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EVALUATION OF OPTIONS FOR MANAGING NORTHERN ANCHOVY-- A SIMULATION MODEL

By

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ABSTRACT

This report describes a simple bio-economic model (FMPSIM) implemented in FORTRAN-77 that can be used to simulate: 1) the population dynamics of northern anchovy (Engraulis mordax) in the central sub-population, 2) effects of changes in anchovy abundance on the endangered brown pelican (Pelecanus occidentalis californicus), and 3) fisheries associated with the anchovy stock. Two versions of the model were used to evaluate a set of options for modifying the Anchovy Fishery Management Plan to: 1) include a definition of overfishing, and 2) provide a small reduction fishery during years when the spawning biomass is low. One version of the basic model (the simulation program FMPSIM) is general and may, with little or no modification, be useful as a basis for evaluating management options proposed in the future.

A number of biological and economic parameters were estimated in the course of developing the simulation model. In particular, maximum sustained yield was estimated to be 219,000 mt/year at a total biomass level of 586,000 mt.

INTRODUCTION

Management of the central sub-population of northern anchovy (Engraulis mordax) by the Pacific Fishery Management Council (PFMC) is described in the Anchovy Fishery Management Plan (FMP). The current management approach involves an optimum yield (OY) formula for the reduction fishery that depends on the estimated annual spawning biomass (PFMC 1983). Optimal yield for the reduction fishery is:

i) zero, if the spawning biomass is less than or equal to 300,000 metric tons, and

ii) the difference between the spawning biomass and 300,000 mt (up to a limit of 200,000 mt) if the spawning biomass is greater than 300,000 mt.

The reduction quota in the U.S. Exclusive Economic Zone (EEZ) is 70% of the total OY for reduction fishery. For example, if OY for the reduction fishery is 200,000 mt, then the U.S. reduction quota is 0.70 x 200,000 mt = 140,000 mt and the Mexican quota is 0.30 x 200,000 mt = 60,000 mt. A portion of the U.S. quota equal to 9,072 mt or 10% (whichever is smaller) is reserved for the fishery north of Point Buchon. Reduction fishing is prohibited from July 1 through July 30 north of Point Buchon and July 1 through September 14 south of Point Buchon. The regulations specify minimum mesh sizes (5/8 inch stretched measure) for round haul nets used to harvest anchovy. Reduction fishing in most nearshore areas south of Point Buchon and near San Francisco Bay is disallowed.

OY for the nonreduction (excluding live bait) fishery is 7,000 mt, of which 70% (4,900 mt) is reserved for the U.S. EEZ. Nonreduction (excluding live bait) fishing is permitted year-round and is independent of the level of spawning biomass.

The FMP imposes no seasonal restrictions or numeric OY on the live bait fishery.

Reduction OY at Low Levels of Spawning Biomass

The anchovy spawning biomass was estimated to be 214,000 mt during February of 1989 (Jacobson and Lo 1989). By contrast, total biomass during February was estimated to be 1,008,000 mt. The large discrepancy between spawning and total biomass estimates was attributed to the effect of unusually cold water temperatures during the peak spawning period on the sexual maturity of one-year-old fish (Jacobson and Lo 1989).

As noted above, the FMP requires that the anchovy reduction fishery be closed when the spawning biomass is less than or equal to 300,000 mt. Because of the high level of total biomass, however, the Pacific Fishery Management Council's Scientific and Statistical Committee concluded that a modest domestic reduction fishery during the 1989/90 season would produce no significant adverse effect on anchovy abundance. Therefore the Council requested and the Department of Commerce has approved an emergency rule, which took effect on 25 September 1989, allowing a domestic reduction fishery of 5,000 mt in the 1989/90 season.

The Council followed up on the emergency rule by considering an amendment to the FMP. To this end, the Council instructed the Anchovy Plan Development Team to devise and analyze a variety of options for amending the Optimum Yield (OY) formula in the current FMP to allow a small reduction fishery when the spawning biomass falls below the current 300,000 mt cutoff level.

Definition of Overfishing

Revised guidelines for preparation of Fishery Management Plans were published in the Federal Register on 24 July 1989. The revised guidelines specify that each FMP must include a definition of overfishing. The revised guidelines are intended to eliminate directed fishing on stocks that are judged to be overfished by an objective standard. Consequently, the PFMC instructed the Anchovy Plan Development Team to develop and analyze options for defining overfishing as well as options for amending the reduction fishery OY. Two versions of the basic model described in this report were used to evaluate the options devised by the Team.

STRUCTURE OF THE MODEL

In this report, the index t is used for years and the index j is used for fishery types (reduction, live bait or nonreduction commercial). For example, GPROF(t,j) refers to gross profit for fishery j in year t. Unless otherwise noted, units for biomass are million mt. All logarithms are natural logarithms.

Population Dynamics

Spawning is assumed to occur at the beginning of the year. Spawning biomass is given by:

$$TRUESB(t)=B(t)*FRACMAT(t), \quad [1]$$

where TRUESB(t) is spawning biomass at the beginning of year t, B(t) is the total biomass at the beginning of year t and FRACMAT(t) is the fraction of the total biomass that is sexually mature.

As described above, the spawning biomass of northern anchovy is estimated annually. Optimum yield and quotas for the reduction fishery are based on the estimated spawning biomass. In the model, estimated spawning biomass depends on the true spawning biomass and an observation error:

$$OBSSB(t)=TRUESB(t)*e^{TEMP(t)}, \quad [2]$$

where OBSSB(t) is the estimated spawning biomass and TEMP(t) is drawn from a normal distribution with mean zero and a specified standard deviation (SDM). The value of OBSSB(t) is used in the model to determine the annual reduction quota for the year. It is likely that estimates of anchovy spawning biomass currently used to determine quotas are biased (Jacobson and Lo 1989). A more realistic model might, therefore, include bias in the measurement of spawning biomass as well as imprecision.

Biomass at the beginning of year t+1 depends on the biomass at the beginning of year t, catch during year t and a stochastic 'process error' that simulates the effects of variability in fecundity, growth and survival. In the absence of catch, biomass at the beginning of next year is given by:

$$B(t+1)=B(t)*e^{ALPHA+BETA*B(t)} * e^{TEMP2(t)}, \quad [3]$$

where ALPHA and BETA are parameters and TEMP2(t) is the process error. This surplus production relationship is based on the Ricker stock-recruitment model rather than the power model used by Methot and MacCall (1983) for the reasons discussed by Ludwig et al. (1988) and Ludwig and Walters (1989).

Process errors [TEMP2(t)] in the model were assumed to be cyclic and, therefore, autocorrelated:

$$TEMP2(t)=TEMPA(t)+AMP*SIN[MOD(t,PERIOD)/PERIOD*2*PI], \quad [4]$$

where TEMPA(t) is drawn from the normal distribution with mean zero and a specified standard deviation (SDB). AMP and PERIOD are the amplitude and the period, respectively, of the cyclic component in the process error (Koslow 1989).

Equation [3] is valid in the absence of a fishery. When a fishery is present, it is necessary to use a discount factor described by MacCall (1978) to adjust the biomass at the beginning of year t+1 for catches in year t:

$$B'(t+1)=TEMP3(t)-DELTA(t)*CATCH(t), \qquad [5]$$

where B'(t+1) is the adjusted biomass, TEMP3(t) is the right hand side of [3], DELTA(t) is the discount factor and CATCH(t) is the catch. The discount factor accounts for the fact that some fish caught during year t would have died of natural causes and would not have contributed to the biomass at the beginning of year t+1. DELTA(t) was assumed constant in all years during simulations but not, as described below, during parameter estimation. In the model B(t) was not allowed to fall below an arbitrary small value (5,000 mt).

Fishery Dynamics and Economics

Annual quotas for the reduction fishery were determined on the basis of the spawning biomass and total biomass as described below for each FMP amendment option that was evaluated. Catches in each year (if any catch was taken) by the live bait fishery and other nonreduction fisheries were assumed to be constant. In the model, the entire reduction quota or catch was taken if fishing was profitable. No catches were taken if fishing was not profitable.

Profitability was assumed to depend on: 1) anchovy abundance (measured as catch-per-unit-effort in units of 10^6 mt/hour), 2) operating costs (\$/hour) and ex-vessel prices for anchovy (\$/10^6 mt). The relationship between catch-per-unit-effort and abundance was nonlinear:

$$CPUE(t)=CPUE1*B(t)^{CPUEP2}, \qquad [6]$$

where CPUE(t) is catch-per-unit-effort and CPUEP1 and CPUEP2 are parameters. CPUE(t) was assumed to be the same for the reduction, live bait and other nonreduction fisheries.

Fishing effort required to catch the entire quota or catch was calculated as:

$$EFFORT(t,j)=QUOTA(t,j)/CPUE(t), \qquad [7]$$

where EFFORT(t,j) is the required fishing effort (hours of fishing) and QUOTA(t,j) is the quota (for the reduction fishery) or catch (for the live bait and other nonreduction fisheries).

The potential cost of fishing (i.e. taking the entire quota or catch) was calculated as:

$$COST(t,j)=EFFORT(t,j)*COSTEF, \qquad [8]$$

where COST(t,j) is total cost ($) and COSTEF is the cost of one unit of fishing effort (assumed to be the same for the reduction, live bait and other nonreduction fisheries).

Gross profits were calculated as:

$$GPROF(t,j)=QUOTA(t,j)*EXVAL(t,j), \qquad [9]$$

where GPROF(t,j) is gross profits ($) and EXVAL(t,j) is the ex-vessel price. Net profits were calculated by subtracting costs [8] from gross profits [9]. If net profits for a particular fishery were positive, then the entire quota or catch for that fishery was taken.

It can be shown that net profits are positive [GPROF(t,j) > COST(t,j)] whenever:

$$EXVAL(t,j)-COSTEF/CPUE(t) > 0.0, \text{ or} \qquad [10]$$

$$EXVAL(t,j)-COSTEF/[CPUEP1*B(t)^{CPUEP2}] > 0.0. \qquad [11]$$

Maximum Sustained Yield (MSY)

Catch of northern anchovy is given by:

$$C(t)=[B(t+1)-B(t)]/DELTA(t). \qquad [12]$$

Substituting [3] (without the stochastic term) into [12] gives:

$$C(t)=\{B(t)*e^{ALPHA+BETA*B(t)}-B(t)\}/DELTA(t). \qquad [13]$$

If one assumes that DELTA(t) is constant, the first derivative of [13] with respect to B(t) is:

$$C'(t)=\{e^{ALPHA+BETA*B(t)}*[1+BETA*B(t)]-1\}/DELTA. \qquad [14]$$

Total biomass at MSY (B^*) can be estimated by setting [14] equal to zero and solving numerically for B^*. The catch at MSY (C^*)can be estimated by solving [13] using $B(t)=B^*$.

Brown Pelicans

The brown pelican (Pelecanus occidentalis californicus), is an endangered species whose reproductive success is thought to be dependent on anchovy abundance (Anderson et al. 1980; Anderson et al. 1982; PFMC 1983). In order to evaluate potential affects of anchovy management options on brown pelicans, a simple function (described below) relating total biomass of anchovy and breeding success of brown pelicans was included in the model.

