0.000
0.115	0.260	0.225	0.250	0.078	0.052	0.018	0.000	0.002	0.000
0.120	0.252	0.252	0.210	0.087	0.045	0.023	0.007	0.002	0.000
0.240	0.240	0.237	0.155	0.085	0.023	0.013	0.002	0.005	0.000
0.185	0.350	0.268	0.117	0.035	0.025	0.010	0.010	0.000	0.000
0.147	0.280	0.320	0.192	0.045	0.013	0.002	0.000	0.000	0.000
0.145	0.287	0.303	0.205	0.040	0.015	0.002	0.000	0.002	0.000
0.108	0.270	0.310	0.215	0.060	0.027	0.007	0.002	0.000	0.000

Table 9 (cont'd)

0.132	0.273	0.270	0.213	0.068	0.035	0.010	0.000	0.000	0.000
0.127	0.260	0.268	0.222	0.075	0.035	0.010	0.002	0.000	0.000
0.162	0.250	0.273	0.188	0.070	0.035	0.015	0.007	0.000	0.000
0.123	0.295	0.207	0.228	0.075	0.047	0.015	0.005	0.005	0.000

THE RELATIVE FISHING VULNERABILITY IS

0.116	0.314	0.524	0.691	0.807	0.884	0.934	0.966	0.986	1.000

THE ESTIMATES OF INSTANTANEOUS FISHING MORTALITY ARE

0.047	0.127	0.212	0.279	0.326	0.357	0.377	0.390	0.398	0.404
0.041	0.111	0.185	0.244	0.285	0.312	0.329	0.341	0.348	0.353
0.067	0.181	0.302	0.399	0.466	0.510	0.538	0.557	0.569	0.577
0.056	0.153	0.255	0.336	0.392	0.429	0.454	0.469	0.479	0.486
0.064	0.174	0.290	0.383	0.447	0.489	0.517	0.535	0.546	0.554
0.036	0.098	0.165	0.217	0.253	0.277	0.293	0.303	0.309	0.314
0.071	0.191	0.319	0.421	0.491	0.538	0.568	0.588	0.600	0.609
0.065	0.175	0.293	0.386	0.451	0.494	0.522	0.539	0.551	0.559
0.061	0.166	0.277	0.366	0.427	0.467	0.494	0.511	0.522	0.529
0.067	0.182	0.305	0.402	0.469	0.514	0.543	0.561	0.573	0.581
0.084	0.227	0.379	0.499	0.583	0.638	0.674	0.697	0.712	0.722
0.133	0.360	0.601	0.792	0.925	1.012	1.069	1.106	1.130	1.145
0.080	0.216	0.361	0.476	0.556	0.609	0.643	0.665	0.679	0.689
0.106	0.288	0.480	0.633	0.740	0.810	0.855	0.884	0.904	0.916
0.095	0.256	0.428	0.564	0.659	0.721	0.762	0.788	0.805	0.816
0.064	0.172	0.288	0.379	0.443	0.485	0.512	0.530	0.541	0.549
0.095	0.258	0.431	0.568	0.663	0.726	0.767	0.793	0.810	0.821
0.058	0.156	0.260	0.343	0.401	0.439	0.463	0.479	0.489	0.496
0.046	0.123	0.206	0.272	0.317	0.347	0.367	0.380	0.388	0.393
0.047	0.127	0.212	0.279	0.326	0.357	0.377	0.390	0.398	0.404

Table 9 (cont'd)

THE ESTIMATE OF INSTANTANEOUS NATURAL MORTALITY IS 0.400

THE ESTIMATES OF AVERAGE FISHING MORTALITY EACH YEAR ARE

0.292	0.255	0.417	0.351	0.400	0.227	0.440	0.404	0.382	0.420
0.521	0.827	0.497	0.662	0.589	0.396	0.593	0.358	0.284	0.291

THE OBSERVED EFFORT WAS

100.0	94.87	108.0	102.5	113.4	61.49
102.1	103.8	85.33	93.41	118.2	134.5
95.72	100.9	95.72	68.11	77.54	57.22
38.78	36.79				

THE ESTIMATED TIME DEPENDENT CATCHABILITY IS

0.1662E-02	0.1750E-02	0.1844E-02	0.1943E-02	0.2046E-02	0.2156E-02
0.2271E-02	0.2392E-02	0.2520E-02	0.2655E-02	0.2797E-02	0.2947E-02
0.3104E-02	0.3270E-02	0.3445E-02	0.3629E-02	0.3823E-02	0.4028E-02
0.4243E-02	0.4470E-02				

THE CONSTANT AGEING ERROR PROBABILITIES ARE

0.000	0.000	0.800	0.100	0.100
0.000	0.000	0.800	0.100	0.100
0.000	0.100	0.700	0.200	0.000
0.000	0.200	0.700	0.100	0.000
0.100	0.200	0.600	0.100	0.000
0.200	0.200	0.600	0.000	0.000
0.200	0.200	0.600	0.000	0.000
0.200	0.300	0.500	0.000	0.000
0.300	0.300	0.400	0.000	0.000
0.300	0.300	0.400	0.000	0.000

Table 9 (cont'd)

