76-04

Fishery Management Biology Investigation

Northeast Fisheries Center

Woods Hole, Massachusetts 02543

Computer Programs for Fish Stock Assessment

Compiled by the FMB ADP Needs Committee

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Introduction

The following manual is intended to provide personnel at the Northeast Fisheries Center with a package of programs which can be readily accessed and used for fish stock assessment. This package consists of programs written both by Fishery Management, Biology Investigation personnel and by researchers at other laboratories; all have been used extensively both at NEFC and elsewhere and are thought to be free from error. It will be appreciated if problems arising in use of these programs are reported to the ADP Needs Committee; suggestions for addition or deletion will also be welcomed.

The package of programs we have assembled consists of three units; programs in the first two of these units are covered in this manual. Unit I consists of programs which are frequently used in ICNAF stock assessment work and can be run on the terminal in conversational mode or may be "batched" or run at the WHOI Computer Center using data decks and appropriate control cards. Unit II contains programs which would not be used routinely but may prove useful for certain types of assessment work; these are not stored in conversational mode but may be "batched" or run from card decks, as above. The final unit (III) includes programs written for rather specialized population dynamics studies which normally would not be used at NEFC; most of these have not been made compatible with the Sigma 7 system, but decks and documentation are on file and most could be made operational in a relatively short time if necessary.

Programs in these three units are listed below. For programs in Units I and II, write-ups are provided giving references, descriptions, and instructions for use. This material will be periodically revised and updated as new programs and techniques become available.

Unit I - "Conversational" Programs*

All programs are stored as files under the prefix "FMB," *e.g.* FMBGNPD, FMBPRDF, etc. To provide the conversational mode option, additional files were required; these may be accessed by typing the letter "C" after the file name (*e.g.* the file FMBGNPDC allows the user to run GENPROD in conversational mode, or jobs may be "batched" using file FMBGNPD. This is true of all programs in this group except the virtual population and prediction programs which run exclusively in conversational mode on both the WHOI and RAMUS systems. Note also that all of the above files are stored in Account 345 at the WHOI Center and must be accessed from this account before being run.

File Name	Program and Description	Page
FMBGNPD	GENPROD--fits the generalized stock production model $dP/dt = HP^m - KP - FP$ to catch and effort data; estimates equilibrium yield as a function of effort. The parameter m can vary but running averages of effort cannot be calculated internally within the program.	9

*Terminal accessing instructions are given on page 94.

Unit I - "Conversational" Programs (continued)

File Name	Program and Description	Page
FMBPRDF	PRODFIT--fits the generalized stock production model to catch and effort data; estimates equilibrium yield as a function of effort. The parameter m may be estimated or fixed at 2 (logistic model), 1 (Gompertz model) or 0 (asymptotic yield model). Running averages of effort may be calculated internally within the program.	18
FMBPRED	"Prediction" Program--predicts stock size and catch by age groups and year given stock at age in any initial year and recruitment and mortality estimates.	27
FMBRIKR	FRG 708 (Piece-wise Integration of Yield Curves)--provides equilibrium yield for a given recruitment using Ricker's method. This program is extremely general in that time-intervals may vary and multipliers may be used to adjust F in terms of partial recruitment.	44
FMBVBRT	BGC 2 (von Bertalanffy fit)--fits the von Bertalanffy growth in length curve to equally spaced age groups with unequal sample sizes.	58

File Name	Program and Description	Page
FMBVPOP	Virtual Population Analysis--estimates F, μ (exploitation rate), and initial population size by year for a given cohort given catch at age data, natural mortality, and a starting F value (for the oldest age fished). Time intervals must be equally spaced, and catch data must be available for all time periods.	62
FMBYPCT	Yield Per Recruit--provides equilibrium yield for a given recruitment using Beverton and Holt's method. The model is less flexible than Ricker's in that F is considered constant over the fishable life span and "knife-edge" recruitment is assumed; also, b in the length-weight equation is assumed equal to 3.	64

Unit II

Programs in this unit are stored as files under the prefix "Y9," *e.g.* Y9CTCV, Y9FPOW, etc. All may be "batched" or run from card decks at WHOI using the proper file name. Again, all files are stored in Account 345 and must be brought into the user's account before being run.

File Name	Program and Description	Page
Y9CHRT	COHORT--estimates F, μ (exploitation rate), and initial population size by year for a given cohort given catch at age data, natural mortality, and a starting F value. Time intervals may vary and catches may be 0 for a given interval; different sets of M and starting F values may be examined.	68
Y9CTCV	FRG 705 (Catch-curve)--computes mortality and survival rates and a variety of associated statistical measures for vectors of catch at age data.	71
Y9FPOW	FR 731 (Fishing Power)--computes relative fishing power, relative population density, confidence intervals, and corrections for bias.	77

Unit II Programs (continued)

File Name	Program and Description	Page
Y9VBPD	Predicts length at age given parameters of the von Bertalanffy growth equation; allows computation and use of a weighted t_0 estimate.	84
Y9YPER	YPER--uses a modification of the Beverton-Holt yield equation to produce relative yield per recruit isopleths for different E ($F/_{F+M}$) and C (l_c/l_∞) values as a function of M and K.	86
Y9YPIB	FRG 701 (Yield Per Recruit)--uses the incomplete beta function to produce an array of coordinates for plotting yield isopleths. The model assumes F constant over the fishable life span and "knife-edge" recruitment; however, b in the length-weight equation can be other than 3.0.	90

Unit III

In the past this group of programs has had little if any application at NEFC; however, card decks and documentation are available should the need arise. Programs follow:

Program	Description
Chapman-Junge Analysis	Estimates size of "stratified" populations from mark-recapture data.
Chapman-Richards Growth Curve	Computes a growth curve by a modification of the Brody-von Bertalanffy relationship which includes an additional parameter controlling the position of the inflection point.
GXPOPS	Simulates trends in exploited populations under differing assumptions of growth, mortality, maturation, and reproductive success.
Jolly-Seber Analysis	Computes estimates of mortality and population size from mark-recapture data using Jolly's stochastic model.
MGEAR	Computes yield per recruit estimates for fisheries exploited by several gears with differing vectors of age-specific fishing mortality, using Ricker's model.

Unit III Programs (continued)

Program	Description
MURFR2	Computes estimates of F and initial population size for a given cohort for varying time intervals, given mortality and catch at age data.

Program: GENPROD (FMBGNPD, FMBGNPDC)

Programmers: J. J. Pella and P. K. Tomlinson, Operations Research Branch, California Fish and Game Department, Terminal Island, California

References: Pella, J. J. and P. K. Tomlinson. 1969. A generalized stock production model. Bull. Inter-Am. Trop. Tuna Comm. 13:419-496.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191. 382 pp.

Description: Program FMBGNPD fits the generalized stock production model

$$dP/dt = HP^m - KP - FP$$

where

P = average stock biomass;

K = instantaneous rate of stock increase at densities approaching zero;

F = qf, catchability multiplied by fishing effort;

H = K/P_{max}, where P_{max} equals maximum stock size, and

m = an arbitrarily selected exponent determining the shape of the yield curve.

An iterative procedure is used in which trial values of f_{opt} (optimum fishing effort), q (catchability), r (simple correlation coefficient), and U_{max} (maximum catch/effort) are read in and changed in steps (Δ) are determined by the user until the sum of squares is minimized.

Note that fitting the above model requires estimation of a number of parameters; consequently, numerous iterations are necessary and unless reasonable constraints are placed on m the estimates obtained may be completely unrealistic (Ricker, 1975). This is particularly true for estimates of q (which may be suspect no matter what constraints are placed on m). The user should consult Pella and Tomlinson's paper before attempting to run GENPROD.

Hints on Running GENPROD[1]

When the addition or subtraction of ΔF, ΔQ, Δr, or ΔU fails to reduce the sum of squares, the Δ's are divided by 10 and the process repeated. The number of times the Δ's are divided by 10 (KK) is controlled by the user. The best estimates of the parameters f_{opt}, q, r, and u_{max} are those corresponding to the minimum value of sum of squares found.

Since guesses are required when using GENPROD, some hints for evaluating these are appropriate. The general situation is depicted as one in which data (catch and effort) are distributed over a range of population sizes, including the optimum. The technique suggested is to choose fopt equal to the mean of the observed efforts; choose Umax equal to the maximum observed catch-per-effort; choose Pmax equal to 4 times the maximum observed catch and set Q equal to Umax divided by Pmax; choose r equal to 0.8. The lower bounds of Fopt and Umax are set at 1/10 the guesses and the upper bounds are set at 10 times the guesses. The bounds of Q should be more liberal, say 1/100 and 100 times. The bounds of r are obviously 0 and 1. The values for the Δ are simply set equal to the guesses.

Of course, if it is known that the catch-effort data were obtained from a segment of the range of population sizes, then the guessing process must be modified. If serious doubt exists, one should make guesses as suggested at the same time set very wide bounds and utilize relatively large Δ's for a quick search across the range. If any of the final estimates equal a bound, the data should be rerun with wider bounds. As for the values of m, it is appropriate to choose a range of values greater than 0 but less than 4 (m = 1 must be excluded). If little is known about the shape of the production curve, try 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, and 3.2 for a first run, then try additional values when the approximate range is determined by examining the values of S.

[1]Source: unpublished report on file at the NMFS Southwest Fisheries Center, La Jolla, Calif.

Notation

(1)	(2)	(2)
m	M	(exponent in GENPROD model)
F_{opt}	FOPT	(optimum fishing effort)
U_{max}	UMAX	(maximum catch/effort)
Q	Q	(catchability)
P_o	P(0)/PMAX	(Initial population/Max population)
C_{max}	CMAX	(maximum equilibrium yield)
P_{opt}	POPT	(optimum stock size)
P_{max}	PMAX	(maximum stock size)
H	H	(K/P_{max})
K	K	(instantaneous rate of stock increase)
S	SUM OF SQUARES	
R	R	(correlation coefficient)
$\sum^{n} C_i$	TOTAL CATCH	
$\sum^{n} \frac{1}{n} C_i$	AVERAGE CATCH	
t	AT TIME	
P_i	POPULATION SIZE	
E_i	APPLIED EFFORT	
C_i	OBSERVED CATCH	
$\hat{C}_i$	EXPECTED CATCH	
U_i	OBSERVED CATCH/EFFORT	
$\hat{U}_i$	EXPECTED CATCH/EFFORT	

Column (1). Used by Pella and Tomlinson (1969).

Column (2). Used in program output.

Program GENPROD may be run on the WHOI system in interactive mode by logging on and entering "PLATEN 132" followed by "RUN FMBGNPDC.345" when prompted by "!". The user then enters alphameric information, control values (note that the number of parameters to be estimated = 4), catch and effort data[1], and best guesses and limits for f_{opt}, q, r, and U_{max} as suggested above. Program GENPROD may also be run using card decks or on the terminal in "batch" mode. In the former case, the following control cards are required.

```
!JOB 712, - - - - (USER ID)
!LIMIT (TIME,2),(CORE,10)
!ASSIGN F:5,(DEVICE,SI)
!ASSIGN F:6,(DEVICE,LO)
!LOAD (EF,(FMBGNPD,345))
!RUN
!DATA
```

Data input consists of the following:

Set #1 (Title)	1 card		FORMAT (20A4)
	Cols. 1-80:		Header card with alphameric information.

[1]When typing more than one line of data, the user is cautioned to omit the final comma on each line; otherwise a "0" value will be erroneously generated internally.

Set #2 1 card (Intervals)

		FORMAT (3I4, 4F10.0)
	Cols. 1-4:	Number of catch intervals (ND). Right justify with no decimal.
	Cols. 5-8:	Numeral 4 punched in column 8.
	Cols. 9-12:	Number of times (KK) the step intervals (DEL) are divided by 10. The larger this value, the greater execution time--but answers contain more significant digits. If in doubt, try 3. Right justify with no decimal.
	Cols. 13-22*	Starting step (DEL(1)) for X(1) = fopt. If in doubt, leave blank. Punch decimal.
	Cols. 23-32*	Starting step for X(2) = Q. If in doubt, leave blank. Punch decimal.
	Cols. 33-42*	Starting step for X(3) = r. If in doubt, leave blank. Punch decimal.
	Cols. 43-52*	Starting step for X(4) = Umax. If in doubt, leave blank. Punch decimal.

* If columns 13-52 left blank, each DEL will be set equal to its respective guess (GUESS).

Set #3 $1 \leq$ cards ≤ 125 (Catches)

		FORMAT (8F10.0)
	Cols. 1-80:	Each card has 8 fields, with each field containing 10 columns. The catches, C(I), are punched with C(1) in field 1, C(2) in field 2, ..., C(ND) in field ND. Punch 8 catches to a card. Punch decimals.

Set #4 (Efforts)	$1 \leq$ cards ≤ 125	FORMAT (8F10.0)
	Cols. 1-80:	Like set #3, only each field contains the effort, E(I), used to make its respective catch.
Set #5 (delta-times)	$1 \leq$ cards ≤ 125	FORMAT (8F10.0)
	Cols. 1-80:	Like set #3, only each field contains the length of time, T(I) associated with its respective catch.
Set #6 (lower limits)	1 card	FORMAT (4F10.0)
	Cols. 1-10:	Lower limit, A(1), of fopt. Justify with decimal.
	Cols. 11-20:	Lower limit, A(2), of Q. Justify with decimal.
	Cols. 21-30:	Lower limit, A(3), of r. Justify with decimal.
	Cols. 31-40:	Lower limit, A(4), of Umax. Justify with decimal.
Set #7 (upper limits)	1 card	FORMAT (4F10.0)
	Cols. 1-40:	Like set #6, only these four fields contain the upper limits, A(5), A(6), A(7) and A(8) of fopt, Q. r, and Umax respectively.
Set #8 (guesses for initial values)	1 card	FORMAT (4F10.0)
	Cols. 1-10:	Best guess of fopt (try average observed?). Justify with decimal.
	Cols. 11-20:	Best guess of Q (try Q = max. observed catch-per-effort divided by 4 x max. observed catch). Justify with decimal.
	Cols. 21-30:	Best guess of r (try r = .8). Justify with decimal.
	Cols. 31-40:	Best guess of Umax (try observed maximum?). Justify with decimal.
	Cols. 41-50:	CVAL--Test value to stop iteration. CVAL stops the iteration on a percent improvement basis rather than an absolute improvement basis; if left blank, absolute improvement mode will be used. Justify with decimal.