Implementation

The simulation models used in this analysis were written in FORTRAN-77. The program FMPSIM was used to analyze options for amending the formula for reduction quotas. The program FMPTIME was used primarily to analyze options for the definition of overfishing. FMPSIM calculates the effect of different options for reduction quotas on mean annual reduction harvests, mean annual reduction profits, brown pelican reproductive success and a variety of other factors. FMPTIME calculates the mean and probability distribution for 'recovery times' (recovery times are the amount of time required for the anchovy stock to increase from a low to a high level of spawning biomass). All input files (appendices A and C) and output files (appendices B and D) are self documenting. The source code for the FORTRAN programs is internally documented (appendices E and F).

PARAMETER ESTIMATES

Estimates of total biomass and spawning biomass from the Anchovy Stock Synthesis Model (Methot 1986; 1989) were used as 'data' for parameter estimation. Data for 1954-1963 were obtained from Methot (1989) and data for 1964-1989 were obtained from Jacobson and Lo (1989, Figure 1). Inclusion of the data for 1954-1963 resulted in bad (unreasonable) estimates of MSY possibly due to differences between the statistical procedures used by Methot (1989) and Jacobson and Lo (1989). Data for 1986-1989 are not thought to be reliable (Jacobson and Lo 1989). Consequently, only the data for 1964-1985 were included in this analysis (Table 1).

Spawning Stock Biomass and Fraction Mature

Parameters used in the model to determine the fraction of the total biomass that spawned in each year [FRACMAT(t)] were estimated from the total and spawning biomass data (Table 1). Values of fraction mature for 1964-1985 were calculated as the ratio of the spawning biomass and total biomass in each year.

The observed distribution of logit transformed values for fraction mature was used in the model as a basis for calculating FRACMAT(t) in [1]. The logit transform of the variable FRACMAT(t) is:

$$LOGIT[FRACMAT(t)]=LOG\{FRACMAT(t)/[1-FRACMAT(t)]\}. \quad [15]$$

The distribution of logit transformed maturity data was approximately normal with mean = 2.616 and standard deviation = 1.736. The fraction of the stock that was sexually mature in the model was, therefore, determined by:

$$FRACMAT(t)=e^{TEMP4(t)}/[1+e^{TEMP4(t)}], \quad [16]$$

where TEMP4(t) is drawn from a normal distribution with mean 2.616 and standard deviation 1.736. Note that [16] is obtained from [15] by solving for FRACMAT(t). Fraction mature was modeled as an independent random variable because there was no evidence of correlation in plots of observed fraction mature (after logit transformation) versus observed total biomass. FRACMAT(t) was not allowed to take values lower than 0.3 because extremely low values have never been observed (Table 1). In this analysis, the standard deviation for errors in the observation of spawning biomass (SDM in [2]) was set to zero because there were no data from which its value could be estimated.

Production

Catch data and total biomass estimates for anchovy during 1964-1985 (Table 1) were used to estimate parameters in the model that determined production. The biomass estimates were for the middle of February in each year. It was necessary, therefore, to tabulate the catch data on the basis of a February to January year (Table 1).

Parameters were estimated using an error-in-variables version of the linear regression model:

$$LOG[PT(t)]=ALPHA'+BETA*B(t). \qquad [17]$$

PT(t) is the 'productivity' in year t and is given by:

$$PT(t)=B'(t+1)/B(t). \qquad [18]$$

Note that [17] is (neglecting the stochastic term) a linearized version of [3]. The difference between ALPHA' in [17] and ALPHA in [3] is explained below.

The discount factor [DELTA(t)] used in [5] to calculate B'(t+1) in [18] depends strongly on the rates of growth and natural mortality and is weakly dependent on the rate of fishing mortality (MacCall 1978). For this analysis, the fishing mortality rate was arbitrarily assumed to be 1.0 yr^{-1} and the exponential growth rate (estimated from data in MacCall and Methot 1983, Table 2-2) was assumed to be 0.16 yr^{-1}.

Natural mortality is thought to be a function of Pacific mackerel (*Scomber japonicus*) biomass (Methot 1986) given by:

$$M(t)=0.6+0.4*PACMAC(t), \qquad [19]$$

where M(t) is the instantaneous rate for natural mortality and PACMAC(t) is the biomass of Pacific mackerel in units of 10^6 mt on 1 July (Table 1). Pacific mackerel biomass data were obtained from the California Department of Fish and Game (Jacobson and Lo 1989).

Estimation of parameters in [17] is complicated by the 'errors-in-variables' problem [i.e. error in the measurement of the independent variable B(t)] (Wonnacott and Wonnacott 1970, MacCall and Methot 1983). The appropriate estimator for the slope parameter BETA in this situation is:

$$\text{BETA}=\text{THETA}\pm(\text{THETA}^2+\text{LAMBDA})^{0.5}, \qquad [20]$$

where LAMBDA is the ratio of the variance in the dependent variable (due to measurement error and stochastic variation) and the variance due to measurement error in the independent variable. THETA is given by:

$$\text{THETA}=(SS_{YY}-\text{LAMBDA}*SS_{XX})/(2*SS_{XY}), \qquad [21]$$

where SS_{YY} is the variance in the dependent variable, SS_{XX} is the variance in the independent variable, and SS_{XY} is the covariance.

A 'pure error' estimate of error variance for the dependent variable in a regression model (e.g. Y = AX + B) can be obtained from the variance of Y values that share the same or nearly equal values of X (Weisberg 1980). A pure error estimate of SS_{YY}=0.133 was obtained from the variance of LOG[PT(t)] for values of B(t) in the range of 0.35 to 0.43.

Year	B(t)	LOG[P(t)]
1967	0.385	0.0298
1968	0.358	0.0729
1969	0.357	0.131
1970	0.350	0.726
1978	0.429	0.791
1984	0.377	0.702
	variance=	0.133

In order to estimate SS_{xx}, it was assumed that the stock synthesis model (from which the estimates of B(t) were obtained) is as precise as the egg production method (EPM) for estimating spawning stock biomass (Lasker 1985). The variance of EPM estimates during 1980-1985 was calculated from the mean values and coefficients of variation (CV) given in Fiedler et al. (1986, Table 1).

Year	CV	Mean	Variance
1980	0.26	0.870	0.0512
1981	0.22	0.635	0.0195
1982	0.06	0.415	0.000620
1983	0.21	0.652	0.0187
1984	0.17	0.309	0.00276
1985	0.19	0.522	0.00984
		mean =	0.0171

The mean of the variances (0.0171) was used as an estimate of SS_{xx}. The resulting value for LAMBDA (7.79) was quite large indicating that similar results would have been obtained by ordinary least squares regression. The estimates obtained using the error in variables model were ALPHA'= 0.4056 and BETA = -0.36531 (Figure 1). Estimates from ordinary least squares regression were ALPHA' = 0.38117 and BETA = -0.33164.

The parameter estimates obtained so far are appropriate for prediction of LOG[PT(t)] from B(t). In order to predict PT(t) values on an arithmetic scale it was necessary to adjust the estimate of ALPHA' (Beauchamp and Olson 1973). The adjustment is given by:

$$ALPHA=ALPHA'+VAR/2, \qquad [22]$$

where ALPHA = 0.4554 is the adjusted value of the intercept and VAR = 0.0995 is the variance of residuals from the regression analysis. The line finally fitted to the arithmetic scale data is shown in Figure 2.

A pure error estimate of the standard deviation for natural variability in production of anchovy (TEMPA in [4]) was obtained from the variance of observed LOG[B'(t+1)] values (Table 1) for values of B(t) in the range of 0.35 to 0.43.

Year	B(t)	LOG[B'(t+1)]
1967	0.385	-0.925
1968	0.358	-0.954
1969	0.357	-0.899
1970	0.350	-0.324
1978	0.429	-0.0557
1984	0.377	-0.273
	variance=	0.159
	st. dev.=	0.399

The standard deviation was 0.399 which means that the multiplicative error affecting production would be between 0.45

and 2.18 about 95% of the time (i.e. the value of $e^{0.399v}$, where v is drawn from the standard normal distribution, falls between 0.45 and 2.18 about 95% of the time). The value obtained in this manner may be an overestimate of the actual variability, however, because values of the independent variable used for the pure error estimate were not exactly equal. For this reason, a slightly smaller value (0.35) for the standard deviation was used in the model. A standard deviation of 0.35 means that the multiplicative process error affecting production is between 0.5 and 2.0 about 95% of the time.

A plot of the residuals from the regression analysis (Figure 3) suggested that the residuals (and process errors) were autocorrelated although the evidence was not strong statistically (p-value > 0.05, runs test for the null hypothesis of no serial correlation). There was no clear evidence of periodicity in the plot (particularly during recent years). In order to introduce some autocorrelation into the analysis without introducing strong long term cycles, a short period (PERIOD=5.0 years) and an amplitude small relative to the stochastic effects (AMP=0.05) was assumed for the cyclic component of the process error in [4].

<u>Discount Factor for Catches</u>

As noted above, the discount factor used to determine the affect of catches in year t on biomass at the beginning of year t+1 depends on the natural mortality rate in year t. For northern anchovy, the natural mortality rate depends on Pacific mackerel biomass. Variability in the discount factor due to variability in natural mortality was considered during parameter estimation as described above. In the model itself, however, it was assumed that natural mortality and the discount factor were constant from year to year. The mean biomass of Pacific mackerel (730,000 mt) during 1981-1988 (Table 1) was used in equation [19] to compute the discount factor (DELTA=0.7) used in the simulations. The fishing mortality rate used to calculate DELTA for the simulations was set arbitrarily to 1.0 yr^{-1}.

Catch-per-unit-effort

Parameters relating CPUE to total biomass were estimated using simple linear regression and the linear model that results from log transforming both sides of equation [6]. The CPUE data used (Table 1) were obtained from the existing Anchovy FMP (PFMC 1983). An error-in-variables model was not used for parameter estimation because, as noted above, the apparent magnitude of errors in measurement of the independent variable [B(t)] relative to variability in the dependent variable [CPUE(t)] results in near equality of simple linear regression and error-in-variables estimates (Figure 4).

Operating Costs

Operating costs (exclusive of depreciation, insurance and maintenance costs) for the reduction, nonreduction and live bait fisheries were assumed to be $288.29/hour. This figure was obtained by converting the figure for reduction fishery costs used in the current FMP (PFMC 1983) to 1988 dollars by correcting for inflation. No data concerning operating costs in the live bait and non-reduction fisheries were available.

Ex-vessel Prices

Ex-vessel prices for the live bait, nonreduction and reduction fisheries were assumed to be $681/mt, $287/mt and $79/mt, respectively. The ex-vessel price for live bait was obtained by converting the figure used in the current FMP to 1988 dollars by correcting for inflation. The nonreduction ex-vessel price used in the model is the mean of ex-vessel prices (converted to 1988 dollars) paid during 1980-1988 (Table 2). The reduction fishery ex-vessel price used in the model is the price paid during 1981 (the most recent season in which U.S. reduction landings exceeded 50,000 mt) converted to 1988 dollars (Table 3). The value used ($79/mt) is about 2.5 times greater than the price actually paid during 1988 ($32/mt). A relatively high price was used in order to exaggerate the potential effects of the various options on the anchovy stock.

Live-bait and Commercial Nonreduction Landings

Live bait landings in the model were assumed to be 4,078 mt and nonreduction landings were assumed to be 1,188 mt per season. These values are the average of live bait and nonreduction landings, respectively for the nine seasons beginning in 1979/80 (Table 4).