THE PREDICTED APPARENT AGE STRUCTURE OF THE CATCH IS

0.077	0.179	0.203	0.226	0.120	0.081	0.080	0.024	0.007	0.003
0.110	0.182	0.219	0.200	0.114	0.073	0.047	0.039	0.011	0.005
0.097	0.237	0.215	0.209	0.093	0.065	0.037	0.024	0.017	0.006
0.137	0.215	0.253	0.196	0.085	0.048	0.029	0.018	0.010	0.009
0.150	0.264	0.226	0.208	0.074	0.041	0.019	0.012	0.005	0.002
0.134	0.277	0.255	0.192	0.076	0.035	0.016	0.008	0.004	0.002
0.150	0.251	0.262	0.209	0.067	0.037	0.013	0.007	0.003	0.002
0.100	0.291	0.255	0.221	0.078	0.032	0.014	0.005	0.002	0.001
0.119	0.219	0.293	0.225	0.084	0.039	0.012	0.006	0.002	0.001
0.115	0.244	0.240	0.244	0.090	0.043	0.015	0.005	0.002	0.001
0.135	0.243	0.255	0.204	0.095	0.044	0.016	0.006	0.002	0.001
0.225	0.257	0.227	0.179	0.060	0.035	0.011	0.004	0.001	0.000
0.174	0.367	0.222	0.161	0.045	0.019	0.009	0.003	0.001	0.000
0.151	0.307	0.297	0.179	0.040	0.017	0.005	0.002	0.001	0.000
0.141	0.290	0.277	0.221	0.049	0.015	0.005	0.002	0.001	0.000
0.123	0.276	0.277	0.221	0.074	0.022	0.005	0.002	0.000	0.000
0.136	0.250	0.271	0.224	0.077	0.034	0.006	0.002	0.000	0.000
0.126	0.272	0.254	0.220	0.080	0.035	0.011	0.002	0.001	0.000
0.164	0.238	0.259	0.204	0.079	0.038	0.012	0.004	0.001	0.000
0.124	0.291	0.236	0.212	0.077	0.039	0.014	0.005	0.001	0.000

THE ESTIMATE FOR THE VARIANCE OF THE EFFORT-FISHING MORTALITY RELATIONSHIP IS 0.01

THE RESIDUALS FOR THE EFFORT -FISHING MORTALITY RELATIONSHIP ARE

-0.003	-0.137	0.172	0.001	-0.022	-0.029	0.074	-0.080	0.009	-0.039
-0.109	0.170	-0.050	0.130	0.015	-0.093	0.128	-0.124	-0.020	0.007

TABLE 10. Partial output from the reconstruction done on the data in Table 8 with the seven oldest age classes grouped in the input data. KPAR(28) is set equal to zero.

THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

290.	213.	150.	232.	0.	0.	0.	0.	0.	0.
327.	187.	127.	80.	109.	0.	0.	0.	0.	0.
296.	212.	114.	71.	41.	52.	0.	0.	0.	0.
355.	188.	121.	56.	30.	16.	18.	0.	0.	0.
384.	228.	110.	62.	26.	13.	6.	7.	0.	0.
372.	244.	130.	55.	27.	10.	5.	2.	2.	0.
419.	242.	150.	74.	29.	13.	5.	2.	1.	1.
287.	266.	137.	72.	31.	11.	5.	2.	1.	0.
317.	183.	152.	68.	31.	12.	4.	2.	1.	0.
301.	203.	106.	77.	30.	13.	5.	1.	1.	0.
324.	192.	116.	53.	33.	12.	5.	2.	0.	0.
442.	204.	106.	54.	21.	12.	4.	1.	0.	0.
369.	268.	100.	39.	15.	5.	2.	1.	0.	0.
336.	233.	148.	46.	15.	5.	2.	1.	0.	0.
287.	207.	120.	60.	15.	4.	1.	0.	0.	0.
251.	178.	110.	51.	21.	5.	1.	0.	0.	0.
253.	160.	102.	54.	22.	8.	2.	0.	0.	0.
222.	157.	85.	44.	19.	7.	2.	0.	0.	0.
305.	143.	92.	43.	20.	8.	3.	1.	0.	0.
255.	197.	86.	50.	21.	9.	3.	1.	0.	0.

Table 11. As Table 10, but with KPAR(28) set equal to 1.

THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

290.	213.	150.	170.	59.	3.	1.	0.	0.	0.
327.	187.	127.	80.	82.	26.	1.	0.	0.	0.
296.	212.	114.	71.	41.	39.	12.	1.	0.	0.
355.	188.	121.	56.	30.	16.	14.	4.	0.	0.
384.	228.	110.	62.	26.	13.	6.	5.	1.	0.
372.	244.	130.	55.	27.	10.	5.	2.	2.	0.
419.	242.	150.	74.	29.	13.	5.	2.	1.	1.
287.	266.	137.	72.	31.	11.	5.	2.	1.	0.
317.	183.	152.	68.	31.	12.	4.	2.	1.	0.
301.	203.	106.	77.	30.	13.	5.	1.	1.	0.
324.	192.	116.	53.	33.	12.	5.	2.	0.	0.
442.	204.	106.	54.	21.	12.	4.	1.	0.	0.
369.	268.	100.	39.	15.	5.	2.	1.	0.	0.
336.	233.	148.	46.	15.	5.	2.	1.	0.	0.
287.	207.	120.	60.	15.	4.	1.	0.	0.	0.
251.	178.	110.	51.	21.	5.	1.	0.	0.	0.
253.	160.	102.	54.	22.	8.	2.	0.	0.	0.
222.	157.	85.	44.	19.	7.	2.	0.	0.	0.
305.	143.	92.	43.	20.	8.	3.	1.	0.	0.
255.	197.	86.	50.	21.	9.	3.	1.	0.	0.

Table 12. The simulated data set with density-dependent catchability.

THE NUMBER OF FISH AT AGE IS

300.	200.	130.	110.	60.	40.	50.	20.	10.	4.
320.	196.	125.	77.	63.	34.	22.	28.	11.	6.
250.	209.	123.	75.	45.	36.	19.	13.	16.	6.
260.	160.	124.	67.	39.	22.	18.	9.	6.	7.
150.	167.	95.	68.	35.	19.	11.	9.	4.	3.
240.	94.	92.	46.	30.	15.	8.	4.	3.	2.
300.	154.	56.	51.	24.	15.	7.	4.	2.	2.
330.	187.	85.	27.	22.	10.	6.	3.	2.	1.
430.	206.	103.	41.	12.	9.	4.	3.	1.	1.
360.	272.	118.	54.	20.	6.	4.	2.	1.	1.
300.	228.	157.	62.	26.	9.	3.	2.	1.	0.
330.	187.	126.	76.	27.	11.	4.	1.	1.	0.
300.	197.	92.	50.	26.	9.	3.	1.	0.	0.
250.	185.	105.	42.	20.	10.	3.	1.	0.	0.
100.	149.	90.	41.	14.	6.	3.	1.	0.	0.
200.	59.	70.	33.	13.	4.	2.	1.	0.	0.
200.	120.	29.	29.	12.	4.	1.	1.	0.	0.
300.	115.	53.	10.	8.	3.	1.	0.	0.	0.
350.	183.	60.	23.	4.	3.	1.	0.	0.	0.
250.	221.	104.	30.	11.	2.	1.	0.	0.	0.