Set #9 1 card (number of m-values)	FORMAT (2I4)
Cols. 1-4:	Number of trial values (NM) of m to be read in. Right justify with no decimal.
Cols. 5-8	Number of subintervals (N) each time interval is to be divided into. If in doubt, try 1. Right justify without decimal.
Set #10 $1 \leq$ cards ≤ 3 (m-values)	FORMAT (8F10.0)
Cols. 1-80:	Each card has 8 fields, with each field containing 10 columns. The trial values of m (XM(I)) are punched with XM(1) in field 1, XM(2) in field 2, ..., XM(NM) in field NM. Punch 8 values per card. Justify with decimal.

* Repeat all sets for additional jobs.

Error messages:	Power function errors can occur without destroying the iteration process.
Storage requirements:	About 4000 for ND $\leq$ 1000.

To run GENPROD in "batch" mode, the user enters the following information on the teletype:

```
!EDIT
EDIT HERE
*BUILD_ _ _ _ (job name)
 1.000 !JOB
 2.000 !LIMIT (TIME,2),(CORE,10)
 3.000 !ASSIGN F:5,(DEVICE,SI)
 4.000 !ASSIGN F:6,(DEVICE,LO)
 5.000 !LOAD (EF,(FMBGNPD,345))
 6.000 !RUN
 7.000 !DATA
 8.000 Data card images typed as per above format specifications
       (etc.)
19.000  Ret"
*END
!BATCH (job name)
ID = - - - -          SUBMITTED       (Time)        (Date)
```

Restrictions: Number of trial m values $\leq$ 24;

number of catch intervals $\leq$ 1000.

Program: PRODFIT (FMBPRDF, FMBPRDFC)

Programmer: W. W. Fox, Jr., National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, California.

Reference: Fox, W. W., Jr. 1975. Fitting the generalized stock production model by least squares and equilibrium approximation. Fish. Bull., U.S., 73: 23-37.

Description[1]:

The generalized stock production model is

$$dP/dt = HP_t^m - KP_t - qf_tP_t \qquad (1)$$

where P is the population size (usually in terms of weight), f is effective fishing effort, i.e., standardized from nominal fishing effort to be proportional to the instantaneous fishing mortality coefficient, q is the constant of proportionality (the catchability coefficient), and H, K, and m are constant parameters. At equilibrium (i.e., dP/dt = 0)

$$P^{m-1} = (K/H) + (q/H)f$$

or

$$U^{m-1} = (Kq^{m-1}/H) + (q^m/H)f$$

and

$$U = (a + bf)^{\frac{1}{m-1}} \qquad (2)$$

where U is the catch per unit effort.

---

[1]Source: "PRODFIT User's Manual" by W. W. Fox, Jr. (unpublished), on file at the NMFS Southwest Fisheries Center, La Jolla, Calif. 92037.

The management implications of the generalized stock production model are computed as

$$U_{max} = a^{\frac{1}{m-1}}$$

$$U_{opt} = (a/m)^{\frac{1}{m-1}}$$

$$f_{opt} = (a/b)(1/m - 1)$$

$$Y_{max} = (a/b)(1/m - 1)(a/m)^{\frac{1}{m-1}}$$

where U_{max} is the relative density of the population before exploitation; U_{opt} is the relative population density providing the maximum sustainable yield; f_{opt} is the amount of fishing effort to obtain the maximum sustainable yield; and Y_{max} is the maximum sustainable yield.

Estimation Procedure

Since catch and fishing effort data usually do not represent equilibrium conditions as required by equation (2), the fishing effort must be adjusted to approximate equilibrium conditions. This is done by computing a weighted average of fishing effort for year i over some previous number of years, k, which corresponds to the number of year classes making a significant contribution to the catch in year i, i.e.

$$\bar{f}_i = [k \cdot f_i + (k-1) \cdot f_{i-1} + \ldots + f_{i-k+1}] / [k + (k-1) + \ldots + 1]. \qquad (3)$$

The data set of $(U_i, \bar{f}_i)$ pairs are then utilized to estimate the parameters in equation (2). Note that k - 1 data points at the beginning of the set are lost unless some information about those k - 1 years prior to the data set can be entered. Note that k can be different each year.[2]

PRODFIT provides least-squares estimates of the parameters a, b, and m in equation (2) by minimizing

$$S = \sum_i W_i(U_i - \hat{U}_i)^2$$

where W_i are statistical weights for specifying a multiplicative error structure. An iterative pattern search optimization routine is utilized to locate the least-squares parameter estimates. In order to facilitate termination of the searching procedure, however, the sum-of-squares space is searched with m, U_{max}, and Y_{max}. The catchability coefficient, q, is estimated after estimating a, b, and m by utilizing the integral of equation (1) to compute a q for each year, then the yearly q-values are averaged using arithmetic and geometric means.

Variability indices, V(X), of all the parameters are computed by the "delta", or propagation of error, method. These are not actual variances, but are useful for judging the fit of the model in a quantitative manner. An error index is computed for convenience as

$$E_X = [100\sqrt{V(X)}]/\hat{X}$$

where $\hat{X}$ is the estimated parameter.

[2] The validity of this method has not been examined.

Data Input

Option 1.--A catch and fishing effort history, $\left\{C_i, f_i\right\}$, of i = 1. . . n years length and a vector of significant year class numbers $\left\{k_i\right\}$ are read in. There may be embedded zeros, if they are true zeros and do not simply reflect a lack of information. The only real problem with unreal zeros, however, occurs in the estimation of q. The catch per unit effort vector is computed internally and the averaged fishing effort vector is computed by equation (3) with SUBROUTINE AVEFF.

Option 2.--If one wishes to compute the averaged fishing effort vector by another method or if data are obtained which represent equilibrium conditions, then this option is selected and the vectors of catch per unit effort and averaged (or equilibrium) fishing effort $\left\{U_i, \bar{f}_i\right\}$ are read in directly. No estimate of q can be made, however.

Starting Values

Option 1.--Initial estimates of the parameters are computed in SUBROUTINE INEST and the user provides the starting estimate for m, either 0, 1, or 2.

Option 2.--Occasionally the data are so variable that INEST does not provide compatible starting values for the parameters. In this case, or in any case, the user may opt to enter directly all the initial parameter estimates.

Model Option

The user may allow PRODFIT to estimate m to any desired precision. Frequently, however, the data are so variable that no significant reduction in the residual sum of squares is obtained by varying m. The user then has the option to fix m at 2, the logistic model; at 1, Gompertz model; or at 0, the asymptotic yield model.

Weighting Option

The user may select statistical weights assuming a multiplicative error structure or may choose to not weight the observations, i.e., $W_i = 1$ for all i.

Output

The output of PRODFIT provides a listing of the input data, the transformed data, initial parameter estimates, the iterative solution steps, the final estimates of a, b, and m and their variability indices, the management implications of the final model U_{max}, U_{opt}, f_{opt}, and Y_{max} and their variability indices, the observed and predicted values and error terms, estimates of the catchability coefficient, q, and a table of equilibrium values.

Program PRODFIT may be run on the WHOI system in interactive mode by logging on and entering "PLATEN 132" followed by "RUN FMBPRDFC. 345" when prompted by "!". The user then supplies alphameric information, control values, catch and effort data,[1] and other information as directed.

Program PRODFIT may also be run using card decks or on the terminal in "batch" mode. In the former case, the following control cards are required:

```
!JOB 712, _ _ _ _ (User ID)
!LIMIT (TIME,2),(CORE,15)
!ASSIGN F:5,(DEVICE,SI)
!ASSIGN F:6,(DEVICE,LO)
!LOAD (EF,(FMBPRDF,345))
!RUN
!DATA
```

Data input consists of the following:

1. Title card

   Cols. 1-80.   Header card with alphameric information.

[1]When typing more than one line of data, the user is cautioned to omit the final comma on each line; otherwise, a "0" value will be erroneously generated internally.

2. Control card

Cols. 1-3	Number of data points entered (NC). Right adjusted, no decimal. Less than 100 points.
Col 6	Data preparation option (NDP). 0 if $\bar{f}_i$ are to be calculated. 1 if data represent equilibrium.
Col. 9	Starting values option (NST). 0 if starting values computed internally. 1 if starting values are entered by user.
Cols. 10-12	Number of digits to which the parameters are searched (KK). Right adjusted, no decimal. (Suggest 5)
Cols. 13-15	Number of digits past the decimal to which the parameter m is searched (NPM). Right adjusted, no decimal. (Suggest 2)
Cols. 16-19	Fraction for determining the parameter upper and lower limits in the searching procedure (VL); with decimal, [i.e., parameter x (1 ± fraction)]. (Suggest 0.25)
Cols. 20-23	Starting value for m (XM). Either 0.0, or 1.0, or 2.0.
Col. 27	Model option (XS). 0 estimate m. 1 fix m at starting value.
Col. 31	Weighting option (XW). 0 additive error model (unweighted). 1 multiplicative error model (weighted). (Suggest 1)

3. Catch cards [C(I)], FORMAT (8F10.0). (Or CATCH PER UNIT EFFORT if 1 was punched in column 6 of the Control card.) Punch NC values.

and

Fishing effort cards [XE(I)], FORMAT (8F10.0). Punch NC values.

5. Number of significant year-class cards [XK(I)], FORMAT (8F10.0). OMIT if 1 was punched in Column 6 of the Control card. Punch NC values.

6. Starting values for a, b, m, and residual sum of squares, FORMAT (4E13.6). OMIT if 0 was punched in Column 9.

As many runs as desired may be made by stacking the data decks.

X. Error Messages

1. ****STARTING VALUES INCOMPATIBLE****
   Testing the computed starting values
   (i) for $m \geq 1$, $a > 0.0$ and $b < 0.0$, or
   (ii) for $m < 1$, $a > 0.0$ and $b > 0.0$ has
   failed. User must enter starting values directly.

2. ERROR, ZERO DEGREES OF FREEDOM
   Too few data points entered. No variability indices calculated.

3. ERROR, LOG NEGATIVE VALUE
   Tried to take the logarithm of zero or a negative value in computing the variability indices. No variability indices calculated.

To run Program PRODFIT in "batch" mode, the user enters the following information on the teletype:

```
!EDIT
EDIT HERE
*BUILD _ _ _ _(Job name)
 1.000  !JOB
 2.000  !LIMIT (TIME,2),(CORE,15)
 3.000  !ASSIGN F:5,(DEVICE,SI)
 4.000  !ASSIGN F:6,(DEVICE,LO)
 5.000  !LOAD (EF,(FMBPRDF,345))
 6.000  !RUN
 7.000  !DATA
 8.000  Data card images typed as per above format specifications
               (etc.)
13.000  "Ret"
*END
!BATCH  (Job name)
ID = _ _ _ _        SUBMITTED       (Time)       (Date)
```

Restrictions: Number of catch intervals $\leq$ 100.

Program: Prediction Model (FMBPREDC, RMPRED*)

Programmer: R. K. Mayo, NMFS, NEFC, Woods Hole, Massachusetts

Reference: Tomlinson, P. K. 1968. A generalization of the Murphy catch equation. J. Fish. Res. Bd. Can. 27: 821-825.

Description: This program will calculate stock size and catch in numbers and weight for the jth age group and the ith year from age j to age k ($k \leq 15$) and from year i to year n ($n \leq 10$), given stock at age in year i and recruitment and mortality estimates in year i and in succeeding years.

Catch (numbers at age) in year i is calculated from stock size at age at the beginning of year i according to

$$NC_{ij} = NS_{ij} \cdot \frac{F_{ij}}{F_{ij}+M} \left(1-e^{-(F_{ij}+M)}\right)$$

where

NC_{ij} = catch in numbers (jth age);

NS_{ij} = stock size in numbers (jth age);

F_{ij} = fishing mortality coefficient (x selection coefficient for the jth age); and

M = natural mortality value (constant over all ages).

*RAMUS system.

Catch in weight at age is then computed by

$$WC_{ij} = NC_{ij} \cdot AW_j$$

where

WC_{ij} = weight caught, and

AW_j = average weight at age j

Stock size (numbers at age) at the beginning of the succeeding year is then calculated by

$$NS_{i+1,j} = NS_{ij} \cdot e^{-(F_{ij}+M)} \text{ (for } j = 2,k)$$

and

$$NS_{i+1,1} = R_{i+1,1}$$

where

$R_{i+1,1}$ = recruitment estimate in numbers for year i+1.

Stock size in weight at age is then computed by

$$WS_{i+1,j} = NS_{i+1,j} \cdot AW_j$$

where

$WS_{i+1,j}$ = weight of stock at age j.

The program can be run repeatedly with trial F values on the same data set ("conversational mode") or will accept a number of data sets. The latter option requires estimates of fishing mortality and recruitment for each year in each data set. For both options, the user may enter new selection coefficients and average weights at age directly, or, selection coefficients and average weights can be taken from DATA statements in the program if desired. See below instructions on accessing the program for information on changing DATA statements.

The following material explains data input in detail and presents examples of program operation for "conversational mode" and for a series of data sets.

Sample Input

(1)

```
THE ANSWERS TO THE FOLLOWING QUESTIONS WILL DETERMINE WHETHER THE
PROGRAM WILL RUN FOR ONLY ONE YEAR OR FOR A SERIES OF YRS AND DATA SETS
IF YOU WANT WRITTEN QUESTIONS, ENTER 1,
IF NOT, ENTER 2
INPUT:00366
```

A "1" will cause the program to print detailed questions for input.