Dependent Species-Brown Pelicans

Data describing breeding success (fledglings/pair) of brown pelicans on Anacapa and Coronado islands (Table 5) were obtained from Lewis (in prep.). The linear regression model fitted to the data for breeding pelicans on Anacapa Island was:

$$S(t)=P0 + P1*t + P2*B(t) + E(t), \qquad [23]$$

where S(t) is breeding success in year t, E(t) is the stochastic error in year t and P0, P1 and P2 are parameters. All of the parameters in the model were significantly different from zero (see below) and there was no evidence of lack of fit in residual plots. The results of this analysis suggest that breeding success on Anacapa Island has improved since 1964 and is correlated with anchovy biomass (Anderson et al. 1980; Anderson et al. (1982); PFMC 1983). The trend over time may be due to decreasing levels of DDT and other pollutants in the ecosystem.

Parameter	Estimate	S.D.	t-ratio	P
P0	-4.44	0.781	-5.69	< 0.001
P1	0.0599	0.00976	6.14	< 0.001
P2	0.428	0.128	3.35	0.005

The regression model explained 75% of the variation in the breeding success data for pelicans nesting on Anacapa Island during 1964-1985.

A modified version of equation [23] was used in the model for predicting breeding success:

$$S(t)=(P0 + P1*85) + P2*B(t), \qquad [24]$$

where the intercept is (P0 + P1*85) = 0.652 (note 85 is the last year in the data set) and the slope is P2 = 0.428. This approach assumes that conditions affecting brown pelican breeding success (other than anchovy biomass) are constant at the level that prevailed in 1985. Values of S(t) obtained from [24] were constrained to lie within the interval (0.05, 1.2). Stochastic variation in pelican breeding success was not included in the model.

MANAGEMENT OPTIONS

Reduction Fishery OY

The Anchovy Plan Development Team devised three different options (summarized in Table 6) for amending the reduction fishery OY formula:

i) Option 1 is the "Status Quo" option and involves no modification to the current FMP and OY formulas.

ii) Option 2 is the "Conditional" option which increases the reduction OY to 7,000 mt (U.S. quota increased to 4,900 mt) when two conditions prevail simultaneously: (a) the spawning biomass is less than or equal to 307,000 mt, and (b) the total biomass is greater than or equal to 375,000 mt. If the spawning biomass falls between 300,000 mt and 307,000 mt and the total biomass is less than 375,000 mt, then the reduction OY is the difference between the spawning biomass and 300,000 mt (as for the Status Quo option).

iii) Option 3 is the "Unconditional" option which increases the reduction OY to 7,000 mt (U.S. quota increased to 4,900 mt) whenever the spawning biomass falls below 307,000 mt.

Option 1 (Status Quo) closes the reduction fishery when the spawning biomass falls below 300,000 mt. Use of a 300,000 mt cutoff level for the other options would, however, have produced some anomalous results. For example, specification of a 300,000 mt cutoff under Option 3 would cause the reduction fishery to receive a 1,000 mt quota if the spawning biomass were 301,000 mt but a 7,000 mt OY if the spawning biomass were 299,000 mt. By setting the cut-off at 307,000 mt for this option, the reduction fishery is allowed to take 7,000 mt when the spawning biomass is less than or equal to 307,000 mt, and the difference between the spawning biomass and 300,000 mt when the spawning biomass is greater than 307,000 mt, up to a maximum of 200,000 mt. Using a similar rationale, the cut-off level for spawning biomass was set at 307,000 mt for Option 2.

The reduction OY under Option 2 is the difference between the spawning biomass and 300,000 mt when the spawning biomass falls between 300,000 mt and 307,000 mt and the total biomass is less than 375,000 mt because without this adjustment the reduction OY could be zero under conditions that currently allow a small fishery. The cutoff level of 375,000 mt was chosen for total biomass under Option 2 because spawning biomass can be regarded as a poor measure of total biomass when the fraction spawning is less than 80% of the total (i.e. 375,000 mt x 0.80 = 300,000 mt, the original cutoff value).

Definition of Overfishing

The Team developed two options for the definition of overfishing. The first option was to define overfishing as fishing that exceeds OY. Under the first option, a particular fishery would cease when the respective OY level was exceeded (e.g. reduction fishing would cease when the reduction harvest exceeded the reduction OY). The second option was to define overfishing as fishing at spawning biomass levels below 50,000 mt. Under the second option, all fishing (reduction, live bait and non-reduction commercial) would cease in years when the estimated spawning biomass was below 50,000 mt. In practical terms, the first option amounts to maintaining the status quo and the second option amounts to adopting a spawning biomass cutoff level for all fishing.

The three options for reduction OY and the two options for the definition of overfishing can be combined to make six options in total. In this report, the suffix 'L' indicates that the respective option includes a lower cutoff for all fishing at 50,000 mt. For example, Option 1L includes a lower cutoff for all fishing while Option 1 does not.

RESULTS

A preliminary analysis of the numeric properties of the program FMPSIM (given the parameter estimates described above) showed that about 1 million simulated years were required to obtain results that were sufficiently precise. Each management option was evaluated, therefore, on the basis of a single run of the model involving one million simulated years. The same sequence of random numbers was used in the simulation run for each option.

A preliminary analysis of the numeric properties of the program FMPTIME showed that results from 500,000 individual simulation runs were required to obtain results that were sufficiently precise. The result obtained from each simulation run was the time required for the stock to reach a spawning biomass level of 300,000 mt from an initial spawning biomass of 25,000 mt.

MSY

Deterministic MSY was estimated to be about 219,000 mt at a total biomass of about 586,000 mt. The value obtained for MSY is lower than the value for MSY (276,000 mt at a spawning biomass of 626,000 mt) estimated by Methot and MacCall (1983).

Management Options

Results obtained using the program FMPSIM showed no differences among options in terms of total biomass, reduction catch, pelican breeding success or reduction profit (Table 7). Mean annual biomass was 840,000 mt, mean annual catch was 150,000 mt and mean annual profit was 3.7 million dollars for all options. It should be noted that these catch and profit figures are much higher than the values historically experienced in the reduction fishery. The reason for this disparity is that the simulation model incorporates two unrealistic assumptions that were made in order to exaggerate the effects of fishing on the stock. The two assumptions are: 1) that fisherman take the entire OY when fishing is profitable, and 2) that the ex-vessel reduction price is $79 per mt.

Table 7 also describes the frequency and duration of no-fishing intervals under each of the options. According to Table 7, reduction fishing would cease completely in 11% (options 2, 2L, 3 and 3L) to 15% (options 1 and 1L) of all years. The mean length of intervals with no reduction catch would be about two years for all options.

An important distinction is whether cessation of fishing occurs as a result of FMP-mandated closures at low levels of spawning biomass or because prevailing ex-vessel prices and costs make fishing unprofitable. According to Table 7, FMP-mandated closures would occur in 13% of all years under options 1 and 1L and in 9% of all years under option 2 and 2L. No FMP-mandated closures and would occur under options 3 and 3L. Fishing would be unprofitable, however, in 11% of all years under each of the options.

"Break-even" ex-vessel prices were computed for various levels of anchovy abundance using equation [11]. The plotted values (Figure 5) show that ex-vessel prices for reduction fishing would have to be in excess of $80/mt to make fishing profitable at total biomass levels as low as 350,000 mt. These results suggest that fishermen generally would not find it profitable to fish at low levels of spawning biomass even if fishing were allowed by the FMP. Lack of profit appears to be a more binding constraint on reduction fishing than FMP-mandated closures.

Results obtained using the program FMPTIME (Table 8) suggest a modest difference in recovery times due to the presence of a 50,000 mt cutoff level on all fishing. The mean time required for a stock with an initial spawning biomass of 25,000 mt to recover to a spawning biomass level of 300,000 mt was 7.9 years (CV 31%) with a cutoff level and 8.6 years (CV 56%) without a cutoff level. The difference between mean recovery time with a cutoff and mean recovery time without a cutoff was 0.7 years. It should be noted, however, that the parameters in the simulation model were estimated from data for 1964-1985 which were years in which anchovy biomass was moderate to high (Jacobson and Lo 1989). Estimates of mean recovery times at low levels of spawning biomass obtained from the model are, therefore, extrapolations and possibly unreliable. The true effect of a 50,000 mt cutoff on mean recovery times may be larger than the estimate of 0.7 years obtained in this study.

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Table 1. Anchovy data for 1964-1985. Units for biomass are 10^6 mt unless otherwise noted. B(t) is the 'observed' total biomass on 15 February estimated using the Stock Synthesis Model (SSM), TRUESB(t) is the observed spawning biomass on 15 February estimated using the SSM, and FRACMAT(t) is TRUESB(t)/B(t). CATCH(t) is landings tabulated on the basis of a February-January year. PACMAC(t) is estimated biomass of Pacific Mackerel on 1 July (from CDF&G). M(t) is natural mortality for anchovy. DELTA(t) is the discount factor used to adjust biomass levels in year t+1 for catches in year t. B'(t+1) is the adjusted biomass [e.g. B'(t+1) for 1964 is the biomass that would have been observed at the beginning of 1965 if there had been no catch during 1964]. P(t) is the productivity [B'(t+1)/B(t)] in year t. LOG[P(t)] is the natural logarithm of productivity. S_CPUE(t) and F_CPUE are spring and fall catch-per-unit-effort (mt/hour) for seven typical vessels used in the U.S. reduction fishery. CPUE(t) is the mean of S_CPUE(t) and F_CPUE(t) weighted by catches in the spring [S_CAT(t)] and fall [F_CAT(t)].

Table 1

YEAR	B(t)	TRUESB(t)	FRACMAT(t)	CATCH(t)	PACMAC(t)	M(t)	DELTA(T)	B'(t+1)	P(t)	LOG[P(t)]
1964	0.645	0.639	0.991	0.012	0.053	0.621	0.758	0.732	1.135	0.126
1965	0.723	0.528	0.730	0.018	0.018	0.607	0.765	0.570	0.788	-0.238
1966	0.556	0.541	0.973	0.052	0.009	0.604	0.767	0.425	0.764	-0.269
1967	0.385	0.368	0.956	0.050	0.005	0.602	0.767	0.397	1.030	0.030
1968	0.358	0.340	0.950	0.037	0.005	0.602	0.767	0.385	1.076	0.073
1969	0.357	0.335	0.938	0.074	0.005	0.602	0.767	0.407	1.140	0.131
1970	0.350	0.273	0.780	0.124	0.005	0.602	0.767	0.723	2.066	0.726
1971	0.628	0.264	0.420	0.064	0.005	0.602	0.767	0.981	1.563	0.447
1972	0.932	0.523	0.561	0.094	0.005	0.602	0.767	1.434	1.538	0.431
1973	1.362	1.335	0.980	0.145	0.005	0.602	0.767	1.759	1.292	0.256
1974	1.648	1.094	0.664	0.139	0.005	0.602	0.767	1.507	0.914	-0.090
1975	1.400	1.204	0.860	0.202	0.010	0.604	0.766	1.138	0.813	-0.207
1976	0.983	0.947	0.963	0.182	0.010	0.604	0.766	0.926	0.942	-0.059
1977	0.787	0.786	0.999	0.246	0.097	0.639	0.750	0.613	0.779	-0.249
1978	0.429	0.429	1.000	0.158	0.132	0.653	0.744	0.946	2.205	0.791
1979	0.828	0.544	0.657	0.261	0.292	0.717	0.715	0.951	1.148	0.138
1980	0.764	0.757	0.991	0.304	0.252	0.701	0.722	0.992	1.298	0.261
1981	0.772	0.736	0.953	0.303	0.333	0.733	0.707	0.678	0.878	-0.130
1982	0.464	0.419	0.903	0.229	0.359	0.744	0.703	0.711	1.532	0.427
1983	0.550	0.533	0.969	0.084	0.244	0.698	0.723	0.438	0.796	-0.228
1984	0.377	0.371	0.984	0.108	0.157	0.663	0.739	0.761	2.019	0.702
1985	0.681	0.532	0.781	0.128	0.457	0.783	0.686	0.695	1.020	0.020
	0.607	0.601								

YEAR	S_CPUE(t)	S_CAT(t)	F_CPUE(t)	F_CAT(T)	CPUE(t)
1967	2.100				2.100
1968			2.400		2.400
1969	4.600	0.016	6.700	0.054	6.221
1970	5.600	0.029	5.800	0.067	5.739
1971	4.200	0.015	6.600	0.029	5.792
1972	3.900	0.026	3.300	0.037	3.548
1973	4.600	0.039	6.400	0.091	5.861
1974	5.600	0.026	6.900	0.065	6.531
1975	6.400	0.049	7.400	0.102	7.075
1976	4.400	0.034	5.000	0.070	4.805
1977	6.400	0.034	4.200	0.071	4.912
1978			2.200		2.200
1979	6.000				6.000

Table 2. Ex-vessel prices (1988 $) for anchovy taken by the U.S. nonreduction (excluding live bait) fishery during 1980-1988.