THE RELATIVE FISHING VULNERABILITY IS

0.135	0.369	0.608	0.781	0.886	0.943	0.973	0.988	0.996	1.000

THE INST. FISHING MORT IS

0.03	0.07	0.12	0.15	0.17	0.18	0.19	0.19	0.19	0.19
0.02	0.07	0.11	0.14	0.16	0.17	0.18	0.18	0.18	0.18
0.05	0.13	0.21	0.27	0.30	0.32	0.33	0.34	0.34	0.34
0.04	0.12	0.20	0.25	0.29	0.30	0.31	0.32	0.32	0.32
0.07	0.19	0.32	0.41	0.47	0.50	0.51	0.52	0.53	0.53
0.04	0.11	0.19	0.24	0.27	0.29	0.30	0.31	0.31	0.31
0.07	0.20	0.33	0.43	0.48	0.51	0.53	0.54	0.54	0.55
0.07	0.19	0.31	0.40	0.46	0.49	0.50	0.51	0.52	0.52
0.06	0.16	0.26	0.33	0.38	0.40	0.41	0.42	0.42	0.42
0.06	0.15	0.25	0.32	0.37	0.39	0.40	0.41	0.41	0.41
0.07	0.20	0.32	0.42	0.47	0.50	0.52	0.53	0.53	0.53
0.12	0.31	0.52	0.67	0.76	0.81	0.83	0.84	0.85	0.85
0.09	0.23	0.39	0.50	0.56	0.60	0.62	0.63	0.63	0.63
0.12	0.32	0.53	0.68	0.78	0.83	0.85	0.86	0.87	0.88
0.13	0.36	0.59	0.75	0.85	0.91	0.94	0.95	0.96	0.96
0.11	0.30	0.49	0.63	0.71	0.76	0.78	0.80	0.80	0.80
0.15	0.42	0.70	0.89	1.01	1.08	1.11	1.13	1.14	1.14
0.09	0.25	0.42	0.54	0.61	0.65	0.67	0.68	0.68	0.69
0.06	0.17	0.27	0.35	0.40	0.42	0.44	0.44	0.45	0.45
0.06	0.16	0.26	0.33	0.38	0.40	0.42	0.42	0.43	0.43

Table 12 (cont'd)

THE DEVIATIONS IN EFF-FISH MORT ARE
-0.01 -0.19 0.12 -0.11 0.03 -0.08 0.00 -0.06 0.04 -0.03
-0.08 0.16 0.00 0.14 -0.03 -0.03 0.14 -0.04 0.07 0.09

THE VALUES FOR DENSITY-DEP. Q FOR EACH YEAR ARE
0.00072 0.00081 0.00093 0.00110 0.00135 0.00154 0.00143 0.00135 0.00115
0.00104
0.00106 0.00112 0.00130 0.00140 0.00182 0.00203 0.00203 0.00187 0.00155
0.00143

RELATIVE STOCK BIOMASS VALUES FOR EACH YEAR ARE
0.597 0.475 0.340 0.167-0.039-0.170-0.093-0.039 0.125 0.222
0.204 0.149-0.001-0.074-0.337-0.447-0.444-0.364-0.173-0.096

THE RELATIVE WEIGHT AT AGE IS
0.350 0.550 0.680 0.780 0.850 0.920 0.960 1.000 1.000 1.000

Table 13. Shown below is the relevant part of the reconstruction analysis done on the data shown in Table 12.

THE VALUE OF THE OBJECTIVE FUNCTION WAS 85.2

THE GPAR VALUES ARE

20.00 10.00 1.00 1.00 0.20 0.40 5.00 0.0010

THE KPAR VALUES ARE

1	30	100	40	1	-1	1	1	0	1
1	0	0	0	0	0	0	0	0	25
1	0	0	0	1	0	0	0		

THE ESTIMATED NUMBERS OF FISH IN THE POPULATION ARE

293.	207.	124.	96.	46.	36.	39.	11.	6.	0.
336.	191.	129.	73.	55.	26.	20.	21.	6.	3.
260.	219.	119.	77.	42.	30.	14.	11.	11.	3.
260.	166.	129.	64.	38.	20.	14.	6.	5.	5.
149.	166.	98.	69.	32.	18.	9.	6.	3.	2.
215.	93.	93.	48.	31.	13.	7.	4.	2.	1.
301.	138.	56.	51.	25.	15.	6.	3.	2.	1.
326.	187.	75.	26.	21.	10.	6.	2.	1.	1.
427.	205.	104.	37.	12.	9.	4.	2.	1.	0.
343.	272.	119.	55.	18.	5.	4.	2.	1.	0.
314.	218.	157.	62.	26.	8.	2.	2.	1.	0.
356.	197.	122.	78.	28.	11.	3.	1.	1.	0.
320.	214.	97.	49.	26.	8.	3.	1.	0.	0.
252.	199.	116.	46.	21.	10.	3.	1.	0.	0.
109.	152.	98.	47.	16.	6.	3.	1.	0.	0.
223.	64.	72.	37.	14.	4.	2.	1.	0.	0.
224.	136.	33.	31.	14.	5.	1.	0.	0.	0.
361.	131.	62.	12.	9.	3.	1.	0.	0.	0.
420.	225.	72.	30.	5.	4.	1.	0.	0.	0.
291.	268.	132.	39.	15.	2.	2.	1.	0.	0.