A "2" will cause the program to print only the line number (RAMUS) or a question mark (WHOI).

(2)

```
DO YOU WANT TO READ IN NEW SEL.COEFFS. AND AVE WTS (ENTER 1) OR USE
THE CURRENT VALUES IN DATA STATEMENTS 20 AND 30 (ENTER 2)
INPUT:00430
```

A "1" will require input for statements (3) and (4).

A "2" will cause these statements to be bypassed and the program will use the data in the DATA statements.

(3)

```
TYPE IN THE SEL. COEFFS. FOR EACH AGE GROUP (20 VALUES)
INPUT:00480
? .5,.5,.4,.4,.3,.3,.2,.2,.1,1,1,1,1,1,1,1,1,1,1,1
```

Enter one coefficient for each age group you plan to run. This variable is DIMENSIONED at 20, and 20 values must be entered.

(4)

```
TYPE IN THE AVE. WTS. FOR EACH AGE GROUP (2Ø VALUES)
INPUT:ØØ52Ø
? .2,.3,.4,.5,.6,.7,.8,.9,1.,1,1,1,1,1,1,1,1,1,1,1
```

Enter one average weight for each age group you plan to run. This variable is DIMENSIONED at 20, and 20 values must be entered.

(5)

```
DO YOU WANT TO CONVERSE (ENTER 1) OR RUN SETS OF DATA (ENTER 2)
INPUT:ØØ56Ø
```

A "1" will require data for statements (6) to (10). The program will operate in a conversational mode, cycling for one year at a time with a new value of F each year.

A "2" will cause the program to print (6), bypass (7) to (10) and proceed to (11). The program will accept a number of data sets and years for prediction in this mode.

(6)

```
TYPE VAL OF M, AGE AT RCRTMT, NO OF AGE GPS, NO DAT STS, INIT YR
INPUT:ØØ6ØØ
? .2,3,6,1,1973
```

Enter the following values on the same line separated by commas:

Natural Mortality
Age at Recruitment
Number of Age Groups (Max 15)
Number of Data Sets (Max 3) (1 if in conversational mode)
Initial year

(7)

```
TYPE THE VALUE OF F, THE NUMBER OF RECRUITS, AND THE  5 VALUES OF
INITIAL STOCK SIZE AT AGES  4 THROUGH  8
INPUT:00730
 ? .569,1000,800,700,600,500,400
```

Enter the following values on the same line separated by commas:

Fishing Mortality
Number of Recruits
Initial Stock Size for each age group

Input requirements have now been satisfied for the first cycle in conversational mode. A table of stock sizes and catches by age group will be printed followed by the next three questions.

(8)

```
*************************************************************************
TRY ANOTHER F IF YOU WISH, OR ENTER 0.0 TO RUN
DATA SETS, OR -0.1 TO END PROGRAM
INPUT:02070
```

Enter a new fishing mortality.

A positive value causes the program to run for another cycle with the same initial stock size and number of recruits, but with a new F.

A zero value causes the program to return to (1) to allow for entry of new stock sizes and F or to run sets of data.

A negative value causes the program to terminate.

(9)

```
DO YOU WANT TO STOP PRINTING SEL. COEFFS. AND AVE WTS (ENTER 1),
OTHERWISE, (ENTER 2)
INPUT:02140
```

A "1" will suppress printing of these data.

A "2" will allow printout.

(10)

```
DO YOU WANT TO PRINT JUST TOTAL STOCK AND CATCH (ENTER 1),
OTHERWISE, (ENTER 2)
INPUT:02200
```

A "1" will cause only totals to be printed.

A "2" will cause the full table of stock size and catch by age to be printed.

(11)

```
OPITION 2- RUN DATA SETS. ANSWER THE FOLLOWING QUESTION. ENTER VALUES
CORRESPONDING TO EACH DATA SET ON A NEW LINE. PROGRAM WILL ACCEPT UP TO
3 DATA SETS W/10 YRS EA W/UP TO 15 AGE GPS
```

A data set consists of the initial stock size (numbers at each age), the number of recruits in each year, and the fishing mortality in each year. Up to three data sets, each involving up to 10 years of prediction, may be run. In each data set, the user may change one or all of the following parameters:

Initial stock size
Number of recruits
Fishing mortalities
Number of years.

However, the partial recruitment selection coefficient for F, the average weights, the number of age groups, the natural mortality, age at recruitment, and the initial year must remain the same for all data sets.

(12)

```
TO PRINT ONLY TOT STOCK AND CTCH,ENTER 1
OTHERWISE, ENTER 2
INPUT:02838
```

A "1" will allow only total stock size and catch to be printed for each year.

A "2" will cause the program to print the stock size and catch for each age group.

(13)

```
TYPE THE NUMBER OF YEARS TO BE RUN IN THE
FIRST DATA SET, THE SECOND DATA SET,ETC.
(TYPE INTEGER VALUES)
INPUT:00910
 ? 2

INPUT:00910
 ? 2
```

Enter the number of years to be run for predictions for each data set on a new line. (Maximum of 10 years per data set). In this example, two years will be run in each of two data sets.

(14)

```
TYPE THE FISHING MORTALITIES CORRESPONDING
TO EACH YEAR IN THE FIRST DATA SET, THE
SECOND DATA SET,ETC. (REAL NO.)
INPUT:01010
 ? .569,.452

INPUT:01010
 ? .785,.418
```

Enter one value of F for each year specified in (13).

(15)

```
TYPE THE NUMBER OF RECRUITS IN EACH YEAR IN
THE FIRST DATA SET. THE SECOND DATA SET,ETC
INPUT:01090
 ? 1000,900

INPUT:01090
 ? 1050,950
```

Enter one value for each year specified in (13).

(16)

(16)

```
TYPE THE  5 VALUE FOR INITIAL STOCK
SIZE AT AGES  4 THROUGH  8 FOR
THE FIRST DATA SET,SECOND DATA SET,ECT.
INPUT:01200
? 800,700,600,500,400

INPUT:01200
? 850,750,650,550,450
```

Enter one value for initial stock size for each age group past recruitment for the first year of each data set, using a new line for each data set.

Data requirements have now been satisfied and the appropriate tables of stock size and catch will be printed for the years specified.

When all data have been printed, the following question will be asked:

(17)

```
TRY SOME MORE F VALUES
INPUT:02303
```

New fishing mortalities may now be entered in the same manner as in (14) and the program will recycle and print new tables. All other parameters, however, will remain unchanged.

To stop running, type an "S" (RAMUS) or hit "Break" (WHOI).

Examples

The following examples show the two options under which the program can be run. In the first case the program is running in a conversational mode where new F values must be entered after each cycle. After each analysis, the program may be switched back to (1) to allow a new choice of options. In the second case, the program was run with two sets of data, each with two years of analysis followed by input of new F values. An additional example shows a run without printed questions in which two data sets are run for ten years of prediction. In this example, only total stock and catch were printed in order to decrease output time.

Example #1: Conversational Mode

```
THE ANSWERS TO THE FOLLOWING QUESTIONS WILL DETERMINE WHETHER THE
PROGRAM WILL RUN FOR ONLY ONE YEAR OR FOR A SERIES OF YRS AND DATA SETS
IF YOU WANT WRITTEN QUESTIONS, ENTER 1.
IF NOT, ENTER 2
INPUT:00366
 ? 1

DO YOU WANT TO READ IN NEW SEL.COEFFS. AND AVE WTS (ENTER 1) OR USE
THE CURRENT VALUES IN DATA STATEMENTS 20 AND 30 (ENTER 2)
INPUT:00430
 ? 2

DO YOU WANT TO CONVERSE (ENTER 1) OR RUN SETS OF DATA (ENTER 2)
INPUT:00560
 ? 1

TYPE VAL OF M, AGE AT RCRTMT, NO OF AGE GPS, NO DAT STS, INIT YR
INPUT:00600
 ? .2,3,6,1,1973

TYP THE VALUE OF F, THE NUMBER OF RECRUITS, AND THE  5 VALUES OF
INITIAL STOCK SIZE AT AGES  4 THROUGH  8
INPUT:00730
 ? .569,1000,800,700,600,500,400
```

```
*************************************************************************
AGE   SEL. COEFF    AVE.WEIGHT
***   **********    **********
 3     0.18000       0.09500
 4     0.50000       0.17500
 5     0.90000       0.26600
 6     1.00000       0.35000
 7     1.00000       0.43200
 8     1.00000       0.50600
*************************************************************************
DATA SET  1   YEAR 1973   M= 0.2000   F= 0.5690   Z= 0.7690
*************************************************************************
AGE   RECRUITS(NO.)   RECRUITS(WT.)      CATCH(NO.)     CATCH(WT.)
***   *************   *************      **********     **********
 3       1000.000         95.000            88.383          8.396
*****************************************
AGE    STOCK(NO.)      STOCK(WT.)
***    **********      **********
 4      800.000         140.000            180.386         31.568
 5      700.000         186.200            256.425         68.209
 6      600.000         210.000            238.191         83.367
 7      500.000         216.000            198.493         85.749
 8      400.000         202.400            158.794         80.350
*************************************************************************
TOTAL      (NO.)          (WT.)     TOTAL     (NO.)           (WT.)
STOCK    3000.000        954.600    CATCH   1120.673         357.639
AGE 4                               AGE 3
TO  8                               TO  8
*************************************************************************
*************************************************************************
TRY ANOTHER F IF YOU WISH, OR ENTER 0.2 TO RUN
DATA SETS, OR -0.1 TO END PROGRAM
INPUT:02070
 ? .452

DO YOU WANT TO STOP PRINTING SEL. COEFFS. AND AVE WTS (ENTER 1),
OTHERWISE, (ENTER 2)
INPUT:02140
 ? 1

DO YOU WANT TO PRINT JUST TOTAL STOCK AND CATCH (ENTER 1),
OTHERWISE, (ENTER 2)
INPUT:02200
 ? 1

    F= 0.4520    CATCH(WT)=  297.957
 ****************************************
TRY ANOTHER F IF YOU WISH, OR ENTER 0.0 TO RUN
DATA SETS, OR -0.1 TO END PROGRAM
INPUT:02070
 ? 0.0
```

Example 2. Data Sets.

```
THE ANSWERS TO THE FOLLOWING QUESTIONS WILL DETERMINE WHETHER THE
PROGRAM WILL RUN FOR ONLY ONE YEAR OR FOR A SERIES OF YRS AND DATA SETS
IF YOU WANT WRITTEN QUESTIONS, ENTER 1.
IF NOT, ENTER 2
INPUT:00366
 ? 1

DO YOU WANT TO READ IN NEW SEL.COEVFS. AND AVE WTS (ENTER 1) OR USE
THE CURRENT VALUES IN DATA STATEMENTS 20 AND 30 (ENTER(2)
INPUT:00430
 ? 2

DO YOU WANT TO CONVERSE (ENTER 1) OR RUN SETS OF DATA (ENTER 2)
INPUT:00560
 ? 2

TYPE VAL OF M, AGE AT RCRTMT, NO OF AGE GPS, NO DAT STS, INIT YR
INPUT:00600
 ? .2,3,6,2,1973

OPITION 2- RUN DATA SETS. ANSWER THE FOLLOWING QUESTION. ENTER VALUES
CORRESPONDING TO EACH DATA SET ON A NEW LINE. PROGRAM WILL ACCEPT UP TO
 3 data sets w/10 yrs ea w/up to 15 age gps.
TYPE THE NUMBER OF YEARS TO BE RUN IN THE
FIRST DATA SET, THE SECOND DATA SET,ETC.
(TYPE INTEGER VALUES)
INPUT:00910
 ? 2

INPUT:00910
 ? 2

TYPE THE FISHING MORTALITIES CORRESPONDING
TO EACH YEAR IN THE FIRST DATA SET, THE
SECOND DATA SET,ETC. (REAL NO.)
INPUT:01010
 ? .569,.452

INPUT:01010
 ? .785,.418

TYPE THE NUMBER OF RECRUITS IN EACH YEAR IN
THE FIRST DATA SET. THE SECOND DATA SET,ETC
INPUT:01090
 ? 1000,900

INPUT:01090
 ? 1050,950

TYPE THE  5 VALUE FOR INTITIAL STOCK
 SIZEAT AWES  4 THROUGH  8 FOR
THE FIRST DATA SET,SECOND DATA SET,ECT.
INPUT:01200
 ? 800,700,600,500,400

INPUT:01200
 ? 850,750,650,550,450
```

3
10

AGE	SEL. COEFF	AVE.WEIGHT
3	0.10000	0.09500
4	0.50000	0.17500
5	0.90000	0.26600
6	1.00000	0.35000
7	1.00000	0.43200
8	1.00000	0.50600

DATA SET 1 YEAR 1973 M= 0.2000 F= 0.5690 Z= 0.7690

AGE	RECRUITS(NO.)	RECRUITS(WT.)	CATCH(NO.)	CATCH(WT.)
3	1000.000	95.000	88.383	8.396

AGE	STOCK(NO.)	STOCK(WT.)	CATCH(NO.)	CATCH(WT.)
4	800.000	140.000	180.386	31.568
5	700.000	186.200	256.425	68.209
6	600.000	210.000	238.191	83.367
7	500.000	216.000	198.493	85.749
8	400.000	202.400	158.794	80.350

	(NO.)	(WT.)		(NO.)	(WT.)
TOTAL STOCK AGE 4 TO 8	3000.000	954.600	TOTAL CATCH AGE 3 TO 8	1120.673	357.639

DATA SET 1 YEAR 1974 M= 0.2000 F= 0.4520 Z= 0.6520

AGE	RECRUITS(NO.)	RECRUITS(WT.)	CATCH(NO.)	CATCH(WT.)
3	900.000	85.500	63.828	6.063

AGE	STOCK(NO.)	STOCK(WT.)	CATCH(NO.)	CATCH(WT.)
4	739.028	129.330	136.001	23.800
5	492.804	131.086	150.291	39.977
6	343.429	120.200	114.041	39.914
7	278.086	120.133	92.343	39.892
8	231.738	117.260	76.952	38.938