Year	Price
1980	$296
1981	$97
1982	$313
1983	$246
1984	$450
1985	$518
1986	$187
1987	$184
1988	$292

Table 3. U.S. reduction landings (mt) and ex-vessel prices (1988 $) for northern anchovy by calendar year.

Year	U.S. Reduc. Landings	Price
1974	73,400	$99
1975	141,586	$68
1976	112,270	$76
1977	99,674	$92
1978	10,339	$87
1979	47,408	$77
1980	43,699	$79
1981	51,290	$79
1982	43,742	$51
1983	2,854	$46
1984	1,722	$37
1985	825	$33
1986	546	$29
1987	149	$28
1988	234	$32

Table 4. Northern anchovy nonreduction catch in California, by season and disposition of catch (metric tons).

	Live Bait	Other	Total
1979/80	4,036	1,241	5,277
1980/81	4,364	892	5,256
1981/82	4,629	866	5,495
1982/83	3,711	1,363	5,074
1983/84	4,487	1,493	5,980
1984/85	3,838	839	4,677
1985/86	4,180	1,521	5,701
1986/87	3,175	967	4,142
1987/88	4,283	1,511	5,794
1988/89	2,967[2]	647[2]	3,614

[1] Catches that have been reported to the California Department of Fish and Game via mandatory fish logs. Figures do not reflect actual catches to date because of some delinquent logs.

[2] Preliminary estimates reflecting catches through April 1989.

Table 5. Breeding success of pelicans on Anacapa and Coronado Islands during 1969-1985. 'NP' is the number of breeding pairs, 'NF' in the number of fledglings raised and 'NF/NP' is the number of fledglings raised per breeding pair.

	Anacapa Island			Coronado Island		
Year	NP	NF	NF/NP	NP	NF	NF/NP
1969	750	4	0.00533	375	0	0.000
1970	552	1	0.00181	175	4	0.0229
1971	540	7	0.0130	110	35	0.318
1972	261	57	0.218	250	150	0.600
1973	247	34	0.138	350	100	0.286
1974	416	305	0.733	870	880	1.01
1975	292	256	0.877	339	407	1.20
1976	417	279	0.669	473	487	1.03
1977	76	39	0.513	263	216	0.821
1978	210	37	0.176	265	62	0.234
1979	1258	980	0.779	960	920	0.958
1980	2244	1515	0.675	758	350	0.462
1981	--	--	0.600	--	--	--
1982	--	--	0.450	--	--	--
1983	1856	1149	0.619	--	--	--
1984	628	530	0.844	--	--	--
1985	5148	6387	1.24	--	--	--

Table 6. Summary of options for the reduction optimum yield. Note that the reduction and nonreduction quotas for U.S. fisherman are 70% of the OY values for reduction and nonreduction fishing. For example, under Option 2 the U.S. reduction quota is 0.7 x 4,000 = 4,900 mt and the U.S. non-reduction quota is 0.7 x 3,000 = 2,100 mt. Figures in the table are given in metric tons.

Option	Reduction OY Below Cut-off	Cutoff Levels	Nonreduction OY (Excluding Live Bait)
1. Status quo	0	SB<300,000	7,000
2. Conditional	7,000	SB<307,000 TB>375,000	7,000
3. Unconditional	7,000	SB<307,000	7,000

SB=spawning biomass
TB=total biomass

Table 7. Results of simulation analyses (using the program FMPSIM).

	Options		
	1, 1L (StatQuo)	2, 2L (Cond)	3, 3L (Uncond)
Total biomass (million mt)			
Mean	0.84	0.84	0.84
Standard deviation	0.46	0.46	0.46
Coefficient of variation	54%	54%	54%
Reduction catch (million mt)			
Mean	0.15	0.15	0.15
Standard deviation	0.077	0.077	0.077
Coefficient of variation	51%	51%	51%
Reduction profit (million $)			
Mean	3.7	3.7	3.7
Standard deviation	2.6	2.6	2.6
Coefficient of variation	70%	70%	70%
Brown pelican breeding success (fledglings/pair)			
Mean	0.99	0.99	0.99
Standard deviation	0.14	0.14	0.14
Coefficient of variation	15%	15%	15%
Intervals with no reduction landings			
% of years	15%	11%	11%
Mean number per 100 years	9.2	6.1	5.9
Mean length of intervals	1.7	1.9	1.9
Intervals with no reduction landings due to no quota			
% of years	13%	9%	0%
Mean number per 100 years	8.3	5.0	0.0
Mean length of intervals	1.6	1.8	0.0
Intervals with no reduction landings due to no potential profit			
% of years	11%	11%	11%
Mean number per 100 years	5.9	5.9	5.9
Mean length of intervals	1.9	1.9	1.9
Percent of years when spawning biomass < or = criteria levels			
Criteria Level			
300K mt	13%	13%	13%
200K mt	4.3%	4.3%	4.3%
100K mt	0.5%	0.5%	0.5%
90K mt	0.4%	0.4%	0.4%
80K mt	0.2%	0.2%	0.2%
70K mt	0.1%	0.1%	0.1%
60K mt	0.0%	0.0%	0.0%

Table 8. Results of simulation analysis using the program FMPTIME.

	No Cutoff	With Cutoff
Mean Number Years to Recovery	8.6	7.9
Standard Deviation	4.8	2.4
Coefficient of Variation	56%	31%

Figure 1. Error-in-variables model fit to the anchovy data.

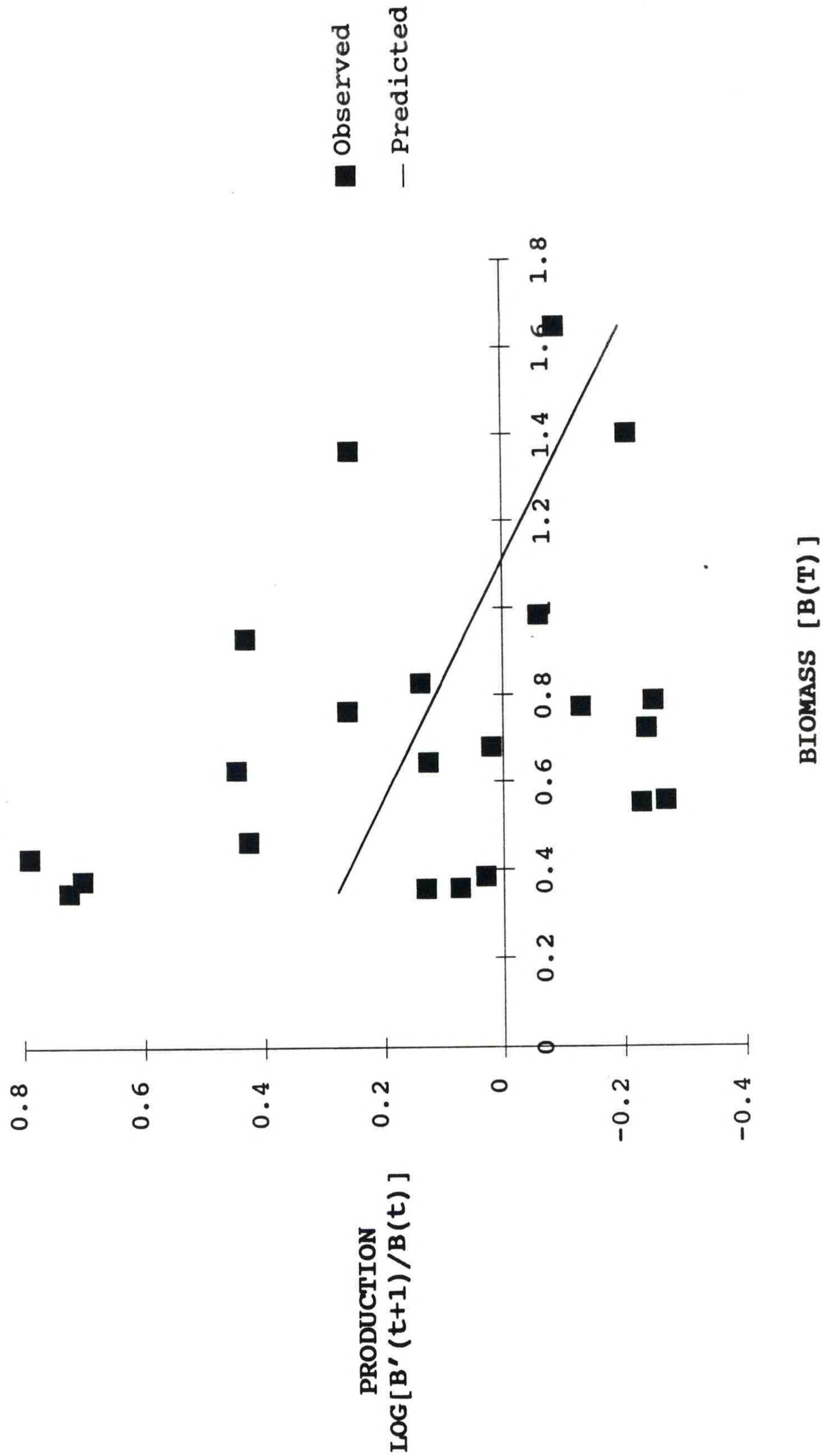
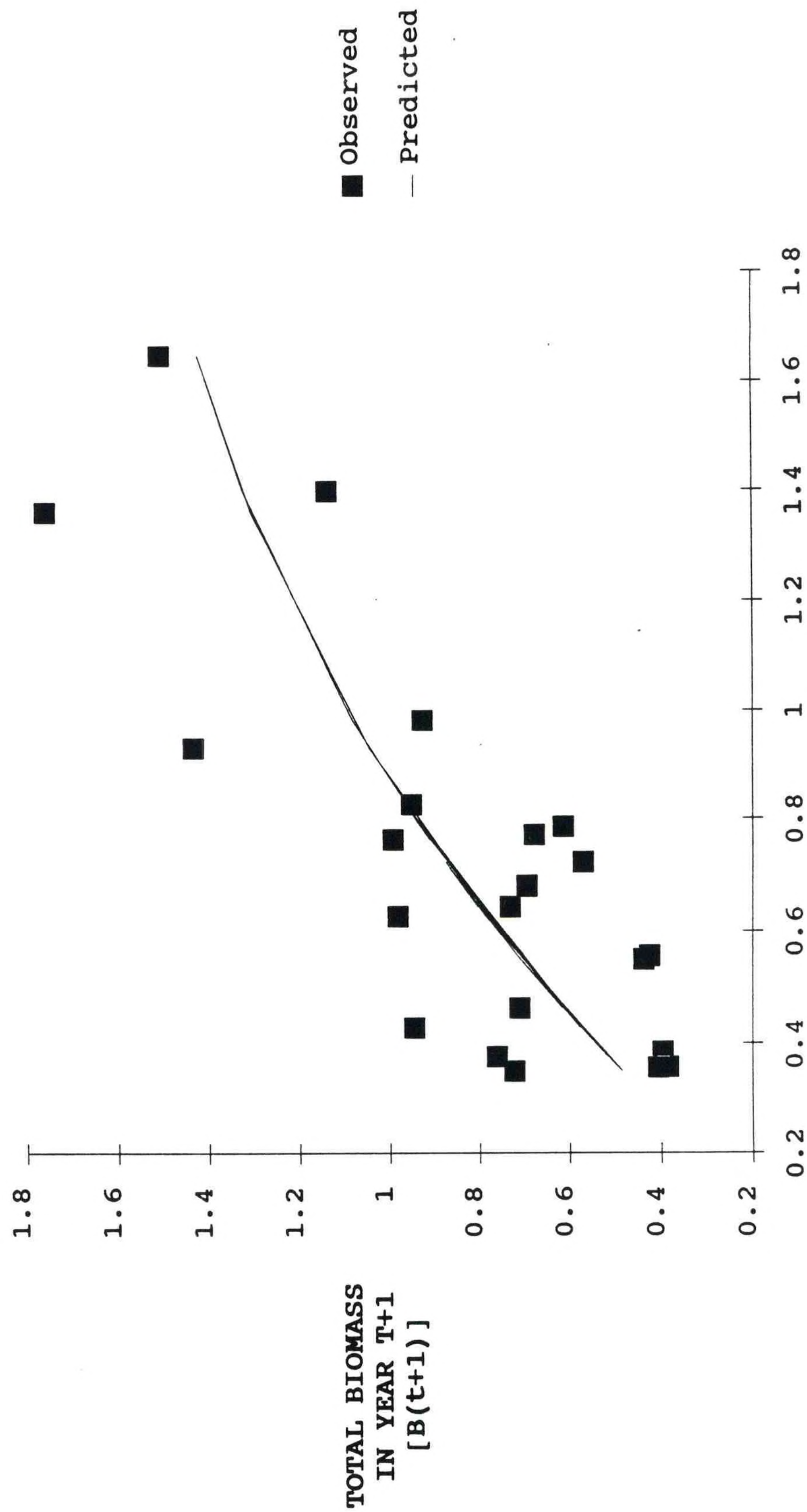