THE RELATIVE FISHING VULNERABILITY IS

0.112	0.313	0.528	0.696	0.812	0.888	0.937	0.968	0.987	1.000

THE ESTIMATES OF INSTANTANEOUS FISHING MORTALITY ARE

0.027	0.074	0.125	0.165	0.193	0.211	0.222	0.230	0.234	0.237
0.026	0.072	0.121	0.159	0.186	0.203	0.215	0.222	0.226	0.229
0.047	0.131	0.221	0.291	0.340	0.371	0.392	0.405	0.413	0.418
0.047	0.131	0.220	0.291	0.339	0.371	0.391	0.404	0.412	0.418
0.065	0.182	0.306	0.404	0.472	0.516	0.544	0.562	0.574	0.581
0.042	0.118	0.199	0.262	0.306	0.335	0.353	0.365	0.372	0.377
0.076	0.213	0.358	0.472	0.551	0.602	0.635	0.656	0.670	0.678

Table 13 (cont'd)

0.066	0.184	0.310	0.409	0.477	0.522	0.551	0.569	0.580	0.588
0.052	0.145	0.244	0.322	0.376	0.411	0.434	0.448	0.457	0.463
0.052	0.146	0.246	0.324	0.378	0.414	0.436	0.451	0.460	0.466
0.065	0.181	0.305	0.402	0.469	0.513	0.541	0.559	0.571	0.578
0.109	0.305	0.513	0.677	0.790	0.864	0.912	0.942	0.961	0.973
0.076	0.212	0.356	0.470	0.548	0.599	0.632	0.653	0.666	0.675
0.109	0.304	0.512	0.675	0.788	0.862	0.909	0.939	0.958	0.970
0.124	0.347	0.584	0.771	0.899	0.983	1.037	1.071	1.093	1.107
0.092	0.258	0.434	0.572	0.668	0.730	0.770	0.795	0.812	0.822
0.136	0.381	0.642	0.847	0.988	1.080	1.140	1.177	1.201	1.216
0.072	0.201	0.339	0.447	0.522	0.570	0.602	0.622	0.634	0.642
0.046	0.130	0.219	0.289	0.337	0.368	0.388	0.401	0.409	0.415
0.043	0.119	0.201	0.265	0.310	0.339	0.357	0.369	0.376	0.381

THE ESTIMATE OF INSTANTANEOUS NATURAL MORTALITY IS 0.400

THE RELATIVE STOCK BIOMASS EACH YEAR IS

0.333	0.391	0.320	0.117	-0.130	-0.298	-0.233	-0.108	0.257	0.433
0.422	0.301	0.014	-0.134	-0.407	-0.498	-0.459	-0.307	-0.053	0.039

THE ESTIMATES OF AVERAGE FISHING MORTALITY EACH YEAR ARE

0.172	0.166	0.303	0.303	0.421	0.273	0.491	0.426	0.335	0.337
0.419	0.705	0.489	0.702	0.802	0.595	0.881	0.465	0.300	0.276

THE ESTIMATE FOR THE CATCHABILITY IS 0.1552E-02

THE ESTIMATED DENSITY DEPENDENT CATCHABILITY IS

0.1205E-02	0.1153E-02	0.1216E-02	0.1420E-02	0.1714E-02	0.1947E-02
0.1853E-02	0.1685E-02	0.1277E-02	0.1117E-02	0.1126E-02	0.1234E-02
0.1536E-02	0.1718E-02	0.2115E-02	0.2267E-02	0.2201E-02	0.1961E-02
0.1616E-02	0.1507E-02				

THE ESTIMATE FOR THE VARIANCE OF THE EFFORT-FISHING MORTALITY RELATIONSHIP IS 0.01

THE RESIDUALS FOR THE EFFORT -FISHING MORTALITY RELATIONSHIP ARE

-0.256	-0.247	0.118	-0.037	-0.050	-0.049	0.027	-0.090	0.092	0.089
0.009	0.256	-0.041	0.104	0.028	-0.051	0.188	-0.084	0.008	-0.005

APPENDIX A

This appendix decribes the 28 KPAR variables in detail. Once these are read in, the model converts them to IPAR variables as discussed in Appendix C.

KPAR(1) - maximum number of function evaluations before the run terminates. Usually this number is kept low (20 or so) until some progress has been made with the minimization and until all the options have been added to the analysis. Then KPAR(1) is increased to the 60-100 range to allow enough function evaluations to find the minimum.

KPAR(2) - the number of iterations of the function minimizer between printout of intermediate results. If this number is larger than KPAR(1), one will only see the final results on the terminal screen. If smaller, one may see some intermediate results displayed on the screen (if the number of iterations reaches KPAR(2)). An iteration only occurs at a particular function evaluation if the minimizer has made some progress at that evaluation (i.e. if the change that was made in the parameters results in a lower function value). Therefore, the number of iterations is always less than or equal to the number of evaluations. Also, once the model has reached a minimum, additional runs will result in more function evaluations but no more iterations since no progress can be made.

KPAR(3) - estimate of amount of decrease in the log-likelihood function. This determines the initial step size that the program takes, and is generally set at 100 and subsequently ignored. However, should the model have trouble making progress right from the very start, the user can try a smaller value than 100, as discussed in section 6.2.

KPAR(4) - maximum number of function evaluations without an iteration before terminating the run. This is usually set quite high (around 40) since one wants to give the model as much chance as possible to find a direction in which it can further minimize the objective function. If this KPAR is set low the model doesn't have enough opportunity to explore around its current position to find which direction it can go to find a lower function value; that is, the model isn't allowed to do enough function evaluations to determine which parameters (if any) it can vary to lower the objective function. As an aside, a summary is presented here of the usual ways a particular run is terminated:

i. the minimizer is still making progress, but the number of function evaluations reaches that determined by KPAR(1). The message displayed on the screen is "MAXIMUM NUMBER OF FUNCTION EVALUATIONS EXCEEDED" and this is followed by coordinate and gradient values. The displayed values of the flag variables IEXIT and IHANG are 3 and 0 respectively.

ii. a "FUNCTION MINIMIZER NOT MAKING ENOUGH PROGRESS" message indicates that the minimizer has gone through a period of 10 evaluations without decreasing the function value by more than 0.01 over that period. Flag values are IEXIT=1 and IHANG=1, and no coordinate or gradient values are displayed on the terminal screen.

iii. if the number of function evaluations exceeds KPAR(4) without an iteration, then the message "PROGRAM CAME TO NORMAL TERMINATION"appears and no coordinate or gradient values are displayed. Flag values are IEXIT=1 and IHANG=0. On rare and unfortunate occasions,some other error messages may be displayed. The reader is referred to subroutine FMIN of the FORTRAN code in these cases.