	(NO.)	(WT.)		(NO.)	(WT.)
TOTAL STOCK AGE 4 TO 8	2085.085	618.008	TOTAL CATCH AGE 3 TO 8	633.453	188.585

DATA SET 2 YEAR 1973 M= 0.2000 F= 0.7850 Z= 0.9850

AGE	RECRUITS(NO.)	RECRUITS(WT.)	CATCH(NO.)	CATCH(WT.)
3	1050.000	99.750	125.697	11.941

AGE	STOCK(NO.)	STOCK(WT.)	CATCH(NO.)	CATCH(WT.)
4	850.000	148.750	251.729	44.053
5	750.000	199.500	348.417	92.679
6	650.000	227.500	324.571	113.600
7	550.000	237.600	274.637	118.643
8	450.000	227.700	224.703	113.700

	(NO.)	(WT.)		(NO.)	(WT.)
TOTAL STOCK AGE 4 TO 8	3250.000	1041.050	TOTAL CATCH AGE 3 TO 8	1549.754	494.616

```
*****************************************************************************
DATA SET  2   YEAR 1974   M= 0.2000   F= 0.4180   Z= 0.6180
*****************************************************************************
AGE   RECRUITS(NO.)   RECRUITS(WT.)        CATCH(NO.)      CATCH(WT.)
***   *************   *************        **********      **********
 3         950.000           90.250            62.485           5.936
*****************************************
AGE     STOCK(NO.)       STOCK(WT.)
***     **********       **********
 4         746.368          130.618           128.033          22.406
 5         470.002          125.020           134.397          35.750
 6         302.952          106.033            94.459          33.061
 7         242.735          104.862            75.684          32.695
 8         205.392          103.928            64.040          32.404
*****************************************************************************
TOTAL      (NO.)             (WT.)   TOTAL      (NO.)            (WT.)
STOCK    1967.468          570.461   CATCH    559.097          162.251
AGE 4                                AGE 3
TO  8                                TO  8
*****************************************************************************
TRY SOME MORE F VALUES
INPUT:02303
? .5,.6

INPUT:02303
? .4,.9

*****************************************************************************
DATA SET  1   YEAR 1973   M= 0.2000   F= 0.5000   Z= 0.7000
*****************************************************************************
AGE   RECRUITS(NO.)   RECRUITS(WT.)        CATCH(NO.)      CATCH(WT.)
***   *************   *************        **********      **********
 3        1000.000           95.000            78.125           7.422
*****************************************
AGE     STOCK(NO.)       STOCK(WT.)
***     **********       **********
 4         800.000          140.000           161.054          28.184
 5         700.000          186.200           231.624          61.612
 6         600.000          210.000           215.749          75.512
 7         500.000          216.000           179.791          77.670
 8         400.000          202.400           143.833          72.779
***************************************************************************** ??
```

Example 3. Run without printed questions and output of total stock and catch only.

```
THE ANSWERS TO THE FOLLOWING QUESTIONS WILL DETERMINE WHETHER THE
PROGRAM WILL RUN FOR ONLY ONE YEAR OR FOR A SERIES OF YRS AND DATA SETS
IF YOU WANT WRITTEN QUESTIONS, ENTER 1.
IF NOT, ENTER 2
INPUT:00366
 ? 2

INPUT:00430
 ? 2

DO YOU WANT TO CONVERSE (ENTER 1) OR RUN SETS OF DATA (ENTER 2)
INPUT:00500
 ? 2

INPUT:00600
 ? .2,3,6,2,1973

OPITION 2- RUN DATA SETS. ANSWER THE FOLLOWING QUESTION. ENTER VALUES
CORRESPONDING TO EACH DATA SET ON A NEW LINE. PROGRAM WILL ACCEPT UP TO
3 DATA SETS W/10 YRS EA W/UP TO 15 AGE GPS
TO PRINT ONLY TOT STOCK AND CTCH,ENTER 2
OTHERWISE, ENTER 1
INPUT:00830
 ? 2

INPUT:00910
 ? 10

INPUT:00910
 ? 10

INPUT:01010
 ? 10*.8

INPUT:01010
 ? 10*.4

INPUT:01090
 ? 10*1000

INPUT:01390
 ? 10*500

INPUT:01200
 ? 800,700,600,500,400

INPUT:01200
 ? 800,700,600,500,400

  ****************************************************************
  AGE   SEL. COEFF    AVE.WEIGHT
  ***   **********    **********
   3     0.18000       0.09500
   4     0.50000       0.17500
   5     0.90000       0.26600
   6     1.00000       0.35000
   7     1.00000       0.43200
   8     1.00000       0.50600
  ****************************************************************
```

```
*****************************************************************************
 STOCK    3000.000          954.600  CATCH   1450.529           459.115
 STOCK    1831.609          526.915  CATCH    887.465           248.529
 STOCK    1456.703          374.216  CATCH    699.670           171.774
 STOCK    1355.170          328.733  CATCH    648.279           148.774
 STOCK    1333.768          318.446  CATCH    637.456           143.572
 STOCK    1331.073          317.082  CATCH    636.093           142.882
 STOCK    1331.073          317.082  CATCH    636.093           142.882
 STOCK    1331.073          317.082  CATCH    636.093           142.882
 STOCK    1331.073          317.082  CATCH    636.093           142.882
 STOCK    1331.073          317.082  CATCH    636.093           142.882
*****************************************************************************
 STOCK    3000.000          954.600  CATCH    807.536           266.416
 STOCK    1920.722          630.354  CATCH    543.988           179.951
 STOCK    1342.741          428.034  CATCH    377.198           120.973
 STOCK    1070.665          319.194  CATCH    295.359            88.235
 STOCK     954.431          266.896  CATCH    260.397            72.504
 STOCK     906.102          242.441  CATCH    245.860            65.148
 STOCK     906.102          242.441  CATCH    245.860            65.148
 STOCK     906.102          242.441  CATCH    245.860            65.148
 STOCK     906.102          242.441  CATCH    245.860            65.148
 STOCK     906.102          242.441  CATCH    245.860            65.148
TRY SOME MORE F VALUES
INPUT:02303
 ? 10*.1

INPUT:02303
 ? 10*.2

*****************************************************************************
 STOCK    3000.000          954.600  CATCH    235.843            76.567
 STOCK    2765.851          869.222  CATCH    216.077            69.330
 STOCK    2613.894          804.723  CATCH    202.922            63.750
 STOCK    2531.839          765.970  CATCH    195.831            60.402
 STOCK    2501.986
                            750.748  CATCH    193.254            59.087
 STOCK    2503.306          751.415  CATCH    193.368            59.145
 STOCK    2503.306          751.415  CATCH    193.368            59.145
 STOCK    2503.306          751.415  CATCH    193.368            59.145
 STOCK    2503.306          751.415  CATCH    193.368            59.145
 STOCK    2503.306          751.415  CATCH    193.368            59.145
*****************************************************************************
 STOCK    3000.000          954.600  CATCH    437.234           145.087
 STOCK    2203.600          737.636  CATCH    339.354           115.315
 STOCK    1683.207          563.813  CATCH    258.101            87.867
 STOCK    1374.202          443.145  CATCH    207.175            67.976
 STOCK    1203.704          367.023  CATCH    179.060            55.428
 STOCK    1111.485          320.360  CATCH    163.859            47.736
 STOCK    1111.485          320.360  CATCH    163.859            47.736
 STOCK    1111.485          320.360  CATCH    163.859            47.736
 STOCK    1111.485          320.360  CATCH    163.859            47.736
 STOCK    1111.485          320.360  CATCH    163.859            47.736
TRY SOME MORE F VALUES
INPUT:02303
 ? S


RUNNING TIME:    10.3 SECS   I/O TIME :    11.7 SECS

READY
SAVE

READY
BYE

OFF AT 15:05
```

Accessing instructions for this program at WHOI differ according to whether or not the user wishes to change the DATA statements. If no change is necessary, the user merely logs on and enters "FORT4 FMBPREDC. 345" when prompted by "!". The word "OPTIONS" is then printed, to which the response is "NS."

If DATA statements are to be changed, the user logs on, copies "FMBPREDC. 345" to a new file within the account he is using, and proceeds as follows:

```
!EDIT - - - - (file name)
EDIT HERE
* IN 8
     8.000 - - - - - - DATA FW/a,b,c,d (k values)
* IN 9
     9.000 - - - - - &1,1,1,1....1/(comprising a
                                total of 20 values)
```

The same procedure is followed for DATA WEIGHT/...... on lines 10 and 11, etc.

```
*
```

After editing, the command "TY 8-11" will cause the above lines to be retyped. If the statements were altered correctly, the user then enters END; the signal "!" is then printed, at which the user enters "FORT4 - - - -" (file name), followed by "NS" after the word "OPTIONS" is printed. The user then enters "RUN" when an exclamation point is printed.

The same program may also be run on the RAMUS system by accessing the system and using the file RMPRED. New selection coefficients and average weights are entered on lines 480 and 490, respectively (type LIST NH:480, allow the data to be printed, and retype the lines).

Restrictions: Up to 3 data sets, 10 years/set and 15 age groups/year.

PIECE-WISE INTEGRATION OF YIELD CURVES[1]

IDENTIFICATION

FRG 708 -- Piece-wise Integration of Yield Curves (FMBRIKR, FMBRIKRC)
Lawrence E. Gales -- April, 1964
Fisheries Research Institute, University of Washington

PURPOSE

This program will compute an approximate yield isopleth for a given number of recruits to a fishery when both growth and natural mortality are estimated empirically. The calculations are carried out using a modified form of Ricker's method for estimating equilibrium yield (see Ricker, 1957, pp. 208-217). The program is extremely general in that growth, natural mortality and fishing mortality rates need not be measured using the same time intervals. Fishing mortality rates can be age specific (up to 400 different rates can be applied during the life of the fish) but the over-all level of fishing mortality can be varied by means of multipliers which apply to all of the individual age specific rates. The range and the intervals between ages at first capture can also be varied by the user.

The program has two approximation options: 1) an exponential mode which assumes that the biomass of the stock changes in a strictly exponential manner during any interval when growth, natural mortality and fishing rates are all constant (see equation 10.4, Ricker, 1958); or, 2) an arithmetic mode which uses the arithmetic mean of the stock biomass at the start and at the end of any interval during which all three rates are constant as an estimate of the average biomass present during the interval (see equation 10.3 Ricker, 1958).

Input to the program can be given in the form of instantaneous rates for growth, natural mortality and fishing mortality or the program can compute the instantaneous growth and natural mortality rates from weight-at-time input and from numbers-at-time input. If the latter form of input is employed the instantaneous average growth rate during the i^{th} period is calculated from the formula:

$$g_i = \ln (W_{t_{i+1}}/W_{t_i})/(t_{i+1} - t_i)$$

where t_i = time at which the weight of an individual fish is exactly W_{t_i} weight units

W_{t_i} = weight of an individual fish at time t_i

Instantaneous natural mortality rates are calculated similarly from the formula:

$$M_i = - \ln(N_{t'_{i+1}}/N_{t'_i})/(t'_{i+1} - t'_i)$$

where t'_i = time at which the number of fish in the stock is exactly $N_{t'_i}$ pieces if natural mortality is the only source of mortality present

M_i = instantaneous natural mortality rate during the i^{th} time interval

$N_{t'_i}$ = number of fish in the stock at time t'_i when natural mortality is the only source of mortality.

[1]Unpublished report on file at College of Fisheries, University of Washington, Seattle, WA 98105.

The program will compute and print out at specified times the biomass of the stock when only natural mortality and growth are present. This biomass vector is useful for determining the optimum harvest times for stocks (*e.g.* oyster stocks) that may be completely harvested at one time.

Program FRG 708 may be run on the WHOI system in interactive mode by logging on and entering "PLATEN 132" followed by "RUN FMBRIKRC. 345" when prompted by "!". The user then supplies control values, alphameric information, and growth and mortality data and other information as directed.

Program FRG 708 may also be run using card decks or on the terminal in "batch" mode. In the former case, the following control cards are required:

```
!JOB 712, _ _ _ _(User ID)

!LIMIT (TIME,2),(CORE,10)

!ASSIGN F:5,(DEVICE,SI)

!ASSIGN F:6,(DEVICE,LO)

!LOAD (EF,(FMBRIKR,345))

!RUN

!DATA
```

Data input consists of the following:

I Parameter Card

A Purpose:

This card reads in four parameters (NG, NM, NØPT, NØPT1) which control input and output, plus an output label, and is punched according to FØRMAT (4I1, 11A6).

B Card format:

LOCATION ON CARD	FORTRAN SYMBOL	PURPOSE
Col. 1	NG	If 1 read in vector WT If 2 read in vector G
Col. 2	NM	If 1 read in vector ANT If 2 read in vector AM
Col. 3	NØPT	If 1 compute Y_A - yield arithmetic mode If 2 compute Y_E - yield exponential mode
Col. 4	NØPT1	If 1 skip sets 6 and 7, output biomass only If 2 output biomass and yield matrix If 3 output yield matrix only
Col. 5-70	CØMNTS	Any desired label

II Data Cards

A Set descriptions and mathematical and FØRTRAN equivalents:

SET	DESCRIPTION	MATH EQVLNT	FØRTRAN EQVLNT
1	Divisions of growth scale	t	T
2	Wt. at growth scale divisions (NG=1) or Instantaneous growth rates (NG=2)	W_t / g	WT / G
3	Divisions of nat. mort. scale	t'	TP
4	Nos. for nat. mort. computations (NM=1) or Instantaneous nat. mort. rates (NM=2)	$N_{t'}$ / M	ANT / AM
5	Divisions of fishing scale	t''	TPP
6	Instantaneous fish. mort. rates	F	F
7	Multipliers	m	AAM
8	Values of Tau	τ	TAU
9	Number at start and Ave. weight at start	N_I / W_I	ANI / AWI

where all mathematical and FØRTRAN symbols except for N_I, W_I, ANI, AWI stand for the vectors whose subscripted components are described in PURPOSE, e.g., t stands for the vector $(t_1, \ldots, t_n)$ where t_i = a division of growth scale = time at which weight of an individual fish is exactly W_{t_i} weight units, and T = (T(1),..., T(n)) is its FORTRAN equivalent.