Observed
Predicted
PRODUCTION
LOG[B'(t+1)/B(t)]
BIOMASS [B(T)]
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
0.2
0.4
0.6
0.8
1.2
1.4
1.6
1.8

Figure 2. Surplus production model fitted to the anchovy data.



TOTAL BIOMASS IN YEAR T+1 [B(t+1)]
TOTAL BIOMASS IN YEAR T [B(t)]
Observed
Predicted
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

Figure 3. Residuals from fitting the surplus production model plotted against time.

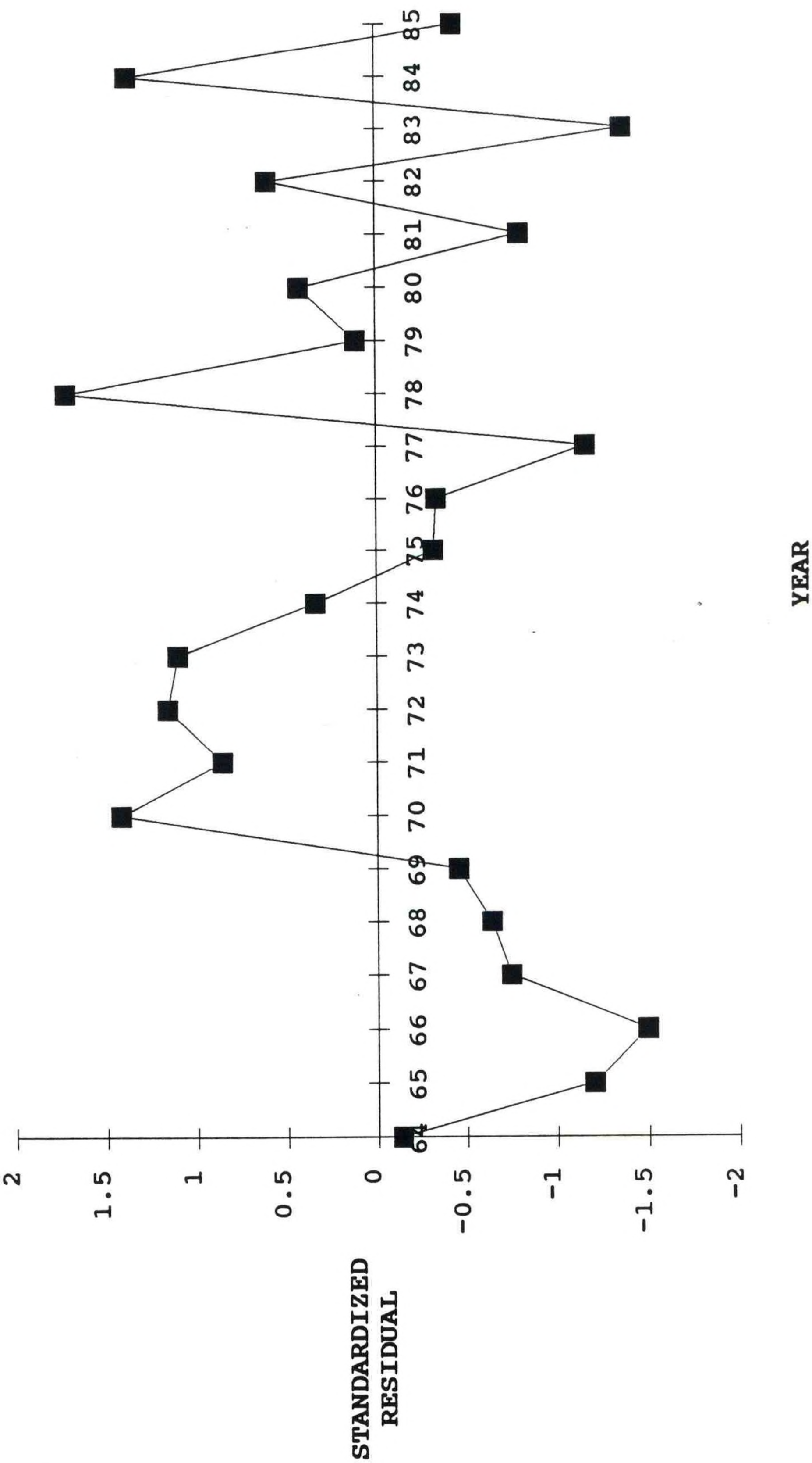

STANDARDIZED RESIDUAL
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
YEAR
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85

Figure 4. CPUE(t) (weighted average of spring and fall CPUE) as a function of total biomass.

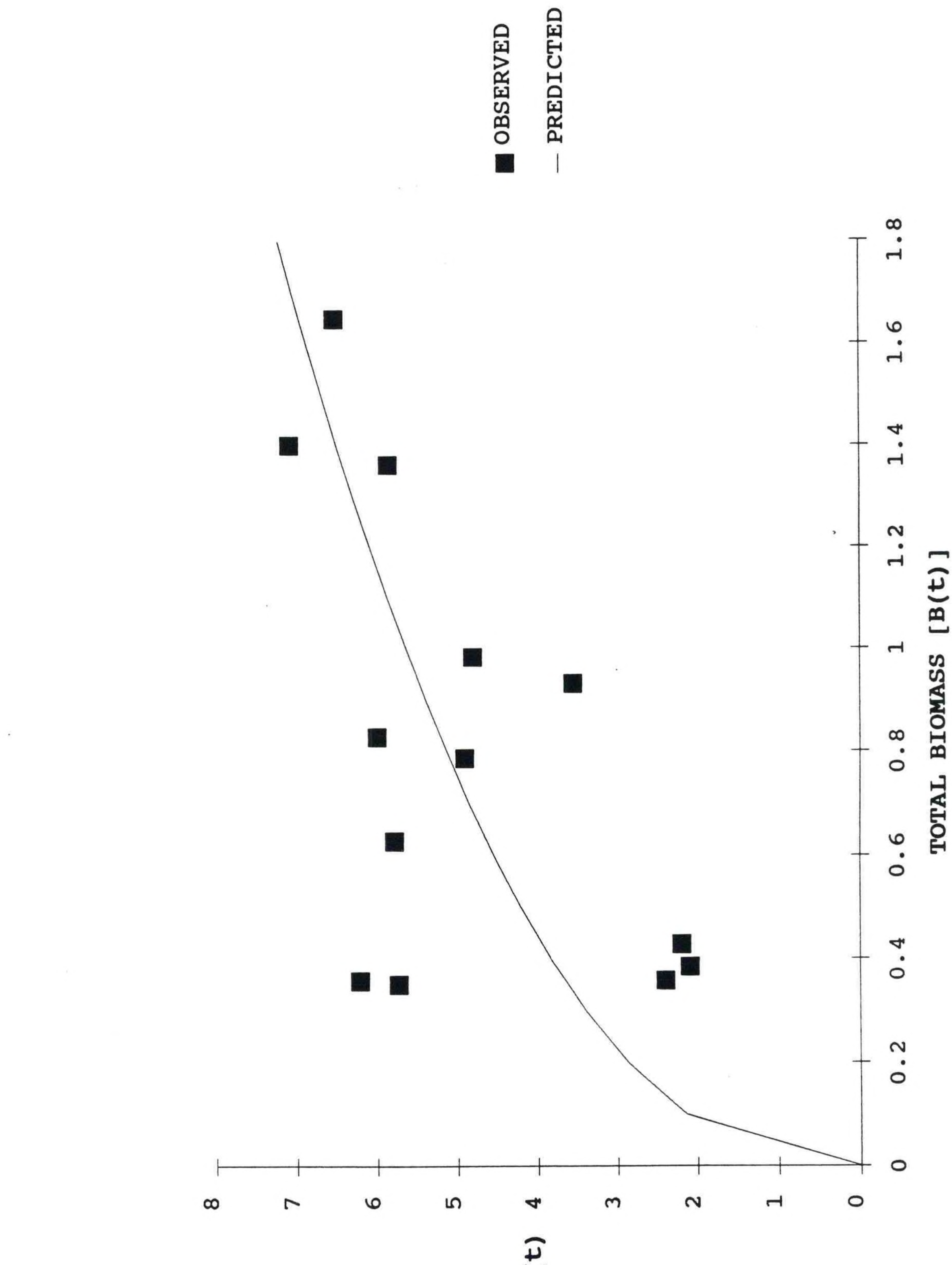
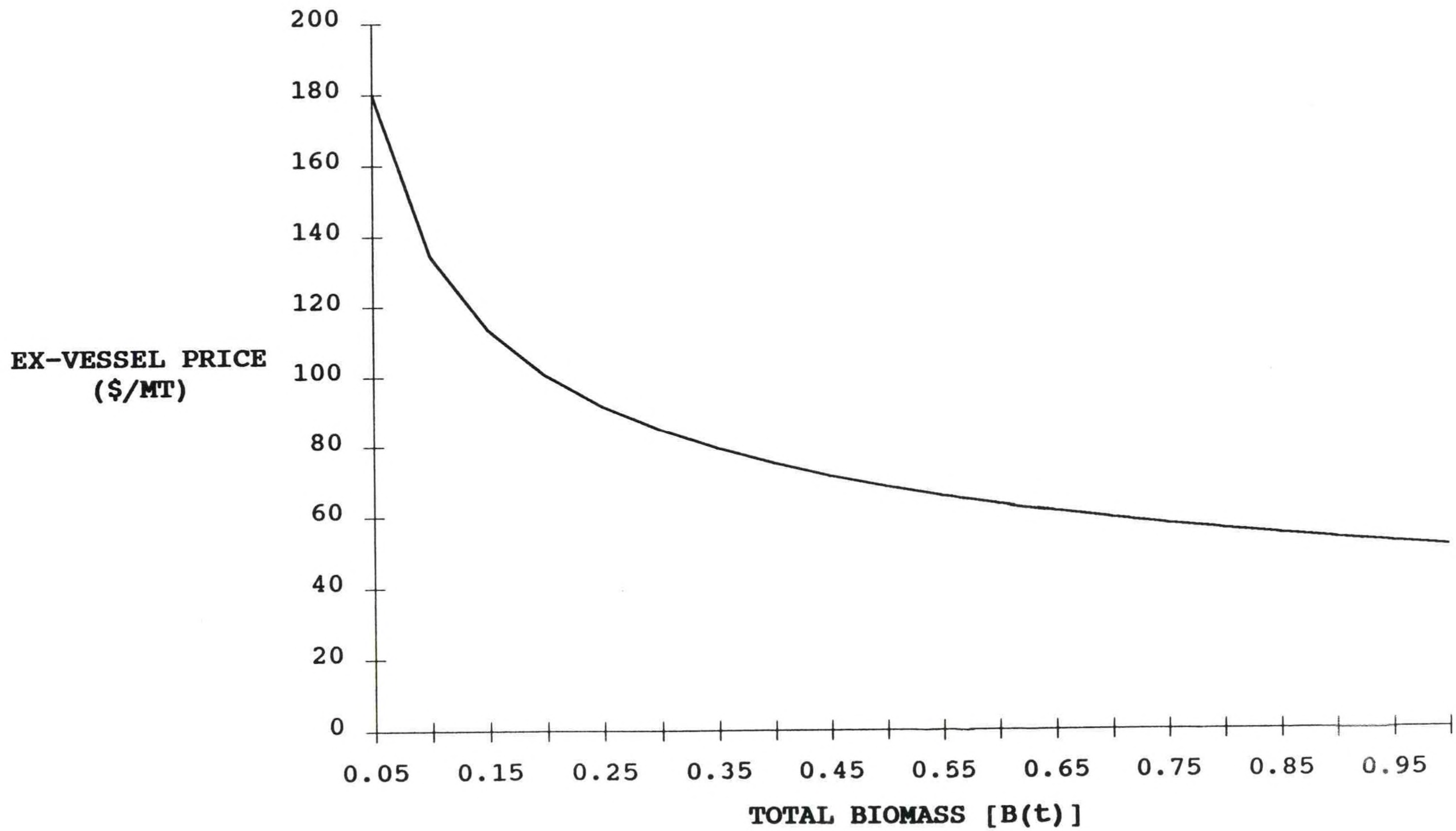