KPAR(5) - if zero, no results are printed into the output file (unit 18). If 1, then only the final estimates for the run are printed into unit 18. If 2, both initial and final estimates are printed out one after another in unit 18. The usual value for this KPAR is 1.

KPAR(6) - the number of function evaluations after which the derivative checker will be invoked. The program will ask the user which parameter is to have its derivative checked. This option is only used for debugging the program and for most users this value can be set to -1.

KPAR(7) - this is set to zero for an initial start on a particular analysis. After a run of a fairly small number of evaluations to get the procedure started, this KPAR value is set to 1 for a restart to enable the model to continue minimizing from where it left off on the previous run.

KPAR(8) - if zero, sample sizes for age structure of the catch each year are taken to be exactly as supplied in the input data. If nonzero, then each age sample size is set equal to 400/KPAR(8) with the following exceptions: if the sample size in any year is <100, it is not scaled - since we want to tell the model that the age structure for that particular year is relatively inaccurate; if the sample size is ≤ 3 in any year, the age structure for that year is assumed equal to the average of the immediately preceding and immediately following years since the data supplied is considered insufficient to establish a reliable age structure for that year (after averaging, sample size scaled to 400). If the user has a sample size greater than 3 but has very little confidence in the sample, then he/she can calculate by hand the average of the preceeding and following years and feed this in as input data, scaled to whatever sample size the user feels is appropriate. This can also be done if the user has no catch at age data for a particular year.

The basic effect of this scaling is that the model will tend to vary more those years with smaller sample sizes if such a change is deemed necessary given all else the model is dealing with.

KPAR(9) - number of years over which ageing errors can be spread (must be 1, 3, or 5). This is used in conjunction with KPAR(12). A value of 3 means the apparent age is within 1 year of the true age; a 5 means that it is within 2 years of the true age (i.e. the spread is true age + 2).

KPAR(10) - if set to zero, then the catch from the last age class (r) in any year i is as follows (from standard catch equation):

$$C(i,r)=(F(i,r)/Z(i,r))*N(i,r)*(1-\exp(-Z(i,r)))$$

This plus deaths due to natural mortality should reduce the number of surviving fish to a very low number since there are no fish older than this in the catch. If there were, then r would not be the oldest age class in the data set. To help reduce the number of survivors from this last age class, the following equation is used when KPAR(10)=1:

C(i,r)=(F(i,r)/Z(i,r))*N(i,r)

Setting KPAR(10) to 1 is usually sufficient to prevent large numbers of fish from reaching the oldest age class since if they do, the resulting catch will be large and therefore not agree with the input catch-at-age data. Again, if there is a large catch for the oldest age class in the input data, then r is probably not the oldest age in the catch.

Therefore, the user should set KPAR(10) to 1 and this will usually keep the estimated number of fish in the oldest age class at less than 1% of the total for that year. If not, then there is cause for concern as the model may be finding a false minimum where many fish are surviving past the oldest age seen in the catch. This can be corrected by using KPAR(26) (see later).

KPAR(11) - if zero, there is no effort information. If nonzero, there is effort information and the penalty for the effort-F relationship in the last year's data is multiplied by KPAR(11). This KPAR is usually set to 1.

KPAR(12) - if zero, then model assumes there are no ageing errors in the input catch at age data. If 1, then the model will expect to see in the input data an estimate of the ageing errors involved. These errors are given for each age class and are assumed to be the same in each year of the time series. Note that the extent of the error cannot exceed 2 years (see KPAR(9)); reasons for this are discussed in the section dealing with the ageing error option.

KPAR(13) - if not equal to 1, there is no stock-recruit relationship. If equal to 1, then the model assumes a stock-recruit relationship exists and KPARs 14, 15, and 16 must also be set.

KPAR(14) - this is the first age class entering into the stock-recruit relationship (first one contributing to reproduction). This is not absolute age, but the number of the age class in the input data (#1=youngest age class).

KPAR(15) - weight for the stock-recruit relationship: 10 is a good fit, 2 is a bad fit or a very weak relation between stock and recruitment. Difficulty may result here from a "2" as there isn't enough weight to drive the relationship. If this difficulty is encountered, try changing this KPAR to 3 or 4 (see section 5.1).

KPAR(16) - age of fish at recruitment. This is the absolute age of fish in the youngest age class of the data set.

KPAR(17) - if zero, catchability is assumed to be time-independent. If 1, then time-dependent catchability is estimated with the log of catchability assumed to change linearly over time. If 2, then the log of catchability is assumed to change in a sigmoid fashion over time with the inflection point halfway through the time series. For the exact equations describing the above, refer to the section on time-dependent catchability in the text (section 5.3) or see the FMORT1 subroutine in the FORTRAN code listing. If the user feels that neither of these two time-dependent trends adequately describes his particular situation, additional equations can be incorporated by making suitable modifications to the FMORT1 subroutine of the FORTRAN code for the model.

KPAR(18) - number of the first age class (#1 = youngest age class in data) used in computing average fishing mortality for each year. This is simply used for comparison of average fishing mortality between years, and is a straightforward arithmetic average of the F values of the oldest IR-KPAR(18)+1 age classes in each year (IR is the number of age classes in the data). If KPAR(18) is zero, the model interprets this as a 1.