B Card format and sequence:

1 Format:

a SETS 1-8

For SETS 1-8 the format is 9F8.0, i.e., 9 numbers per card each of which is a maximum of 7 digits long plus a decimal point.

Each set is preceded by a control card giving the number of values in the set (I5). The vector of numbers $V_1, \ldots, V_n$ is then punched according to 9F8.0 format. $V_1, \ldots, V_9$ are punched in columns 1-72 (V_1 in cols. 1-8, V_2 in cols. 9-16,..., V_9 in cols. 65-72) on one card, $V_{10}, \ldots, V_{18}$ are punched in cols. 1-72 on the next, and so on until this vector is exhausted. Control and data cards for the next set are then punched in the same manner, etc.

b SET 9

SET 9 consists of two numbers ANI and AWI punched according to FØRMAT (2F10.0), i.e., ANI is punched in cols. 1-10, and AWI in cols. 11-20 of the same card.

2 Sequence:

If NØPT1 = 2 or 3 the sequence is as follows:

CARD NO.	DATA	FORTRAN VECTOR
CARD 1	PARAMETER CARD	NG, NM, NOPT, NØPT1, CØMNTS
	Control Card (I5) No. of T values (LAST)	
CARD 2 ... CARD J_1	DATA FOR SET 1	T (Growth scale divisions)
CARD J_1 + 1	CONTROL CARD (I5) No. of WT or G values (LAST)	
CARD J_1 + 2 ... CARD J_2	DATA FOR SET 2	WT or G (Weight at growth scale dimensions or instantaneous growth rates)
CARD J_2 + 1	CONTROL CARD (I5) No. of TP values	
CARD J_2 + 2 ... CARD J_3	DATA FOR SET 3	TP (Natural mortality scale dimensions)
CARD J_3 + 1	CONTROL CARD (I5) No. of ANT or AM values (LAST)	
CARD J_3 + 2 ... CARD J_4	DATA FOR SET 4	ANT or AM (Nos. for natural mortality computation or natural mortality rates)
CARD J_4 + 1	CONTROL CARD (I5) No. of TPP values (LAST)	

CARD J_4 + 2 ... CARD J_5	DATA FOR SET 5	TPP	(Fishing mortality scale divisions)
CARD J_5 + 1	CONTROL CARD (I5)	No. of F values (LAST)	

- -

CARD J_5 + 2 ... CARD J_6	DATA FOR SET 6	F	(Fishing mortality rates)
CARD J_6 + 1	CONTROL CARD (I5)	No. of AAM (multiplier) values (LAST)	
CARD J_6 + 2 ... CARD J_7 + 1	DATA FOR SET 7	AAM	(Multipliers)
CARD J_7 + 1	CONTROL CARD (I5)	No. of TAU values (LAST)	

- -

CARD J_7 + 2 ... CARD J_8	DATA FOR SET 8	TAU	(Age at entry)
CARD J_8 + 1			
CARD J_8 + 2	DATA FOR SET 9	ANI, AWI	(Initial no. and average weight)

IF NØPT1 = 1 the data within the dotted lines, i.e., from CARD J_5 +2 to CARD J_7 + 1, is deleted.

This completes the data for one problem. Additional problems may be handled simply by adding other groups of data cards in the same manner as above.

LIMITATIONS

The vectors T, WT, G, TP, ANT and AM can have a maximum of 99 components, TPP and F a maximum of 400 components, and AAM and TAU a maximum of 20 components.

INPUT AND OUTPUT FOR A SAMPLE PROBLEM

I Input

a Numerical values:

$t_1=0$	$g_1=.258$	$t'_1=0$	$M_1=.025$	$t''_1=0$	$F_1=1$	$m_1=.05$	$T_1=0$	$N_I=1000$
$t_2=1$	$g_2=.151$	$t'_2=1$	$M_2=.025$	$t''_2=1$	$F_2=1$	$m_2=.10$	$T_2=1$	$W_I=1$
$t_3=2$	$g_3=.095$	$t'_3=2$	$M_3=.025$	$t''_3=2$	$F_3=1$	$m_3=.15$	$T_3=2$	
$t_4=3$	$g_4=.063$	$t'_4=3$	$M_4=.025$	$t''_4=3$	$F_4=1$	$m_4=.20$	$T_4=3$	
$t_5=4$		$t'_5=4$		$t''_5=4$		$m_5=.25$	$T_5=4$	

where $(t_1,\ldots,t_5) = t \equiv$ T

$(g_1,\ldots,g_4) = g \equiv$ G

$(t'_1,\ldots,t'_5) = t' \equiv$ TP

$(M_1,\ldots,M_4) = M \equiv$ AM

$(t''_1,\ldots,t''_5) = t'' \equiv$ TPP

$(F_1,\ldots,F_4) = F \equiv$ F

$(m_1,\ldots,m_5) = m \equiv$ AAM

$(T_1,\ldots,T_5) = T \equiv$ TAU

$N_I \equiv$ ANI

$W_I \equiv$ AWI

and " ≡ " means "is the FØRTRAN equivalent to".

b Options and label:

OPTION	PURPOSE
NG=2	Program reads in G
NM=2	Program reads in AM
NØPT=2	Program computes yield (Y_E) in exponential mode
NOPT1=2	Program outputs biomass and yield matrix

LABEL: The label will read "EXPØNENTIAL MØDE".

c Card form and sequence:

	NG	NM	NOPT	NØPT1	CØMNTS
CARD	2	2	2	2	EXPONENTIAL MODE
cols.	1	2	3	4	5 — 20

	T(1)	T(2)	T(3)	T(4)	T(5) - - - 05
CARD	0.	1.	2.	3.	4.
cols.	1—8	9—16	17—24	25—32	33—40

CARD - - - 04

	G(1)	G(2)	G(3)	G(4)
CARD	.258	.151	.095	.063
cols.	1—8	9—16	17—24	25—32

CARD - - - 05

	TP(1)	TP(2)	TP(3)	TP(4)	TP(5)
CARD	0.	1.	2.	3.	4.
cols.	1—8	9—16	17—24	25—32	33—40

CARD - - - 04

	AM(1)	AM(2)	AM(3)	AM(4)
CARD	.025	.025	.025	.025
cols.	1—8	9—16	17—24	25—32

CARD - - - 05

	TPP(1)	TPP(2)	TPP(3)	TPP(4)	TPP(5)
CARD	0.	1.	2.	3.	4.
cols.	1—8	9—16	17—24	25—32	33—40

CARD --- 04

	F(1)	F(2)	F(3)	F(4)
CARD	1.	1.	1.	1.
cols.	1—8	9—16	17—24	25—32

CARD --- 05

	AAM(1)	AAM(2)	AAM(3)	AAM(4)	AAM(5)
CARD	.05	.10	.15	.20	.25
cols.	1—8	9—16	17—24	25—32	33—40

CARD --- 05

	TAU(1)	TAU(2)	TAU(3)	TAU(4)	TAU(5)
CARD	0.	1.	2.	3.	4.
cols.	1—8	9—16	17—24	25—32	33—40

	ANI	AWI
CARD	1000.	1.
cols.	1—10	11—20

II Output

****

EXPØNENTIAL MØDE
PIECE-WISE INTEGRATION OF THE YIELD CURVE

- - - - - - - - - - - - - - - - - - - -

I N P U T   D A T A

- - - - - - - - - - - - - - - - - - - -

DIVISIONS OF GROWTH SCALE, 9 PER LINE

- -

(N= 1) 0 1.0000 2.0000 3.0000 4.0000

INSTANTANEOUS GROWTH RATE, 9 PER LINE

- -

(N= 1) 0.2580 0.1510 0.9500E-01 0.6300E-01 -0

DIVISIONS OF NATURAL MORTALITY SCALE, 9 PER LINE

- -

(N= 1) 0 1.0000 2.0000 3.0000 4.0000

INSTANTANEOUS NATURAL MORTALITY RATES, 9 PER LINE

- -

(N= 1) 0.2500E-01 0.2500E-01 0.2500E-01 0.2500E-01 -0

DIVISIONS OF FISHING SCALE, 9 PER LINE

- -

(N= 1) 0 1.0000 2.0000 3.0000 4.0000

INSTANTANEOUS FISHING MORTALITY RATES, 9 PER LINE

- -

(N= 1) 1.0000 1.0000 1.0000 1.0000 -0

MULTIPLIERS, 9 PER LINE.

- -

(N= 1) 0.5000E-01 0.1000 0.1500 0.2000 0.2500

VAULES OF TAU, 9 PER LINE

- -

(N= 1) 0 1.0000 2.0000 3.0000 4.0000

NUMBER AT START= 1000.000 AVERAGE WEIGHT AT START= 1.000000

****

- -

BIO-MASS VECTOR NO HARVEST

NUMBER	TIME	BIO-MASS
1	0	1000.000
2	1.000000	1262.381
3	2.000000	1431.897
4	3.000000	1535.721
5	4.000000	1595.201

Y I E L D M A T R I X

T(5)=	4.000	0	0	0	0	0
T(4)=	3.000	76.3271	148.908	217.926	283.556	345.963
T(3)=	2.000	144.920	275.801	393.989	500.702	597.042
T(2)=	1.000	203.432	377.448	526.212	653.301	761.790
T(1)=	0.	248.378	448.484	609.316	738.214	841.169

MULTIPLIER...

M(1)= 0.50000E-01
M(2)= 0.10000
M(3)= 0.15000
M(4)= 0.20000
M(5)= 0.25000

References

Ricker, W. E. 1958. Hand book of computations for biological statistics of fish populations. Fish. Res. Bd. Canada Bull. No. 119. 300 pp.

Additions to FRG 708 Write-up

The user is cautioned that all values taken on by TAU, the age at entry, must be represented in the set of TPP values or the isopleth computations will be in error. The program sets all of the instantaneous fishing mortality rates for ages less than a given age at entry equal to zero provided that a fishing mortality rate interval ends at the given age at entry.

For example, if the instantaneous fishing mortality rate is constant from age 2 to age 10 and TAU, the age of entry, is varied over the interval from age 2 to age 10 by one year steps; i.e., TAU = 2.0, 3.0, 4.0,...., 10.0, the set of TPP's must also contain the values 2.0, 3.0, 4.0,...., 10.0; if TPP only contains the values 2.0 and 10.0 all of the yield isopleth computations will be carried out exactly as if TAU were equal to 2.0 for all of the TAU's from 3.0 to 10.0. Since the program will accept 400 TPP's this restriction does not place any serious limitation on its use.

A more complete description of the generalized version of Ricker's equilibrium yield model and its use is given by Paulik and Bayliff (1967).

References

Paulik, G. J. and Bayliff, W. F. 1967. A generalized computer program for the Ricker model of equilibrium yield per recruitment. (Scheduled for publication in the January, 1967 issue of the Journal of the Fisheries Research Board of Canada.)

To submit Program FRG 708 in "batch" mode, the user enters the following information on the teletype:

```
!EDIT
EDIT HERE
*BUILD_ _ _ _(job name)
 1.000  !JOB
 2.000  !LIMIT (TIME,2),(CORE,10)
 3.000  !ASSIGN F:5,(DEVICE,SI)
 4.000  !ASSIGN F:6,(DEVICE,LO)
 5.000  !LOAD (EF,(FMBRIKR,345))
 6.000  !RUN
 7.000  !DATA
 8.000  Data card images, input as per above format specifications
               (etc.)
26.000  "Ret"
*END
!BATCH  (job name)
ID = _ _ _ _            SUBMITTED         (Time)        (Date)
```

Restrictions: T, WT, G, TP, ANT, AM ≤ 99

TPP, F ≤ 400

AAM, TAU ≤ 20

Program: BGC 2--von Bertalanffy Fit (FMVBRT, FMVBRTC)

Programmer: N. J. Abramson, California Department of Fisheries and Game, Menlo Park, California

Reference: Tomlinson, P. K. and N. J. Abramson. 1961. Fitting the von Bertalanffy growth curve by least squares. Cal. Dept. Fish and Game, Fish. Bull. 116. 69 pp.

Description: This program fits the curve $l_t = l_\infty (1-e^{-k(t-t_0)})$ by least squares with weights proportional to sample size at each age group. A constant time interval between ages is required, but the number of lengths in the age groups may be unequal. Output provides estimates of L_∞, k, t_0 and their standard errors, fitted length, sample mean lengths and their standard errors, the variance-covariance matrix, and the standard error of estimate.

Program BGC 2 may be run on the WHOI system in interactive mode by logging on and entering "Run FMBVBRTC. 345" when prompted by "!". The user supplies alphameric information, control values, the number of samples in each age group, and length data at age as directed by the program.

Program BGC 2 may also be run using card decks or on the terminal in "batch" mode. In the former case, the following control cards are required:

```
!JOB 712, _ _ _ _(User ID)
!LIMIT (TIME,2),(CORE,30)
!ASSIGN F:5,(DEVICE,SI)
!ASSIGN F:6,(DEVICE,LO)
!LOAD (EF,(FMBVBRT,345))
!RUN
!DATA
```

Data input consists of the following:

Card No.	Description
1.	Header card with alphameric information (20A4).
2.	Variable format specifying configuration of length data, left parenthesis in Column 1 (20A4).
3.	Number of ages, age of the youngest age group, and time interval between age groups (constant). Left--justify with three decimal places understood (I2, 2F4.3).
4. (+) plus	Number of lengths in each age group, beginning with the first (20I4). If more than 20 age groups are represented, numbers continue onto a second card.
5. (+) plus	Length data printed according to the variable format statement. Age groups are arranged in ascending order, and each age group begins on a new card.