CPUE(t)
0
1
2
3
4
5
6
7
8
TOTAL BIOMASS [B(t)]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
OBSERVED
PREDICTED

Figure 5. Break-even ex-vessel prices for anchovy reduction fishing. The break-even price is the minimum ex-vessel price required to make fishing profitable at a specified level of anchovy biomass.


EX-VESSEL PRICE
($/MT)
200
180
160
140
120
100
80
60
40
20
0
0.05
0.15
0.25
0.35
0.45
0.55
0.65
0.75
0.85
0.95
TOTAL BIOMASS [B(t)]

Appendix A. Example of an input file used with the simulation program FMPSIM. Note that the input file is reproduced in the example output given in Appendix B.

```
COMMENT LINE
rs2-STATUS QUO OPTION, INITIAL BIOMASS = 1.0,AUTOCORRELATE ERRORS
TOTAL BIOMASS CRITERIA LEVEL  1
  2.00000
TOTAL BIOMASS CRITERIA LEVEL  2
  1.80000
TOTAL BIOMASS CRITERIA LEVEL  3
  1.60000
TOTAL BIOMASS CRITERIA LEVEL  4
  1.40000
TOTAL BIOMASS CRITERIA LEVEL  5
  1.20000
TOTAL BIOMASS CRITERIA LEVEL  6
  1.00000
TOTAL BIOMASS CRITERIA LEVEL  7
  .800000
TOTAL BIOMASS CRITERIA LEVEL  8
  .600000
TOTAL BIOMASS CRITERIA LEVEL  9
  .586000
TOTAL BIOMASS CRITERIA LEVEL 10
  .400000
TOTAL BIOMASS CRITERIA LEVEL 11
  .200000
TOTAL BIOMASS CRITERIA LEVEL 12
  .100000
REDUCTION CATCH CRITERIA LEVEL  1
  .200000
REDUCTION CATCH CRITERIA LEVEL  2
  .180000
REDUCTION CATCH CRITERIA LEVEL  3
  .16
REDUCTION CATCH CRITERIA LEVEL  4
  .14
REDUCTION CATCH CRITERIA LEVEL  5
  .12
REDUCTION CATCH CRITERIA LEVEL  6
  .10
REDUCTION CATCH CRITERIA LEVEL  7
  .07
REDUCTION CATCH CRITERIA LEVEL  8
  .04
REDUCTION CATCH CRITERIA LEVEL  9
  .01
REDUCTION CATCH CRITERIA LEVEL 10
  .007
REDUCTION CATCH CRITERIA LEVEL 11
  .005
REDUCTION CATCH CRITERIA LEVEL 12
  .000
UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
  .500000
MAXIMUM REDUCTION QUOTA
  .200000
CURRENT LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
  .300000
CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF
  0.0
MINIMUM REDUCTION QUOTA
  .000
ANNUAL CATCH FOR BAIT (ALL YEARS)
  .004078
COMMERCIAL NONREDUCTION QUOTA
  .118800E-02
COST OF ONE UNIT OF FISHING EFFORT
```

```
  288.290
REDUCTION EXVESSEL VALUE
 79e6
BAIT EXVESSEL VALUE
  .681000E+09
NONREDUCTION COMMERCIAL EXVESSEL VALUE
  .287000E+09
MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS
  .564290E-05
EXPONENT (BETA) FOR CPUE AND BIOMASS
  .420600
MAXIMUM CPUE
  .750000E-05
INTERCEPT PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS
  .652
SLOPE PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS
  .428
MAXIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)
  1.20000
MINIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)
  0.05
LOWEST ATTAINABLE BIOMASS
  .500000E-02
STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)
  1.73600
MEAN VALUE FOR LOGIT(FRACTION SPAWNING)
  2.61600
SMALLEST VALUE FOR FRACTION SPAWNING
  .300000
STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS
  .000000
MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL
  .455400
EXPONENT (BETA) IN STOCK-STOCK MODEL
 -.365310
STANDARD DEVIATION FOR PROCESS ERROR
  .350000
AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)'
  .050000
LENGTH OF CYCLES IN PROCESS ERROR (YEARS)
  5.00000
DISCOUNT RATE FOR CATCH
  .730000
NUMBER OF SIMULATION RUNS
         1
NUMBER OF YEARS IN EACH RUN
         1000000
INITIAL BIOMASS (UNITS ARE MILLION MT)
  1.0
 AUTOMATIC RANDOM NUMBER SEEDS?
NO
 RANDOM VALUE 1
 4345
 RANDOM VALUE 2
 823
 RANDOM VALUE 3
 1760
```

Appendix B. Example of an output file generated by the simulation program FMPSIM from the input given in Appendix A.

```
-----------------FMPSIM - ANCHOVY SIMULATION PROGRAM VERSION 6----------------
                    DATE OF LAST MODIFICATION: 02/NOV/89

TIME -> 18:15:42
DATE ->  8/11/1989

 INPUT FILE -> TEMP.DAT

------------------------------INPUT PARAMETERS-------------------------------

COMMENT LINE
rs2-STATUS QUO OPTION, INITIAL BIOMASS = 1.0,AUTOCORRELATE ERRORS
TOTAL BIOMASS CRITERIA LEVEL  1
  2.00000
TOTAL BIOMASS CRITERIA LEVEL  2
  1.80000
TOTAL BIOMASS CRITERIA LEVEL  3
  1.60000
TOTAL BIOMASS CRITERIA LEVEL  4
  1.40000
TOTAL BIOMASS CRITERIA LEVEL  5
  1.20000
TOTAL BIOMASS CRITERIA LEVEL  6
  1.00000
TOTAL BIOMASS CRITERIA LEVEL  7
  .800000
TOTAL BIOMASS CRITERIA LEVEL  8
  .600000
TOTAL BIOMASS CRITERIA LEVEL  9
  .586000
TOTAL BIOMASS CRITERIA LEVEL 10
  .400000
TOTAL BIOMASS CRITERIA LEVEL 11
  .200000
TOTAL BIOMASS CRITERIA LEVEL 12
  .100000
REDUCTION CATCH CRITERIA LEVEL  1
  .200000
REDUCTION CATCH CRITERIA LEVEL  2
  .180000
REDUCTION CATCH CRITERIA LEVEL  3
  .160000
REDUCTION CATCH CRITERIA LEVEL  4
  .140000
REDUCTION CATCH CRITERIA LEVEL  5
  .120000
REDUCTION CATCH CRITERIA LEVEL  6
  .100000
REDUCTION CATCH CRITERIA LEVEL  7
  .700000E-01
REDUCTION CATCH CRITERIA LEVEL  8
  .400000E-01
REDUCTION CATCH CRITERIA LEVEL  9
  .100000E-01
REDUCTION CATCH CRITERIA LEVEL 10
  .700000E-02
REDUCTION CATCH CRITERIA LEVEL 11
  .500000E-02
REDUCTION CATCH CRITERIA LEVEL 12
  .000000
```

```
UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
  .500000
MAXIMUM REDUCTION QUOTA
  .200000
LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
  .300000
CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF
  .000000
MINIMUM REDUCTION QUOTA
  .000000
ANNUAL CATCH FOR BAIT (ALL YEARS)
  .407800E-02
COMMERCIAL NONREDUCTION QUOTA
  .118800E-02
COST OF ONE UNIT OF FISHING EFFORT
  288.290
REDUCTION EXVESSEL VALUE
  .790000E+08
BAIT EXVESSEL VALUE
  .681000E+09
NONREDUCTION COMMERCIAL EXVESSEL VALUE
  .287000E+09
MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS
  .564290E-05
EXPONENT (BETA) FOR CPUE AND BIOMASS
  .420600
MAXIMUM CPUE
  .750000E-05
INTERCEPT PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS
  .652000
SLOPE PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS
  .428000
MAXIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)
  1.20000
MINIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)
  .500000E-01
LOWEST ATTAINABLE BIOMASS
  .500000E-02
STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)
  1.73600
MEAN VALUE FOR LOGIT(FRACTION SPAWNING)
  2.61600
SMALLEST VALUE FOR FRACTION SPAWNING
  .300000
STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS
  .000000
MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL
  .455400
EXPONENT (BETA) IN STOCK-STOCK MODEL
 -.365310
STANDARD DEVIATION FOR PROCESS ERROR
  .350000
AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)
  .500000E-01
LENGTH OF CYCLES IN PROCESS ERROR (YEARS)
  5.00000
DISCOUNT RATE FOR CATCH
  .730000
NUMBER OF SIMULATION RUNS
             1
NUMBER OF YEARS IN EACH RUN
       1000000
INITIAL BIOMASS (UNITS ARE MILLION MT)
  1.00000
 AUTOMATIC RANDOM NUMBER SEEDS?
```