KPAR(19) - this number of last age classes are grouped together in the input data. Usually done when ageing of older fish is inaccurate or very time consuming and the user wants them grouped into an "older fish" category. A zero here is interpreted as a 1 which means no grouping. If KPAR(19) is set equal to a number other than zero or 1, then KPAR(26) must also be set to provide a proper penalty weight for preventing large numbers of fish from reaching the oldest age class (see section 5.5).

KPAR(20) - if zero, the average level of F in each year is exactly related to the effort. If nonzero, KPAR(20) is the penalty weight for deviations from the level of average F determined by the effort. The larger KPAR(20) the closer the average F is forced to stay to the levels determined by effort. A suggested value here is 25 which corresponds to a variance of 0.02 in the log of the effort-F relationship [1/(2*variance)=KPAR(20)].

KPAR(21) - if nonzero, then the so-called VB parameterization of fishing mortality is used. See Fournier and Archibald (1982) for details.

KPAR(22) - if nonzero, then the Doubleday parameterization of F is used where the F of each age class is essentially independent of other age classes. See Fournier and Archibald (1982) for details.

KPAR(23) - total catches are divided by this number. Used when the estimated numbers at age are too great to fit in the output format. The only difference in the analysis and in the output is that the estimated numbers at age printed out have been divided by KPAR(23). If zero, the model interprets it as a 1.

KPAR(24) - if nonzero, then an environmental factor is included in the stock-recruit relationship. See section 5.2.

KPAR(25) - if not zero, then density-dependent catchability is estimated (see section 5.6).

KPAR(26) - this KPAR divided by 10 is the penalty weight used on the likelihood function to prevent too many fish from reaching the oldest age class. It is used when KPAR(10)=1 is not sufficient to prevent this, and also when the grouping option is invoked (KPAR(19).GT.1). A value of 1 is usually high enough for this KPAR, and higher values should be avoided unless absolutely necessary, since anomalous answers often result if too much weight is applied here.

KPAR(27) - if nonzero, then the variance of the total catch estimates is set equal to 0.5/KPAR(27). If zero, KPAR(27) defaults to 200 and the variance to 0.0025 (0.5/200).

KPAR(28) - if set to 1 when some of the age classes are grouped (KPAR(19).GT.1), then the output shows how the model has distributed the fish in the grouped age classes. This is only used to check that the weight in KPAR(26) is high enough to prevent large numbers of fish from reaching the oldest age class. For more detail, see the section on grouping the older age classes (section 5.5).

APPENDIX B

The FORTRAN code for the catch-at-age model is separated into 12 files to allow for easier manipulation and quicker compilation should any changes be made to parts of the code. The first part of this appendix lists the file names as well as the subroutines and functions that each file contains; the second part provides brief descriptions of each subroutine. These files containing FORTRAN code must of course be individually compiled and then all linked together in order to generate the executable form of the model (as in RECONS.EXE).

FILE	SUBROUTINES	FUNCTIONS
PCOMPS.FOR	BETCAL	DFEXP4
	BETDER	FFPOLY
	DENSFM	FMPOLY
	DERCAL	
	DERCOR	
	DFMCA1	
	DFMCAL	
	DFMCAL1	
	FCOMP	
	FMCAL	
	PHICAL	
PFMIN.FOR	FMIN	
PHESSAP.FOR	HESSAP	IND
PIO.FOR	ANNAD	DFEXP2
	BIOCAL	DFEXP3
	DATPRI	
	ERRPRT	
	GETFMM	
	GETIN	
	SRSUM	
	XSAVE	
PIO1.FOR	GETX1	
PIO2.FOR	GETX	
PNEWCOMPS.FOR	AERCAL	
	ERRDER	
	GETAER	
	NOERR	

PNOERR.FOR	ERRDE1	
	GETAE1	
PREC.FOR	FECAV	ENVFUN
	SRFUN	FECFUN
		RICFUN
PREC1HER.FOR	SPFUN	
	SPPEN	
	SRHFUN	
PSC.FOR	FJCOMP	ACAL
	FMORT	DFJSC1
	FMORT1	DFLOG
	FMORT2	DFPOW
	FMORT71	DFSGN
	SCDER	HFMFUN
	SCOMP	ICOH
PSOURCE.FOR	DERCH	DFATAN
	DOPTN2	DFEXP
	GETX5	DFSQRT
	MAIN	DFTDER
	NVARCAL	DFTINV
	OPTN2	
	ORTHOG	
	RESET	
	SETUP	

A brief description of the function of each subroutine follows, with the subroutines presented in the same order as above:

FILE PCOMPS.FOR

SUBROUTINE BETCAL - THIS ROUTINE EXPRESSES THE FIRST (N-1) BY (IR-1) POPULATION PERCENTAGES IN TERMS OF THE OTHER VARIABLES

SUBROUTINE BETDER - CALCULATE THE DERIVATIVES WITH RESPECT TO BETA WHEN THERE ARE NO AGEING ERRORS

SUBROUTINE DENSFM - ADDITIONAL DERIVATIVE CALCULATIONS WHICH ARE INVOKED UNDER CERTAIN OPTIONS; CALLED FROM SUBROUTINE DERCAL.

SUBROUTINE DERCAL - THIS SECTION CALCULATES ALL THE NECESSARY DERIVATIVES BY A LONG SERIES OF CHAIN RULE CALCULATIONS

SUBROUTINE DERCOR - DERIVATIVE CONTRIBUTIONS FOR REMOVING COVARIANCE

SUBROUTINE DFMCA1 - SAME AS COMMENT FOR SUBROUTINE DENSFM

SUBROUTINE DFMCAL - SAME AS COMMENT FOR SUBROUTINE DENSFM

SUBROUTINE DFMCAL1 - SAME AS COMMENT FOR SUBROUTINE DENSFM

SUBROUTINE FCOMP - THIS CALCULATES THE OBJECTIVE FUNCTION

SUBROUTINE FMCAL - CALCULATES NATURAL AND FISHING MORTALITES AND THEIR LOGS

SUBROUTINE PHICAL - INTERMEDIATE FUNCTION USED IN ELIMINATING POPULATION PERCENTAGES

FILE PFMIN.FOR

SUBROUTINE FMIN - THIS SUBROUTINE IS THE FUNCTION MINIMIZER

FILE PHESSAP.FOR

SUBROUTINE HESSAP - FORMERLY WAS USED TO CALCULATE ASSYMPTOTIC COVARIANCE MATRIX, BUT THIS IS NOT USED IN THE CURRENT VERSION OF THE MODEL.