To submit Program BGC 2 in "batch" mode, the user enters the following information on the teletype:

```
!EDIT
EDIT HERE
*BUILD_ _ _ _(Job name)
 1.000  !JOB
 2.000  !LIMIT (TIME,2),(CORE,30)
 3.000  !ASSIGN F:5,(DEVICE,SI)
 4.000  !ASSIGN F:6,(DEVICE,LO)
 5.000  !LOAD (EF,(FMBVBRT,345))
 6.000  !RUN
 7.000  !DATA
 8.000  Data card images, input as per above format specifications.
        (etc.)
18.000  "Ret."

*END
!BATCH (job name)
ID = _ _ _ _        SUBMITTED       (Time)       (Date)
```

Restrictions: Number of age groups ≤ 30; number of lengths per age group ≤ 600.

VON BERTALANFFY GROWTH IN LENGTH CURVE

BGC II SAMPLE PROBLEM TEST DECK

ESTIMATED PARAMETERS AND STANDARD ERRORS

	L INFINITY	K	T SUB-ZERO
ESTIMATES	1102.17	.190181	-2.3232
STANDARD ERRORS	90.84	.049441	.574846

FITTED LENGTHS AND SAMPLE LENGTHS

AGE	FITTED LENGTH	SAMPLE MEAN LENGTH	S.E. OF SAMPLE MEAN	SAMPLE SIZE
.0	393.62	NO SAMPLE DATA FOR THIS AGE		
1.0	516.34	512.00	17.302	9
2.0	617.80	631.27	15.737	11
3.0	701.69	671.83	18.582	6
4.0	771.04	770.56	9.982	9
5.0	828.39	848.75	11.747	8
6.0	875.81	869.43	13.571	7
7.0	915.01	893.80	17.028	5
8.0	947.43	978.50	14.500	2

SAMPLE DATA BEYOND AGE 8.0 NOT AVAILABLE

VARIANCE-COVARIANCE MATRIX

	L INFINITY	K	T SUB-ZERO
L INFINITY	.82519931+04	-.44147856+01	-.47356272+02
K	-.44147856+01	.24443924-02	.27419964-01
T SUB-ZERO	-.47356272+02	.27419964-01	.33044840-00

STANDARD ERROR OF ESTIMATE-- 43.7393

PROGRAMMED BY BIOMETRICAL ANALYSIS UNIT. MRO. CALIF. FISH AND GAME, MAY, 1964--BGC II

```
BGC II SAMPLE PROBLEM TEST DECK
(11F4.0)
0810001000
00090011000600090008000700050002
048005480503048505950497058304420475
06360688069906520662055405590668064505590622
065906450666066206370762
073508370777074807720790074907640763
08870843085808940841078708460834
0834084409340882089208390861
08550915094009050854
09930964
```

Program: Virtual Population Analysis (FMBVPOPC, FMBMLP*)

Programmer: M. Parrack, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Massachusetts 02543

References Gulland, J. A. 1965. Estimation of mortality rates. Arctic Fish. Working Group Rept. ICES C.M. 9 p.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analyses. ICNAF Res. Bull. 9:65-74.

Description: This program allows estimation of initial population size (N_i) and instantaneous fishing mortality (F_i) for a given cohort in any year i, given catch at age data (C_i), a value(s) for instantaneous natural mortality (M or M_i, constant or age-specific) and an initial estimate of F for the oldest age (t) in which the year-class was fished (F_t). Using F_t, the equation

$$C_t = N_t \frac{F_t}{F_t+M} (1-e^{-(F_t+M)}) \qquad (1)$$

is used to solve for N_t (the stock at the beginning of year t), which is then substituted for N_{i+1} in the equation

$$\frac{N_{i+1}}{C_i} = \frac{(F_i+M)e^{-(F_i+M)}}{F_i(1-e^{-(F_i+M)})} \qquad (2)$$

which is solved iteratively for F_i.

*RAMUS system

The relation

$$N_{i+1} = N_i \ e^{-(F_1+M)} \tag{3}$$

is then used to obtain a population estimate for the preceding year (N_i), which is substituted back into (2) to obtain F_{i-1}, and so on.

This program also estimates the following for each year i:

$$S_i = e^{-(F_i+M)}$$

$$U_i = \frac{F_i}{F_i+M} \left(1-e^{-(F_i+M)}\right)$$

$$E_i = U_i + S_i \cdot E_{i+1}$$

$$E_t = \frac{F_t}{F_t+M} \left(1-e^{-(F_t+M)}\right)$$

$$V_k = \sum_{i+1}^{k} C_i$$

For each cohort, input consists of the youngest and oldest ages fished and cohort birth year, followed by catch at age data beginning with the youngest age. Values for M and a starting value for F at age t are then entered. This program may be run on the WHOI system in interactive mode by logging on and entering "RUN FMBVPOPC. 345" when prompted by "!". The user inputs the necessary information for each cohort as directed. The same program may also be run on the RAMUS system by accessing the system and using the file FMBMLP.

Restrictions: Number of age groups ≤ 30.

Program: Yield per Recruit (FMBYPCT, FMBYPCTC)

Programmer: M. Parrack, National Marine Fisheries Service, Northeast Fisheries Center, Woods Hole, Massachusetts 02543

Reference: Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. Minist. Agric. Fish. Food (GB), Ser. II, 19, 533 p.

Description: This program provides equilibrium yield values for a given recruitment according to the simple formula of Beverton and Holt (1957: 75). The program is written to pass through an inner loop of different ages at entry to the exploited phase (t_p ') within two successive outer loops representing varying levels of fishing and natural mortality. The user specifies the input parameters, the ranges and increments for the "age at entry" and fishing and natural mortality loops, and the number of recruits (R) at age t_p (age at recruitment). The model assumes constant fishing mortality over the fishable life span with "knife-edge" selection, and a value of 3.0 for b in the length-weight equation.

The formula is:

$$Y_w = FRW_{\infty} e^{-M(t_p'-t_p)} \sum_{n=o}^{3} \frac{\Omega_n e^{-nK(t_p'-t_o)}}{F + M + n K} (1-e^{-(F+M+nK)\ (t_\lambda - t_p')})$$

where

Y_w = yield in weight

W_∞ = asymptotic weight

R = number of recruits at age t_p, that is, number entering the area where fishing is in progress and becoming liable to encounters with the gear.

F = instantaneous rate of fishing mortality

M = instantaneous rate of natural mortality

K = coefficient of catabolism

t_o = hypothetical time at which the fish would have been o length according to the von Bertalanffy equation.

t_ρ = age at recruitment, *i.e.* age at which fish become liable to encounters with the gear (t_r of Gulland)

t_ρ' = age at entry to the exploited phase; corresponding to 50% on the mesh selection ogive (t_c of Gulland)

t_λ = end of the life span; corresponds to maximum age for which adequate data are available.

This program may be run on the WHOI system in interactive mode by logging on and entering "RUN FMBYPCTC. 345" when prompted by "!". The user supplies alphameric information and values for M, F, t_o, t_ρ, t_ρ', t_λ, k, W_∞, and R, as directed.

This program may also be run using card decks or on the terminal in "batch" mode. In the former case, the following control cards are required:

```
!JOB 712, _ _ _ _ (user ID)
!LIMIT (TIME,2),(CORE,10)
!ASSIGN F:5,(DEVICE,SI)
!ASSIGN F:6,(DEVICE,LO)
!LOAD (EF,(FMBYPCT,345))
!RUN
!DATA
```

Data input consists of the following:

Card No.	Description
1	Header card with alphameric information.
2+	Data cards, one for each set of yield values (isopleths) desired. A blank card terminates execution normally.

Data cards for Program FMBYPCT are punched as follows:

Cols. 1-4	Lowest instantaneous natural mortality rate (no decimal; four decimal places understood).
Cols. 5-8	Highest instantaneous natural mortality rate (no decimal; four decimal places understood).
Cols. 9-12	Increment through which loop traverses (no decimal; four decimal places understood).
Cols. 13-16	Lowest instantaneous fishing mortality rate (no decimal; three decimal places understood).
Cols. 17-20	Highest instantaneous fishing mortality rate (no decimal; three decimal places understood).
Cols. 21-24	Increment through which loop traverses (no decimal; three decimal places understood).
Cols. 25-28	Lowest age of entry to exploited phase t_p' (no decimal; two decimal places understood).
Cols. 29-32	Highest age of entry to exploited phase t_p' (no decimal; two decimal places understood).

Cols. 33-36	Increment through which loop traverses with two decimal places understood.
Cols. 37-41	t_o (F 5.3)
Cols. 42-44	t_p recruitment age (F 3.2)
Cols. 45-48	t_λ end of life span (F 4.2)
Cols. 49-52	K (F 4.3)
Cols. 53-59	W_∞ (F 7.2)
Cols. 60-66	R (Recruits at age t_p) (F 7.0)
Cols. 67-80	Alphameric ID information for isopleths (7A2).

(Note that alphameric header card precedes all data cards, and a blank card terminates the program).

To run this program in "batch" mode, the user enters the following information on the teletype:

```
!EDIT
EDIT HERE
*BUILD_ _ _ _(Job name)
 1.000  !JOB
 2.000  !LIMIT (TIME,2),(CORE,10)
 3.000  !ASSIGN F:5,(DEVICE,SI)
 4.000  !ASSIGN F:6,(DEVICE,LO)
 5.000  !LOAD (EF,(FMBYPCT,345)
 6.000  !RUN
 7.000  !DATA
 8.000  Data card images, input as per above format specifications.
            (etc.)
10.000  "Ret"
*END
!BATCH  (Job name)
ID = _ _ _ _          SUBMITTED       (Time)        (Date)
```

Program: COHORT (Y9CHRT)

Programmer: W. W. Fox, Jr., NMFS, Southwest Fisheries Center, La Jolla, Calif.

Reference: Tomlinson, P. K. 1970. A generalization of the Murphy catch equation. J. Fish. Res. Bd. Canada, 27: 821-825.

This program provides age specific mortality and exploitation rates and estimates of virtual population size and population size at the beginning of each time interval for a given cohort. Intervals may vary in length and have o catches. Input consists of catch at age data from age t to age T (youngest to oldest), lengths of time intervals (if variable), and mortality estimates; natural mortality rates may be held constant or varied as desired. The program is set up to travel through a loop of starting F values ($N \leq 99$) within a loop of M values or sets.

The program reads a header card containing alphameric information followed by as many data sets as desired. A blank card following the last set will terminate the program normally. Each data set consists of the following cards:

1. A control card, giving:

   a. Cols. 1-3 = ND = Number of data points (I3)

   b. Col. 9 = NT = Time interval option (o-constant; 1-variable) (I1)

   c. Col. 12 = NM = Natural mortality option (o-constant; 1-variable) (I1)

   d. Cols. 13-15 = NDM = Number of trial M values (or sets if variable) (I3)

   e. Cols. 16-18 = NDF = Number of starting F values (I3)

2. Catch card(s), giving catches from the youngest to the oldest ages for each time interval (8F 10.0). As many as necessary to complete the data set.

3. Time interval card(s). One if constant; as many as necessary to complete the set if variable (8F 10.0). If constant, punch interval length in first field.

4. Natural mortality card(s). For each rate or set of rates, one if constant; as many as necessary to complete the set if variable (8F 10.0). If constant, punch M value in first field.

   Note that the program calls for NDM values or sets of values, each of which can contain NDF fishing mortality values.

5. Fishing mortality card(s). NDF starting F values (8F 10.0). Note that the deck is arranged so that for a given natural mortality value or set of values starting F fishing mortality values will be read immediately thereafter. (Thus, NDM sets of natural and fishing mortality values will be read in).

Control cards for running COHORT:

```
!JOB 712, _ _ _ _ (User ID)
!LIMIT (TIME,2),(CORE,10)
!ASSIGN F:5,(DEVICE,SI)
!ASSIGN F:6,(DEVICE,LO)
!LOAD (EF,(Y9CHRT,345)
!RUN
!DATA
        (Data deck)
```

To run Program COHORT in "batch" mode, the user enters the following information on the teletype:

```
!EDIT
EDIT HERE
*BUILD_ _ _ _(Job name)
 1.000  Above control cards ("!JOB" only for statement 1)
       ↓
       ↓
       ↓
 8.000  Data card images
              etc.
*END
!BATCH (Job name)
```

Restrictions: Number of data points ≤1000

Number of starting F values ≤99

ANALYSIS OF A CATCH CURVE PROGRAM

IDENTIFICATION

FRG 705 -- Analysis of a Catch Curve (Y9CTCV)
Lawrence E. Gales -- January, 1964
Fisheries Research Institute, University of Washington

PURPOSE

The general problem of analyzing catch curves is discussed by Chapman and Robson (1960) and Robson and Chapman (1961). This program is based on the results given in these two articles. The user is urged to consult these articles before using the program.

The program computes a number of statistical measures associated with a vector of catch numbers N_0, N_1, ... N_I where N_j = number of fish caught of (coded) age "j". Four options are available:

OPTION 1 assumes 1) recruitment and annual survival constant for all age groups entered in catch vector, 2) all ages in catch vector are fully available to sampling gear, 3) ages are known for all fish in catch vector.

OPTION 1 Computes:
Estimate of survival rate
Variance of survival rate
Standard error of survival rate
95% confidence interval for survival rate
Instantaneous mortality rate
Estimate of instantaneous mortality rate
Variance of instantaneous mortality rate
95% confidence interval for mortality rate

OPTION 2 tests the hypothesis that the relative frequency in the 0-age group as compared to the older ages does not deviate significantly from the expected frequency under Option 1 assumptions.