NO
INITIAL VALUE FOR RANDOM NUMBER SEED 1
4345
INITIAL VALUE FOR RANDOM NUMBER SEED 2
823
INITIAL VALUE FOR RANDOM NUMBER SEED 3
1760

-----------------------------------RESULTS-----------------------------------

MEAN TOTAL BIOMASS
.837378
STANDARD DEVIATION FOR TOTAL BIOMASS
.456025
COEFFICIENT OF VARIATION FOR TOTAL BIOMASS
54.4588 %
MEAN REDUCTION CATCH
.151117
STANDARD DEVIATION FOR REDUCTION CATCH
.771715E-01
COEFFICIENT OF VARIATION FOR REDUCTION CATCH
51.0673 %
MEAN PELICAN REPRODUCTIVE SUCCESS
.986546
STANDARD DEVIATION FOR PELICAN REPRODUCTIVE SUCCESS
.143448
COEFFICIENT OF VARIATION FOR PELICAN REPRODUCTIVE SUCCESS
14.5404 %
MEAN REDUCTION PROFIT
.372006E+07
STANDARD DEVIATION FOR REDUCTION PROFITS
.258949E+07
COEFFICIENT OF VARIATION FOR REDUCTION PROFITS
69.6089 %
PERCENTAGE OF YEARS WITH NO REDUCTION CATCH
15.4712 %
MEAN NUMBER OF NO CATCH INTERVALS PER 100 YEARS
9.16790
MEAN LENGTH OF NO CATCH INTERVALS
1.68754
PERCENTAGE OF YEARS WITH NO QUOTA
13.0189 %
MEAN NUMBER OF NO QUOTA INTERVALS PER 100 YEARS
8.34260
MEAN LENGTH OF NO QUOTA INTERVALS
1.56053
PERCENTAGE OF YEARS WITH NO POTENTIAL PROFIT
10.9817 %
MEAN NUMBER OF NO POTENTIAL PROFIT INTERVALS PER 100 YEARS
5.91900
MEAN LENGTH OF NO POTENTIAL PROFIT INTERVALS
1.85533

PERCENT YEARS TOTAL BIOMASS < OR = TO CRITERIA LEVELS

LEVEL	%
2.000000	97.729700
1.800000	96.209200
1.600000	93.732100
1.400000	89.234300
1.200000	81.418500
1.000000	70.399900
.800000	54.367400

.600000	34.569700
.586000	33.090300
.400000	15.429500
.200000	1.329400
.100000	.127600

PERCENT YEARS REDUCTION CATCH < OR = TO CRITERIA LEVELS

LEVEL	%
.200000	100.000000
.180000	33.328000
.160000	31.105600
.140000	28.827100
.120000	26.386600
.100000	24.068000
.070000	20.687400
.040000	17.621900
.010000	15.925700
.007000	15.742700
.005000	15.654800
.000000	15.471200

-- NORMAL TERMINATION --

Appendix C. Example of an input file used with the simulation program FMPTIME. Note that the input file is reproduced in the example output given in Appendix D.

```
COMMENT LINE
CUTOFF@50K MT,STATQUO OPTIONS,START=25K MT,END=300K MT,RS-A,500k RUNS
 SPAWNING BIOMASS CUTOFF LEVEL FOR ALL FISHING
   .05000
 UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
   .500000
 MAXIMUM REDUCTION QUOTA
   .200000
 CURRENT LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
   .300000
 CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF
   .000000
 MINIMUM REDUCTION QUOTA
   .000000
 ANNUAL CATCH FOR BAIT (ALL PROFITABLE YEARS)
   .407800E-02
 COMMERCIAL NONREDUCTION CATCH (ALL PROFITABLE YEARS)
   .118800E-02
 COST OF ONE UNIT OF FISHING EFFORT
   288.290
 REDUCTION EXVESSEL VALUE
   .790000E+08
 BAIT EXVESSEL VALUE
   .681000E+09
 NONREDUCTION COMMERCIAL EXVESSEL VALUE
   .287000E+09
 MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS
   .564290E-05
 EXPONENT (BETA) FOR CPUE AND BIOMASS
   .420600
 MAXIMUM CPUE
   .750000E-05
 LOWEST ATTAINABLE BIOMASS
   .100000E-02
 STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)
   1.73600
 MEAN VALUE FOR LOGIT(FRACTION SPAWNING)
   2.61600
 SMALLEST VALUE FOR FRACTION SPAWNING
   .300000
 STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS
   .000000
 MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL
   .455400
 EXPONENT (BETA) IN STOCK-STOCK MODEL
  -.365310
 STANDARD DEVIATION FOR PROCESS ERROR
   .350000
 AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)
   .500000E-01
 LENGTH OF CYCLES IN PROCESS ERROR (YEARS)
   5.00000
 DISCOUNT RATE FOR CATCH
   .730000
 NUMBER OF SIMULATION RUNS
          500000
 MAXIMUM NUMBER OF YEARS IN EACH RUN
             100
 INITIAL SPAWNING BIOMASS (MILLION MT)
   .250000E-01
 SPAWNING STOCK BIOMASS RECOVERY LEVEL
   .300000
 AUTOMATIC RANDOM NUMBER SEEDS?
N
```

```
INITIAL VALUE FOR RANDOM NUMBER SEED 1
          345
INITIAL VALUE FOR RANDOM NUMBER SEED 2
          1823
INITIAL VALUE FOR RANDOM NUMBER SEED 3
          12760
```

Appendix D. Example of an output file generated by the simulation program FMPTIME from the input given in Appendix C.

```
---------------FMPTIME - ANCHOVY RECOVERY TIME PROGRAM VERSION 1---------------
                    DATE OF LAST MODIFICATION: 08/DEC/89


 TIME ->17:15:11
 DATE ->11/12/1989


 INPUT FILE -> cut@50_1.dat


-------------------------------INPUT PARAMETERS-------------------------------


COMMENT LINE
CUTOFF@50K MT,STATQUO OPTIONS,START=25K MT,END=300K MT,RS-A,500k RUNS
 SPAWNING BIOMASS CUTOFF LEVEL FOR ALL FISHING
   .500000E-01
 UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
   .500000
 MAXIMUM REDUCTION QUOTA
   .200000
 CURRENT LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA
   .300000
 CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF
   .000000
 MINIMUM REDUCTION QUOTA
   .000000
 ANNUAL CATCH FOR BAIT (ALL PROFITABLE YEARS)
   .407800E-02
 COMMERCIAL NONREDUCTION CATCH (ALL PROFITABLE YEARS)
   .118800E-02
 COST OF ONE UNIT OF FISHING EFFORT
   288.290
 REDUCTION EXVESSEL VALUE
   .790000E+08
 BAIT EXVESSEL VALUE
   .681000E+09
 NONREDUCTION COMMERCIAL EXVESSEL VALUE
   .287000E+09
 MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS
   .564290E-05
 EXPONENT (BETA) FOR CPUE AND BIOMASS
   .420600
 MAXIMUM CPUE
   .750000E-05
 LOWEST ATTAINABLE BIOMASS
   .100000E-02
 STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)
   1.73600
 MEAN VALUE FOR LOGIT(FRACTION SPAWNING)
   2.61600
 SMALLEST VALUE FOR FRACTION SPAWNING
   .300000
 STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS
   .000000
 MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL
   .455400
 EXPONENT (BETA) IN STOCK-STOCK MODEL
  -.365310
 STANDARD DEVIATION FOR PROCESS ERROR
   .350000
 AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)
   .500000E-01
```

LENGTH OF CYCLES IN PROCESS ERROR (YEARS)
5.00000
DISCOUNT RATE FOR CATCH
.730000
NUMBER OF SIMULATION RUNS
500000
MAXIMUM NUMBER OF YEARS IN EACH RUN
100
INITIAL SPAWNING BIOMASS (MILLION MT)
.250000E-01
SPAWNING STOCK BIOMASS RECOVERY LEVEL
.300000
AUTOMATIC RANDOM NUMBER SEEDS?
NO
INITIAL VALUE FOR RANDOM NUMBER SEED 1
345
INITIAL VALUE FOR RANDOM NUMBER SEED 2
1823
INITIAL VALUE FOR RANDOM NUMBER SEED 3
12760

-----------------------------------RESULTS-----------------------------------

MEAN NUMBER OF YEARS TO RECOVERY
7.93682
STANDARD DEVIATION
2.42344
COEFFICIENT OF VARIATION
30.5341 %

FREQUENCY DISTRIBUTION FOR RECOVERY TIMES

YEARS	FREQUENCY	PERCENTAGE
1	0	.0000%
2	0	.0000%
3	3509	.7018%
4	18420	3.6840%
5	49120	9.8240%
6	64921	12.9842%
7	100875	20.1750%
8	92103	18.4206%
9	68420	13.6840%
10	35965	7.1930%
11	25439	5.0878%
12	16668	3.3336%
13	11403	2.2806%
14	5264	1.0528%
15	1754	.3508%
16	5262	1.0524%
17	0	.0000%
18	0	.0000%
19	0	.0000%
20	0	.0000%
21	877	.1754%
22	0	.0000%
23	0	.0000%
24	0	.0000%
25	0	.0000%
26	0	.0000%
27	0	.0000%
28	0	.0000%