FILE PIO.FOR

SUBROUTINE ANNAD - THIS SUBROUTINE IS NOT USED IN THE CURRENT VERSION OF THE MODEL.

SUBROUTINE BIOCAL - THIS SUBROUTINE DEALS WITH RELATIVE STOCK BIOMASS IF KPAR(25) IS ACTIVATED.

SUBROUTINE DATPRI - THIS SUBROUTINE PRINTS OUT FINAL ESTIMATES AND OTHER INFORMATION

SUBROUTINE ERRPRT - THIS SUBROUTINE PRINTS OUT ERROR MESSAGES IN THE EVENT OF CERTAIN ERRORS OCCURRING.

SUBROUTINE GETRMM - THIS SUBROUTINE IS CALLED IF ACTUAL DEVIATIONS ARE READ IN FROM A SIMULATOR. THIS OPTION (CONTROLLED BY IPAR(43), (SEE APPENDIX C) IS NO LONGER OPERATIONAL.

SUBROUTINE GETIN - THIS SUBROUTINE READS IN THE INPUT DATA FROM UNIT (OR OP LABEL) 10. ALSO READS IN RELATIVE WEIGHTS FROM UNIT 9 IF DEALING WITH KPAR(25).

SUBROUTINE SRSUM - PRINTS OUT STOCK-RECRUITMENT RESULTS INTO OUTPUT FILE IF THE STOCK-RECRUIT OPTION IS ACTIVATED.

SUBROUTINE XSAVE - THIS SUBROUTINE SAVES THE RESULTS ON OP LABEL 15 (UNIT 15).

FILE P101.FOR

SUBROUTINE GETX1 - IF RUN IS AN INITIAL RUN, THIS SUBROUTINE SETS UP INITIAL VALUES FOR PARAMETERS.

FILE P102.FOR

SUBROUTINE GETX - IF RUN IS A RESTART RUN, THIS READS IN OLD VALUES OF PARAMETERS (FROM UNIT 13). THE LATTER PART OF THIS SUBROUTINE (FROM THE COMMENT "SET UP INITIAL X VALUES" ONWARD) SETS THE PARAMETER VALUES EQUAL TO X VALUES; THIS CREATES THE X VECTOR WHICH IS HOW THE MODEL DEALS WITH THE PARAMETERS INVOLVED IN A PARTICULAR RUN.

FILE PNEWCOMPS.FOR

SUBROUTINE AERCAL - DEALS WITH A SPECIFIC AGEING ERROR OPTION THAT IS NOT OPERATIONAL IN THE CURRENT VERSION OF THE MODEL.

SUBROUTINE ERRDER - THIS SUBROUTINE CALCULATES THE DERIVATIVES WITH RESPECT TO THE AGEING ERRORS AND THE POPULATION PERCENTAGES.

SUBROUTINE GETAER - DEALS WITH A SPECIFIC AGEING ERROR OPTION THAT IS NOT OPERATIONAL IN THE CURRENT VERSION OF THE MODEL.

SUBROUTINE NOERR - THIS SUBROUTINE ADDS LIKELIHOOD CONTRIBUTION FOR OBSERVED AGE STRUCTURE WHEN THERE ARE NO ERRORS IN AGEING.

FILE PNOERR.FOR

SUBROUTINE ERRDE1 - THIS SUBROUTINE CALCULATES THE DERIVATIVES WITH RESPECT TO THE AGEING ERRORS AND POPULATION PERCENTAGES.

SUBROUTINE GETAE1 - CALCULATES APPARENT AGE STRUCTURE FROM THE TRUE AGE STRUCTURE USING THE GIVEN AGEING ERRORS.

FILE PREC.FOR

SUBROUTINE FECAV - FORMERLY CALCULATED AVERAGE FECUNDITY FOR GROUPED AGE CLASSES (IF KPAR(19).GT.1), BUT NO ONGER USED IN CURRENT VERSION OF MODEL.

SUBROUTINE SRFUN - THIS SUBROUTINE CALCULATES LIKELIHOOD CONTRIBUTION FOR STOCK RECRUITMENT RELATIONSHIP AND THE NECESSARY DERIVATIVES.

FILE PREC1HER.FOR

SUBROUTINE SPFUN - THIS SUBROUTINE CALCULATED LIKELIHOOD CONTRIBUTION FOR STOCK RECRUITMENT RELATIONSHIP AND THE NECESSARY DERIVATIVES. THIS IS NOT OPERATIONAL IN CURRENT VERSION OF MODEL.

SUBROUTINE SPPEN - DEALS WITH A HERRING RECRUIT OPTION THAT IS NOT OPERATIONAL IN THIS VERSION OF THE MODEL.

SUBROUTINE SRHFUN - SAME COMMENT AS FOR SUBROUTINE SPFUN.

FILE PSC.FOR

SUBROUTINE FJCOMP - SUBROUTINE TO COMPUTE SCALED AGE CLASS INDICES.

SUBROUTINE FMORT - SUBROUTINE TO CALCULATE FISHING MORTALITIES WITH SCALING OF AGE CLASS NUMBER; CALLED FROM SUBROUTINE FMCAL WHEN CERTAIN OPTIONS ARE ACTIVE.

SUBROUTINE FMORT1 - SAME COMMENT AS FOR SUBROUTINE FMORT.

SUBROUTINE FMORT2 - SAME COMMENT AS FOR SUBROUTINE FMORT.

SUBROUTINE FMORT71 - SAME COMMENT AS FOR SUBROUTINE FMORT.