OPTION 2 Computes a chi-square statistic associated with the difference between the best estimate and Heinke's estimate. If this statistic exceeds CHI (a chi-square value for desired confidence level) the catch numbers are recoded as follows:

$N_1 \dashrightarrow N'_0$

$N_2 \dashrightarrow N'_1$

$N_3 \dashrightarrow N'_2$

.
.
.

$N_I \dashrightarrow N'_{I-1}$

and the above computations are made for the new vector N'_0, ... N'_{I-1}.

This test is repeated until the statistic is less than CHI, a theoretical chi-square value with one degree of degree which specifies the significance level of the test. CHI is entered on a control card. If the statistic is less than CHI, the output is the same as in OPTION 1.

OPTION 3 is to be used when assumption 1) and 2) of OPTION 1 hold but it is not possible to age fish whose coded age is greater than "K". OPTION 3 assumes that the recorded relative frequencies are not reliable for fish of ages K+1, K+2, ..., I in the vector of catch numbers.

OPTION 3 sums the catch for ages K+1 to I and computes the same output as in OPTION 1 using the catch vector $N_0, N_1, \ldots N_K$, m where $m = N_{K+1} + \ldots + N_I$.

OPTION 4 permits the user to subdivide the catch curve into a number of segments. The assumptions listed under OPTION 1 may be satisfied for the consecutive age groups in one segment but not for age groups in different segments of a catch curve. Because segmentation of a catch curve may be exploratory the program allows the use of overlapping segments, i.e., one age group may appear in more than one segment.

OPTION 4 computes the same output as OPTION 1, for each segment of the catch vector $(i_1, i_2), (i_3, i_4), \ldots (i_p, i_{p+1})$ where, if $i_j = A$ and $i_{j+1} = B$, (i_j, i_{j+1}) means the segment $N_A, \ldots, N_B$.
The estimate of s_j, the survival rate for the jth segment of the catch curve, is obtained by solving equation (19) of Chapman and Robson (1960) by iteration. $\left\{\bar{X}_K = \frac{S}{1-S} - (K+1)\frac{S^{K+1}}{1-S^{K+1}}\right\}$

INPUT

The input common to all options consists of:

Card 1 Number of values (I2)

Set 2 A set of cards for the catch vector punched according to FØRMAT (9F8.0). The catch numbers N_j are punched (with decimal point) in columns 1-8, 9-16, ..., 65-72.

Set 3 One parameter card specifying the option, age at full recruitment (AFR), CHI (OPTION 2, only), K+1 (OPTION 3, only) and identification punched according to FØRMAT (I1, F2.0, F6.3, I4, 6X, 10A6).

Sets 1 and 2 are identical for all options. The parameter card (SET 3) is punched in the following manner:

The option is designated by a single digit number 1, 2, 3, or 4 punched in column 1.

AFR is a 2-digit right adjusted number punched in columns 2 and 3.

CHI is a 5-digit number (plus a decimal point), punched in columns 4-9.

K+1 is a 4-digit right adjusted number (with no decimal point) punched in columns 10-13.

The identification is any alpha-numerical information punched in columns 20-70.

OPTION 4 requires a fourth set of data which reads in the segments (i_1, i_2), (i_3, i_4) ... etc. according to FØRMAT (20I3). i_1 is a 3-digit right adjusted number (with no decimal point) punched in columns 1-3, i_2 is punched in columns 4-6, ..., . i_p (p an odd number, hence the beginning of the segment (i_p, i_{p+1})) is always a 3-digit right adjusted number (with no decimal point) punched in columns 3p-2 to 3p.

INPUT EXAMPLES Sample Data:

N_0 = 118	I = 9
N_1 = 73	AFR = 6
N_2 = 36	CHI = 3.84
N_3 = 30	K+1 = 4
N_4 = 25	(i_1, i_2) = (0, 3)
N_5 = 21	(i_3, i_4) = (2, 4)
N_6 = 16	
N_7 = 14	
N_8 = 10	
N_9 = 1	

As many runs as desired may be made by stacking the data sets.

OPTION 1   CARD 1--No. of values (I2)

Set 2

	N_0	N_1
CARD 2	_ _ _ _ 1 1 8 .	_ _ _ _ _ 7 3 .
cols.	1-8	9-16
	N_2	N_3
"	_ _ _ _ _ 3 6 .	_ _ _ _ _ 3 0 .
	17-24	25-32
	N_4	N_5
"	_ _ _ _ _ 2 5 .	_ _ _ _ _ 2 1 .
	33-40	41-48
	N_6	N_7
"	_ _ _ _ _ 1 6 .	_ _ _ _ _ 1 4 .
	49-56	57-64
	N_8	
"	_ _ _ _ _ 1 0 .	
	65-72	

Set 3

	Option	AFR	IDENTIFICATION
CARD 3	1	_ 6	H A U L 1 _ ....
cols.	1	2 3	20-70

OPTION 2   Cards 1, 2, (Set 1) and 3 (Set 2) the same

Set 3

	Option	AFR	CHI	IDENTIFICATION
CARD 3	2	_ 6	_ _ 3 . 8 4	H A U L 1 _ ....
cols.	1	2 3	4-9	20-70

<u>OPTION 3</u> Cards 1, 2, (Set 1) and 3 (Set 2) the same.

		Option	AFR	CHI	K+1	IDENTIFICATION
Set 3	CARD 3	3	_ 6	— — — — — —	_ _ _ 4	H A U L 1 _ ....
	cols.	1	2 3	4-9	10-13	20-70

<u>OPTION 4</u> Cards 1, 2, (Set 1) and 3 (Set 2) the same.

		Option	AFR				IDENTIFICATION
Set 3	CARD 3	4	_ 6				H A U L 1 _ ....
	cols.	1	2 3				20-70
		i_1	i_2	i_3	i_4		
Set 4	CARD 4	_ 0 0	_ 0 3	_ 0 2	_ 0 4		
	cols.	1 2 3	4 5 6	7 8 9	10 11 12		

(Your data cards)

Chapman, D. C., and D. S. Robson. 1960. The analysis of a catch curve. Biometrics, 16: 354-368.

Robson, D. S., and D. G. Chapman. 1961. Catch curves and mortality rates. Trans. Am. Fish. Soc., 90: 181-189.

Control cards for running FRG 705:

```
!JOB 712,_ _ _ _(User ID)

!LIMIT (TIME,2),(CORE,10)

!ASSIGN F:5,(DEVICE,SI)

!ASSIGN F:6,(DEVICE,LO)

!LOAD (EF,(Y9CTCV,345))

!RUN

!DATA

       (Data deck)
```

To run Program FRG 705 in "batch" mode, the user enters the following information on the teletype:

```
!EDIT

EDIT HERE

*BUILD_ _ _ _(Job name)

 1,000  Above control cards ("!JOB" only for statement 1)
          ↓
          ↓
          ↓
 8,000  Data card images

             etc.

*END

!BATCH (Job name)
```

Restrictions: I ≤ 99

$0 \leq N_i \leq 9999.9$

$0 \leq AFR \leq 99$

Number of segments ≤ 10

Identification

FR 731 -- FPØW Y9FPOW

Programmed by Catherine Berude and Norman J. Abramson, California Department of Fish and Game, Menlo Park, California

Introduction and Estimation Procedure

Analysis of variance as a method for estimating relative fishing power was suggested by Robson (1966). FPØW utilizes this method in estimating relative fishing power, relative population density, approximate confidence intervals and corrections for bias in the parameter estimates.

A simple development of the method may be outlined as follows. The basic model assumed is

$$C_{ij} = q_i f_{ij} \bar{P}_j \varepsilon_{ij} \qquad (1)$$

where C_{ij} is the catch of the i^{th} fishing treatment in the j^{th} area-date stratum, q_i is the catchability coefficient of the i^{th} treatment, f_{ij} is the amount of fishing effort expended by the i^{th} treatment in the j^{th} area-date, $\bar{P}_j$ is the average population size in the j^{th} area-date, and ε_{ij} is a log-normally distributed random variable. The i treatments may be different vessels, vessel types or their attributes (e.g. length, horsepower, tonnage), gear types or characteristics (e.g. gill nets, purse seines, soak times, trawl footrope lengths), or any other way of designating classes within the fishing fleet. It is assumed that (1) effort is measured such that within each treatment q_i is constant, (2) the units of effort operate independently, and (3) there is no interaction between the treatments and area-dates.

Dividing through equation (1) by effort and taking natural logarithms we have

$$\ln(C_{ij}/f_{ij}) = \ln q_i + \ln \bar{P}_j + \ln \varepsilon_{ij}$$

which may be written as

$$Y_{ij} = \alpha_i + \beta_j + \varepsilon'_{ij} \qquad (2)$$

Equation (2) may be recognized as a linear two-factor analysis of variance model where the ε'_{ij} are assumed to be $\sim N(0,\sigma^2)$. If the α_i and β_j were estimable one would have estimates of the logarithms of the catchability coefficients and population densities directly. Since the design matrix is singular and therefore no solution exists, one must re-parameterize the model and obtain estimates of relative catchability--called relative fishing power, ρ_i--and relative population density, D_j, where

$$\rho_i = q_i/q_s ,$$
$$D_j = \bar{P}_j/\bar{P}_s$$

and s designates the treatment and area-date selected to be the standard. Standardized fishing effort is obtained by

$$f_{sj} = \sum_i \rho_i f_{ij}$$
$$\text{such that} \quad C_j = q_s f_{sj} \bar{P}_j ,$$

the desired relation with a single catchability coefficient.

Re-parameterizing equation (2) we have

$$Y_{ij} = \alpha_s + \beta_s + (\alpha_i - \alpha_s) + (\beta_j - \beta_s) + \varepsilon'_{ij}$$

$$\text{or} \quad Y_{ij} = \mu + \alpha'_i + \beta'_j + \varepsilon'_{ij} \qquad (3)$$

where $\mu = \alpha_s + \beta_s$, $\alpha'_i = (\alpha_i - \alpha_s)$, and $\beta'_j = (\beta_j - \beta_s)$.

The design matrix for equation (3) is non-singular and the parameters μ, α'_i, and β'_j are estimated by FPØW solving the usual normal equations.

Biased estimates of relative fishing power and relative density are obtained as

$$\rho_{Bi} = e^{\hat{\alpha}'_i}$$

$$\text{and} \quad \hat{D}_{Bj} = e^{\hat{\beta}'_j}$$

where $\rho_s = 1$ and $D_s = 1$ by definition. The estimates are biased since they are estimated as logarithms (see Laurent, 1963). FPØW applies an approximate correction for bias obtained from a Taylor series expansion of the estimate about its true value. For example, if θ is the desired parameter and $\hat{m}$ is its log-estimate then

$$\hat{\theta}_B = e^{\hat{m}} = e^m + (\hat{m}-m)e^m + \frac{(\hat{m}-m)^2}{2!}e^m + \frac{(\hat{m}-m)^3}{3!}e^m + \frac{(\hat{m}-m)^4}{4!}e^m + \ldots .$$

Taking expectations, the odd terms are all zero and if one neglects the terms higher than second order for $\hat{m}$ near m

$$E(\hat{\theta}_B) \approx e^m + \frac{1}{2}\sigma_{\hat{m}}^2 \cdot e^m .$$

The bias, with $\hat{m}$ close to its true value m, is approximately

$$\frac{1}{2}\sigma_{\hat{m}}^2 \cdot e^m ,$$

so an approximate unbiased estimate is

$$\hat{\theta} = e^{\hat{m}}(1 - \frac{1}{2}\sigma_{\hat{m}}^2) .$$

In terms of the parameters of FPØW

$$\hat{\rho}_i = e^{\hat{\alpha}'_i}(1 - \mathrm{Var}(\hat{\alpha}'_i)/2)$$

and $$\hat{D}_j = e^{\hat{\beta}'_j}(1 - \mathrm{Var}(\hat{\beta}'_j)/2)$$

FPØW computes approximate 95 % confidence intervals as

$$\mathrm{C.I.}\ \hat{\rho}_i = e^{(\hat{\alpha}'_i \pm 1.96 \times \sqrt{\mathrm{Var}(\hat{\alpha}'_i)})}$$

and $$\mathrm{C.I.}\ \hat{D}_j = e^{(\hat{\beta}'_j \pm 1.96 \times \sqrt{\mathrm{Var}(\hat{\beta}'_j)})} .$$

Usage Notes

1. a) The treatments (called BØATS by FPØW) may be given any numeric designation. However, FPØW will always select the smallest numeric value as the standard.

   b) The AREA-DATES also may be given any numeric designation. FPØW will select as the standard that AREA-DATE with the lowest numeric value in which the standard BØAT first occurs.

   c) Since the variances of the estimates include the variance of the standard, that BØAT which appears in the most AREA-DATES should be selected as the standard and be given the lowest numeric designation in order to obtain the smallest variances of the estimates.

2. Each BØAT need not appear in every AREA-DATE and zero catch observations may be entered.

3. Catch per unit effort values are the data entered into the program, but FPØW calls them CATCH.

4. FPØW computes the expected catch per unit effort for the standard BØAT in the standard AREA-DATE. Therefore, standardized catch per unit effort may be obtained by multiplying the expected value times each of the estimates of relative density. However, unless the amount of effort for each BØAT-type is relatively uniform within each AREA-DATE, this procedure is not recommended. The major drawback to this program is that the estimates are not weighted by the amount of effort. With greater effort the variance of the observation is likely to be smaller. One can do nothing about the estimates of relative fishing power, but better estimates of standardized catch per unit effort may be obtained in the long manner of multiplying each BØAT effort by its relative fishing power estimate, summing up the standardized effort and dividing it into the catch.

5. Another drawback is that an analysis of variance is not performed and there is no provision for testing for interaction. Also one cannot use alternative ANOVA models such as nested designs which often may be the appropriate ones. BMDX64 (Dixon 1970) may be used prior to FPØW to examine interaction or alternative designs, but its capacity is less than half that of FPØW. SPSS may also be used.

Card Set

1. Title Card
   - cols. 1-80 — Appears on each table.

2. Sub-title Card
   - cols. 1-80 — Appears only above data summary.

3. Control Card
   - cols. 1-3 — YES if covariance matrix desired. NØ otherwise--left justified.
   - cols. 5-7 — YES if biased estimates also desired. NØ otherwise--left justified.

4. Data Input Card
   - cols. 1-80 — Variable "F" format statement.

5. Data Cards--Must agree with Card (4) in format.
   - field one — An α_i, where i=1...k treatments (BØATS).
   - field two — A β_j, where j=1...n AREA-DATES.
   - field three — A catch per unit effort.

6. Blank Card

References

Dixon, W. J. (ed.) 1970. BMD biomedical computer programs. X-series supplement. U. Calif. Press, Berkeley, 260 p.

Laurent, A. G. 1963. The log-normal distribution and the translation method: description and estimation problems. J. Amer. Stat. Assn. 58:231-235.

Robson, D. S. 1966. Estimation of the relative fishing power of individual ships. I.C.N.A.F. Research Bull. No. 3, p. 5-14.

Control cards for FR 731:

```
!JOB 712,_ _ _ _(User ID)

!LIMIT (TIME,3),(CORE,30)

!PCL
COPY Y9FPOW,345 to Y9FPOW
COPY Y9FPS1,345 to Y9FPS1
COPY Y9FPS2,345 to Y9FPS2
COPY Y9FPS3,345 to Y9FPS3
COPY Y9FPS4,345 to Y9FPS4
COPY Y9FPS5,345 to Y9FPS5
COPY Y9FPS6,345 to Y9FPS6
END

!ASSIGN F:5,(DEVICE,SI)

!ASSIGN F:6,(DEVICE,LO)

!ASSIGN F:1,(FILE,FPOW1),(OUTIN)

!ASSIGN F:2,(FILE,FPOW2),(OUTIN)

!LOAD (EF,(Y9FPOW),(Y9FPS1),(Y9FPS2),(Y9FPS3),

               (Y9FPS4),(Y9FPS5),(Y9FPS6)),; /on !Load card/
!(BREF)

!TREE Y9FPOW-(Y9FPS1,Y9FPS2-(Y9FPS3,Y9FPS4,Y9FPS5),Y9FPS6)

!RUN

!DATA
```

To run Program FR 731 in "batch" mode, the user enters the following information on the teletype:

```
!EDIT

EDIT HERE

*BUILD_ _ _ _(Job name)

 1,000 Above control cards ("!JOB"only for Statement 1)
     ↓
     ↓
     ↓
 8,000 Data card images

            etc.

 *END

 !BATCH (Job name)
```

Restrictions: Number of observations $\leq$2,000
Number of treatments + area dates $\leq$200

PROGRAM: Y9VBPD (VBPRED)

PROGRAMMER: V. Anthony, NMFS, NEFC, Woods Hole, Massachusetts 02543

This program computes l_t values at age according to the Von Bertalanffy growth equation

$$l_t = L_\infty(1-e^{-K(t-t_o)})^M$$

given estimates of L_∞, K, and t_o. If desired, a weighted estimate of t_o can be computed, in which case l_t values are computed using the weighted t_o value. This latter option requires additional input in the form of length at age data. Note also that the equation may be manipulated by varying the exponent "M"; this should be set equal to 1(XM = 1.0) for most applications.

The weighting procedure involves computing

$$t_o = (t + 1/K(l_n(1-l_t/L_\infty))*(l_t - L_\infty)$$

for each age, summing these values over all ages, and dividing by the sum of the weights $(l_t - L_\infty)$.

The program reads a header card containing alphameric information followed by as many data sets as desired. A blank card following the last data set will terminate the program normally. Each data set consists of the following cards:

1. A control card giving:

   a. Col. 1 = TOE = weighted t_o option (0 - not computed; 1 - compute weighted t_o value)

   b. Cols. 8-10 = LL = no. of age intervals (I3)

   c. Cols. 11-25 = XLI = L_∞(F15.0)

   d. Cols. 26-40 = XK = K (F15.0)

   e. Cols. 41-55 = XTO = t_o (F15.0)

   f. Cols. 56-70 = XM = M (1.0 for standard equation (F15.0)

   g. Cols. 71-72 = SIGN (-1 for standard equation (F2.0)

2. (For TOE = 1 only) Variable format statement for length at age data, age values $t(I)$ to be read first (use F specification) (20A4)

3. (For TOE = 1 only) Age and length data punched according to the variable format specification.

4. (For TOE = 1 only) Blank card.

Control cards for Y9VBPD:

```
!JOB 712, - - - - (User ID)

!LIMIT (TIME,2),(CORE,10)

!ASSIGN F:5,(DEVICE,SI)

!ASSIGN F:6,(DEVICE,LO)

!LOAD (EF,(Y9VBPD,345))

!RUN

!DATA
```

To run this program (Data deck) in "batch" mode, the user enters the following information on the teletype:

```
!EDIT

EDIT HERE

*BUILD _ _ _ _ (Job name)

 1.000  Above control cards ("!JOB" only for statement 1)

          ↓
          ↓
          ↓

 8.000  Data card images

                etc.

*END

!BATCH  (Job name)
```

Restrictions: As above.

Program: YPER (Y9YPER)

Programmer: W. H. Lenarz, NMFS, SWFC, LaJolla, Cal.

References: Lenarz, W. H., W. W. Fox, Jr., G. T. Sakagawa, and B. J. Rothschild. 1974. An examination of the yield per recruit basis for a minimum size regulation for Atlantic yellowfin tuna, Thunnus albacares. Fish. Bull. 72(1): 37-61.

Gulland, J. A. 1969. Manual of methods for fish stock assessment. F.A.O. Manual in Fisheries Science #4.

This program utilizes the modified form of the Beverton-Holt yield equation (Gulland 1969: 110) to produce relative yield per recruit isopleths for different E and C values where

E = exploitation rate, $F/_{F+M}$ and

$C = l_{c}/l_{\infty}$, l_c being the mean selection length at age $t_p' = t_c$.

Thus, C is the proportion of the total growth in length made before the fish enters the exploited phase.

Yield isopleths are computed as a function of 3 $M/_K$ values specified by the user to cover the range of conditions under consideration. In addition, tables of optimal length at first capture are produced at specified l_∞ values. Note that the parameter C (vertical axis) decreases from the top of the page to the foot; in consequence, each page represents the numerical equivalent of the yield-isopleth diagram for the $M/_K$ value specified. The model assumes constant fishing mortality over the fishable life span with "knife-edge" selection and a value of 3.0 for b in the length-weight equation.

The equation is:

$$Y' = E(1-c)^{M/K} \sum_{0}^{3} \frac{U_n(1-c)^n}{1 + nK/M\ (1-E)}$$

where Y' = relative yield value independent of units

$E = F/_{F+M}$ (instantaneous fishing and natural mortality coefficients)

$c = l_c/l_\infty$

K = coefficient of catabolism, and

U_n = summation variable, using 1, -3, +3, -1 for

n = 0, 1, 2, 3, respectively

Y' may be converted to weight units (i.e. , gm per recruit at age t_p (= t_r) by multiplying by $W_\infty e^{M(t_r-t_o)}$ and from this to absolute yield Y by multiplying by R = number of recruits at age t_r. Such conversions should be unnecessary for most applications.

For each series of isopleths desired, the program reads a header card with alphameric information followed by a control card and parameter cards. As many data sets as desired may be read; two blank cards following the last data set will terminate the program normally. Cards are punched as follows:

Card	Column	Format	Description
1		A	Title Card
2		F	Control Card
	1-5	F	lowest exploitation rate on isopleth (with decimal point) (suggest 0.05)
	6-10	F	Step size for exploitation rates on isopleths. (suggest 0.05)
	11-15	F	largest c-value on isopleth (suggest 1.0)
	16-20	F	Step size for c-values on isopleths (suggest 0.02)

Card	Column	Format	Description
	21-22	F	Number of different $M/_K$ values for optimum length tables ($\leq$10)
	23-24	I	Number of different E values for optimum length tables ($\leq$10)
	25-26	F	Sealing factor for Isopleths Set at: 5. M/K <3 6. 3$\leq$ M/K <10 7. 10 $\leq$M/K (If blank uses 5.)
3		6F10.0	Parameter card Low, best, High M/K Low, best, High L_∞
4		10F6.0	M/K card; M/K values for optimum length tables
5		10F6.0	E card; E values for optimum length tables

Control cards for Program YPER:

```
!JOB 712, _ _ _ _ (User ID)

!LIMIT (TIME,2),(CORE,10)

!ASSIGN F:5,(DEVICE, SI)

!ASSIGN F:6,(DEVICE,LO)

!LOAD (EF,(Y9YPER,345))

!RUN

!DATA
```

To run Program YPER (Data deck) in "batch" mode, the user enters the following information on the teletype:

```
!EDIT

EDIT HERE

*BUILD _ _ _ _ (Job name)

 1.000  Above control cards ("!JOB" only for statement 1)

        ↓
        ↓
        ↓

 8.000  Data card images

             etc.

*END

!BATCH  (Job name)
```

Restrictions: As above.

Program: FRG 701 (Y9YPIB)

Programmer: Lawrence E. Gales, Fisheries Res. Institute, Univ. Wash.

Reference: Gulland, J. A. 1969. Manual of methods for fish stock assessment. F. A. O. Manual in Fisheries Sciences #4.

Program Y9YPIB uses the incomplete Beta function in the Beverton-Holt yield equation to produce an array of coordinates for plotting yield isopleths. The program accepts up to 50 values of F and t_p' (age at entry to the exploited phase); the yield, Y_w, is evaluated at each pair of F and t_p' to produce each coordinate. The model assumes constant fishing mortality over the fishable life span; it allows for a b value of other than 3.0 from the length-weight equation.

The formula is

$$Y_w = RW_\infty e^{M(t_p-t_o)} g(1-c)^{-g} \int_0^{1-c} y^{(m+g-1)}(1-y)^b \, dy$$

Modified to

$$Y_w = RW_\infty e^{M(t_p-t_o)} g (1-c)^{-g} B_{1-c} (m+g, b+1)$$

by expressing the integral as an incomplete beta function.

Here $g = F/_K$

$m = M/_K$

$1-c = e^{-K(t_p'-t_o)}$

$y = e^{-K(t-t_o)}$

Y_w = yield in weight

W_∞ = asymptotic weight

R = number of recruits at age t_p

t_p = age at recruitment.

t_p' = age at entry to the exploited phase

t_o = hypothetical age of zero length

F = instantaneous rate of fishing mortality

M = instantaneous rate of natural mortality

K = coefficient of catabolism

b = exponent in length-weight equation.

Since the yield values are determined by integration of four third degree polynomials, an initial limit of integration must be calculated. This is given by

$$S = e^{-K(t_\lambda - t_o)}$$

where t_λ = end of the fishable life span

Input consists of two data cards punched in 8F 8.0 format; thus, decimals <u>must</u> be punched. Values are arranged as follows:

<u>Card 1</u>

Cols. 1-8 Initial value of F (FO)

Cols. 9-16 Initial value of t_p' (TPPO)

Cols. 17-24 Final value of F (RANGE)

Cols. 25-32 Final value of t_p' (UPPER)

Cols. 33-40 Increment in F (FDELT)

Cols. 41-48 Increment in t_p' (DELTAT)

Cols. 49-56 b-length-weight exponent (DELTA)

Cols. 57-64 A second exponent (DDELTA)

This is used to compare results of the first computation to the second where b $\neq$ 3.0. If no comparison is desired set this equal to 0.

Card 2

Cols. 1-8 R-number of recruits at t_p (R)

Cols. 9-16 W_∞-asymptotic weight (W)

Cols. 17-24 M - instantaneous natural mortality (AM)

Cols. 25-32 K -coefficient of catabolism (AK)

Cols. 33-40 t_p -age at recruitment (TP)

Cols. 41-48 t_o - age at o length (TO)

Cols. 49-56 t_λ - maximum age (T LAMBA)

Cols. 57-64 S - initial limit of integration (XINTO)

Control cards for FRG 701:

```
!JOB 712, _ _ _ _ (User ID)

!LIMIT (TIME,2),(CORE,10)

!ASSIGN F:5,(DEVICE,SI)

!ASSIGN F:6,(DEVICE,LO)

!LOAD (EF,(Y9YPIB,345))

!RUN

!DATA
```

To run Program FRG 701 (Data deck) in "batch" mode, the user enters the following information on the teletype:

```
!EDIT

EDIT HERE

*BUILD_ _ _ _ (Job name)

 1.000  Above control cards ("!JOB" only for statement 1)

        ↓
        ↓
        ↓

 8.000  Data card images

             etc.

*END

!BATCH  (Job name)
```

Restrictions: Number of F and tp' values ≤ 50.

<u>The following instructions are used to access RAMUS:</u>

1. Terminal settings.

   Speed = 10 or 30

   Duplex = full

   Parity = none

2. Dial the number for the system: 1-800-241-9817 (10 cps)

   1-800-241-1890 (30 cps)

   a. After dialing the number, a high-pitched tone will be heard; at this time place the telephone handset in the terminal acoustic coupler.

   b. "User ID" is then typed; the computer then pauses; at this point type B325. The response will be "password."

      At this type: COMA. The response will be "old or new." Enter "old."

      The response will be "file name." Enter the program name of the file.

      The response will be "ready." Then punch in "run."

<u>The following instructions are used to access the WHOI system:</u>

1. Terminal settings.

   Speed = 10 or 30

   Duplex = full

   Parity = none

2. Dial the number for the system:

Black phone	Blue phone	Speed
540-3745	61	10 cps
540-3612	63	30 cps

   a. After dialing the number, a high-pitched computer tone will be heard; at this time place the handset in the terminal acoustic coupler and press the "break" key.

   b. "Log on please" is then typed; at this point type the account number and your user ID number. The response will be an exclamation point; at this point type "Run" and the file name.