SUBROUTINE SCDER - SUBROUTINE TO COMPUTE DERIVATIVES WITH RESPECT TO COEFFS OF POLYNOMIAL INTERPOPLATING THE SCALING FACTOR.

SUBROUTINE SCOMP - SUBROUTINE FOR CALCULATING SCALING PARAMETER AS A POLYNOMIAL IN THE FISHING YEAR.

FILE PSOURCE.FOR

SUBROUTINE DERCH - THIS CHECKS THE DERIVATIVES.

SUBROUTINE DOPTN2 - THIS SUBROUTINE IS NOT USED IN THE CURRENT VERSION OF THE MODEL.

SUBROUTINE GETX5 - THIS SUBROUTINE WAS FORMERLY CALLED WHEN THE X VECTOR WAS READ IN DIRECTLY, BUT THIS OPTION IS NO LONGER OPERATIONAL.

SUBROUTINE MAIN - THIS IS THE MAIN SUBROUTINE WHICH, DIRECTLY OR INDIRECTLY, CALLS ALL THE OTHER SUBROUTINES.

SUBROUTINE NVARCAL - THIS DETERMINES HOW MANY VARIABLES THE RUN WILL HAVE.

SUBROUTINE OPTN2 - THIS SUBROUTINE IS NOT USED IN THE CURRENT VERSION OF THE MODEL.

SUBROUTINE ORTHOG - THIS SUBROUTINE SETS UP THE ORTHOGONAL POLYNOMIALS FOR THE INSTANTANEOUS MORTALITIES.

SUBROUTINE RESET - THIS SUBROUTINE IS CALLED BY SUBROUTINE FMIN AND IS INVOLVED WITH INFORMING FMIN WHICH PARAMETERS ARE BEING ALLOWED TO VARY IN A PARTICULAR RUN.

SUBROUTINE SETUP - SETS UP GRADIENT AND XVALUES FOR FUNCTION MINIMIZER.

APPENDIX C

Appendix A describes the 28 KPAR variables which control the characteristics and options for each run. The catch-at-age model described here was developed and improved upon over a period of several years, and so the FORTRAN code for the model still contains some options left over from earlier versions. In most cases these options are no longer operative or are no longer considered applicable, and so they have not been discussed in this guide.

All options (both those included in this guide and those omitted) are interpreted by the code in terms of 80 IPAR variables, not 28 KPAR variables. The IPAR variables for those options discussed in this guide have been set equal to certain KPAR variables for ease of input. The remaining IPAR variables (which control options either not operational or not considered in this guide) have been set at fixed values by the GETIN subroutine of the program. The meaning of each IPAR variable is shown at the start of the file PSOURCE.FOR.

Thus, one need only consider IPAR variables when one wishes to work with the actual FORTRAN code for the model, and then it is necessary to know the relationship between KPAR and IPAR variables and the default values for the IPARs not covered by KPAR variables. Also, since the model renames the GPAR variables, it is necessary to know the new names here. All this is shown at the beginning of the GETIN subroutine, and is summarized below.

<u>The IPAR variables</u>

The model reads in 28 KPAR variables and sets them equal to IPAR variables as noted below. The remaining IPAR variables are set equal to default values as noted below.

IPAR(1)=KPAR(1)	IPAR(21)=KPAR(10)	IPAR(41)=0	IPAR(61)=0
IPAR(2)=KPAR(2)	IPAR(22)=KPAR(11)	IPAR(42)=0	IPAR(62)=KPAR(24)
IPAR(3)=KPAR(3)	IPAR(23)=KPAR(12)	IPAR(43)=0	IPAR(63)=0
IPAR(4)=KPAR(4)	IPAR(24)=KPAR(13)	IPAR(44)=0	IPAR(64)=KPAR(25)
IPAR(5)=KPAR(5)	IPAR(25)=KPAR(14)	IPAR(45)=0	IPAR(65)=0
IPAR(6)=KPAR(6)	IPAR(26)=KPAR(15)	IPAR(46)=KPAR(19)	IPAR(66)=0
IPAR97)=KPAR(7)	IPAR(27)=KPAR(16)	IPAR(47)=0	IPAR(67)=0
IPAR(8)=0	IPAR(28)=KPAR(17)	IPAR(48)=0	IPAR(68)=0
IPAR(9)=2	IPAR(29)=KPAR(18)	IPAR(49)=KPAR(20)	IPAR(69)=0
IPAR(10)=0	IPAR(30)=0	IPAR(50)=0	IPAR(70)=0
IPAR(11)=0	IPAR(31)=0	IPAR(51)=0	IPAR(71)=0
IPAR(12)=KPAR(8)	IPAR(32)=0	IPAR(52)=0	IPAR(72)=0
IPAR(13)=0	IPAR(33)=0	IPAR(53)=0	IPAR(73)=KPAR(26)
IPAR(14)=1	IPAR(34)=0	IPAR(54)=0	IPAR(74)=0
IPAR(15)=0	IPAR(35)=0	IPAR(55)=KPAR(21)	IPAR(75)=0
IPAR(16=0	IPAR(36)=0	IPAR(56)=KPAR(22)	IPAR(76)=0
IPAR(17)=KPAR(9)	IPAR(37)=0	IPAR(57)=0	IPAR(77)=KPAR(27)
IPAR(18)=0	IPAR(38)=0	IPAR(58)=0	IPAR(78)=KPAR(28)
IPAR(19)=0	IPAR(39)=0	IPAR(59)=0	IPAR(79)=0
IPAR(20)=0	IPAR(40)=1	IPAR(60)=KPAR(23)	IPAR(80)=0

The GPAR variables

Once the eight GPAR variables are read in, the model renames them as follows:

```
N=GPAR(1)          FIRSTF=GPAR(5)
IR=GPAR(2)         FIRSTM=GPAR(6)
IRSAME=GPAR(3)     FMAXFM=GPAR(7)
INSAME=GPAR(4)     FMINFM=GPAR(8)
```