29	0	.0000%
30	0	.0000%

-- NORMAL TERMINATION --

Appendix E. Source code for FMPSIM. Subroutines used for 'housekeeping' tasks (e.g. opening files) not shown.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      PROGRAM FMPSIM
C
C     MODIFICATION HISTORY (PROGRAMMER / DATE / DESCRIPTION
C     --------------------
C     LARRY JACOBSON / 13 OCT 89
C     MODIFIED SO THAT A MINIMUM LEVEL OF TOTAL BIOMASS (RATHER THAN
C     THE FRACTION MATURE) IS THE ADDITIONAL CRITERIA USED TO
C     DETERMINE THE REDUCTION QUOTA WHEN THE SPAWNING BIOMASS IS
C     BELOW THE CUTOFF LEVEL.
C
C     LARRY JACOBSON / 17 OCT 89
C     CODE USED TO ADJUST CATCHES AND REDUCTION PROFITS WHEN
C     QUOTA IS TOO LARGE (SO THAT BIOMASS DROPS BELOW MINIMUM
C     LEVEL) WAS IMPROVED.
C
C     LARRY JACOBSON / 2 NOV 89
C     -CYCLIC AUTOCORRELATION IN RANDOM ERRORS IMPLEMENTED.
C     -LINEAR RELATIONSHIP BETWEEN PELICAN BREEDING SUCCESS AND
C      TOTAL BIOMASS IMPLEMENTED.
C
C     LARRY JACOBSON / 3 NOV 89
C     -BLANK SPACE ADDED TO FRONT OF EACH LINE OF OUTPUT.
C
C     LARRY JACOBSON / 6 DEC 89
C     -CRITERIA LEVELS FOR SPAWNING BIOMASS INCLUDED IN OUTPUT.
C     -LOWER CUTOFF LEVEL FOR ALL FISHING ADDED.
C
C     PURPOSE
C     -------
C     THIS PROGRAM SIMULATES THE NORTHERN ANCHOVY FISHERY AND WAS
C     DESIGNED TO BE USED IN THE EVALUATION OF MODIFICATIONS TO
C     THE FORMULA USED FOR DETERMINING ANNUAL REDUCTION QUOTAS.
C
C     FOR A GIVEN QUOTA OPTION, THE PROGRAM CALCULATES
C     MEANS, STANDARD DEVIATIONS AND COEFFICIENTS OF
C     VARIATION FOR: 1) TOTAL ANNUAL BIOMASS, 2) ANNUAL
C     REDUCTION CATCH, 3) ANNUAL REDUCTION PROFIT AND 4) PELICAN
C     REPRODUCTIVE SUCCESS.  THE PERCENTAGE OF YEARS WITH NO
C     REDUCTION CATCH, THE MEAN NUMBER OF PERIODS PER 100 YEARS
C     WITH NO REDUCTION CATCH AND THE MEAN DURATION OF PERIODS WITH
C     NO REDUCTION CATCH ARE DETERMINED FOR 1) CLOSURES DUE TO QUOTA
C     REGULATIONS, 2) CLOSURES DUE TO NO POTENTIAL PROFIT, AND 3)
C     CLOSURES DUE TO ANY CAUSE.  THE PERCENTAGE OF YEARS IN
C     WHICH TOTAL BIOMASS AND REDUCTION HARVEST ARE LESS THAN
C     OR EQUAL TO "CRITERIA LEVELS" ARE ALSO CALCULATED.
C
C     INPUT DATA CAN BE SUPPLIED MANUALLY OR VIA A DATA FILE
C     THAT IS ORGANIZED AS FOLLOWS:
C
C          COMMENT LINE 1
C          DATA LINE 1
C          COMMENT LINE 2
C          DATA LINE 2
C              .
C              .
C             ETC.
C
C     THE COMMENT LINES ARE USED TO DESCRIBE THE INPUT DATA.
C
C     OUTPUT CAN BE WRITTEN TO A FILE OR TO THE SCREEN.  THE OUTPUT
C     IS SELF DOCUMENTING AND IS WRITTEN IN SUCH A WAY THAT AN
C     OUTPUT FILE CAN BE EDITED AND USED AS AN INPUT FILE.  THE
C     EASIEST WAY TO CREATE AN INPUT FILE IS TO RUN THE PROGRAM
C     WITH MANUAL INPUT AND THEN EDIT THE RESULTING OUTPUT FILE.
C
C     CALCULATIONS
C     ------------
C     THE UNDERLYING MODEL IS A MODIFICATION OF THE "STOCK-STOCK"
C     SURPLUS PRODUCTION MODEL DESCRIBED IN MACCALL AND METHOT
C     (1983, SWFC ADMIN. REP. LJ-83-17).  A RICKER FUNCTION IS,
C     HOWEVER, USED IN PLACE OF THE POWER FUNCTION USED BY
C     MACCALL AND METHOT.
C
C     THE BIOMASS NEXT YEAR IS THE RESULT
C     OF THE UNDERLYING DETERMINISTIC RELATIONSHIP, AN AUTOCORRELATED
C     RANDOM PROCESS ERROR AND CATCH IN THE CURRENT YEAR:
C
C        NEXTBT=BT*EXP(ALPHA+BETA*BT)*EXP(TEMP)-DELTA*CATCH,
C
C     WHERE NEXTBT IS THE BIOMASS AT THE BEGINNING OF NEXT YEAR,
C     ALPHA AND BETA ARE PARAMETERS IN THE RICKER MODEL, BT
C     IS THE BIOMASS THIS YEAR, TEMP THE STOCHASTIC ERROR (SEE BELOW),
C     CATCH IS THE CATCH THIS YEAR AND DELTA IS A DISCOUNT FACTOR
C     USED TO ADJUST THE CATCH (SEE MACCALL 1978.  CAL. FISH AND GAME
C     64: 225-227).
C
C     THE AUTOCORRELATED RANDOM ERROR (TEMP) IS GIVEN BY:
C
C        TEMP=NORM+AMP*SIN(MOD(YEAR,PERIOD)/PERIOD*2*PI),
C
C     WHERE TEMP IS THE AUTOCORRELATED ERROR (LOG-SCALE),
```

```
C     NORM IS A DEVIATE FROM THE NORMAL DISTRIBUTION WITH MEAN ZERO
C     AND SPECIFIED STANDARD DEVIATION, AMP IS THE AMPLITUDE OF THE
C     UNDERLYING CYCLE, YEAR IS THE CURRENT TIME STEP IN THE SIMULATION,
C     AND PERIOD IS THE LENGTH IN TIME STEPS OF THE CYCLE.  NOTE THAT
C     AMP IS MEASURED IN THE SAMPE UNITS AS THE STANDARD DEVATION.
C
C     THE TRUE SPAWNING BIOMASS IN EACH YEAR IS:
C
C        TRUESBT=BT*FRACMAT,
C
C     WHERE TRUESBT IS THE TRUE SPAWNING BIOMASS AND FRACMAT IS THE
C     FRACTION MATURE.  THE FRACTION MATURE IS:
C
C        FRACMAT=EXP(TEMP)/(1+EXP(TEMP)),
C
C     WHERE TEMP IS A DEVIATE FROM THE NORMAL DISTRIBUTION WITH
C     A SPECIFIED MEAN AND STANDARD DEVIATION.  THE BASIS FOR THIS
C     RELATIONSHIP IS THE OBSERVATION THAT LOGIT TRANSFORMED VALUES
C     OF FRACMAT ARE NORMALLY DISTRIBUTED.
C
C     REDUCTION QUOTA CALCULATIONS ARE BASED ON THE OBSERVED SPAWNING
C     BIOMASS WHICH DIFFER FROM THE TRUE VALUE BY A LOG-NORMAL
C     OBSERVATION ERROR:
C
C        OBSSBT=TRUESBT*EXP(TEMP),
C
C     WHERE TEMP IS DEVIATE FROM THE NORMAL DISTRIBUTION WITH MEAN
C     ZERO AND SPECIFIED STANDARD DEVIATION.
C
C     THE CALCULATIONS FOR THE REDUCTION QUOTA ARE COMPLEX, THE USER
C     SHOULD CONSULT THE RELEVANT CODE.
C
C     THE REDUCTION QUOTA IS REEVALUATED IN EVERY YEAR, NON-REDUCTION
C     COMMERCIAL (I.E. DEAD BAIT) AND LIVE BAIT CATCHES ARE ASSUMED
C     CONSTANT AT LEVELS SPECIFIED BY THE USER.  THE ENTIRE CATCH
C     OR QUOTA IS TAKEN BY A FISHERY IF FISHING IS POTENTIALLY
C     PROFITABLE.
C
C     CATCH PER UNIT EFFORT IS ASSUMED TO BE RELATED TO TOTAL
C     BIOMASS AND THE SAME FOR ALL TYPES OF FISHERIES:
C
C        CPUE=CPUEP1*BT**CPUEP2,
C
C     WHERE CPUEP1 AND CPUEP2 ARE PARAMETERS.  THE FISHING EFFORT
C     REQUIRED TO TAKE A SPECIFIED TONNAGE OF CATCH IS GIVEN BY
C
C       EFFORT=QUOTA/CPUE.
C
C     OPERATING COSTS ARE:
C
C       COSTS=EFFORT*COSTEFF,
C
C     WHERE COSTEFF IS THE COST PER UNIT OF FISHING EFFORT (ASSUMED
C     CONSTANT FOR ALL TYPES OF FISHERIES).  GROSS PROFITS ARE:
C
C       GPROF=QUOTA*EXVALUE,
C
C     WHERE EXVALUE IS THE EXVESSEL VALUE FOR THE FISHERY (EXVESSEL
C     VALUE IS DIFFERENT FOR THE REDUCTION, DEAD BAIT AND LIVE
C     BAIT FISHERIES).  THE ENTIRE CATCH OR QUOTA IS TAKEN IF
C     GPROF - COSTS > ZERO (I.E. IF A PROFIT CAN BE MADE).
C
C     PELICAN BREEDING SUCCESS (NUMBER FLEDGED PER PAIR) IS RELATED
C     TO TOTAL BIOMASS AT THE BEGINNING OF THE YEAR BY:
C
C       PELICAN=PELP1+PELP2*BT,
C
C     WHERE PELICAN IS BREEDING SUCCESS AND PELP1 AND PELP2 ARE
C     PARAMETERS.  UPPER AND LOWER BOUNDS SPECIFIED BY THE USER
C     ENSURE THAT BREEDING SUCCESS DOES NOT FALL OR RISE TO UBSURDLY
C     LOW OR HIGH LEVELS.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C ////////////////////PARAMETER DEFINITIONS //////////////////
C
C     MODDATE IS THE LAST MODIFICATION DATE IN FORM 03/APR/89
      CHARACTER*9 MODDATE
      PARAMETER (MODDATE='06/DEC/89')
C
C     VERSION IS THE VERSION NUMBER
      CHARACTER*1 VERSION
      PARAMETER (VERSION='7')
C
C     INBAT IS THE UNIT NUMBER FOR BATCH INPUT
      INTEGER INBAT
      PARAMETER (INBAT=9)
C
C     DEFALT IS THE DEFAULT UNIT NUMBER FOR INTERACTIVE INPUT
      INTEGER DEFALT
      PARAMETER (DEFALT=5)
C
C     DEFOUT IS THE DEFAULT UNIT NUMBER FOR INTERACTIVE OUTPUT
```

```
      INTEGER DEFOUT
      PARAMETER (DEFOUT=6)
C
C     MAXSEED IS THE LARGEST ALLOWABLE VALUE FOR RANDOM NUMER SEEDS
      INTEGER MAXSEED
      PARAMETER (MAXSEED=30270)
C
C     MAXYR IS THE MAXIMUM NUMBER OF YEARS IN A SIMULATION
      INTEGER MAXYR
      PARAMETER (MAXYR=10000000)
C
C     MAXSIM IS THE MAXIMUM NUMBER OF SIMULATIONS
      INTEGER MAXSIM
      PARAMETER (MAXSIM=100)
C
C     T AND F ARE EASIER TO SPELL THAN .TRUE. AND .FALSE.
      LOGICAL T,F
      PARAMETER (T=.TRUE.)
      PARAMETER (F=.FALSE.)
C
C     NUMSBLV IS THE NUMBER OF TOTAL BIOMASS LEVELS USED
C     TO EVALUATE AN OPTION
      INTEGER NUMBTLV
      PARAMETER (NUMBTLV=12)
C
C     NUMCLEV IS THE NUMBER OF REDUCTION CATCH LEVELS USED TO
C     EVALUATE AN OPTION
      INTEGER NUMCLEV
      PARAMETER (NUMCLEV=12)
C
C     NUMSLEV IS THE NUMBER OF SPAWNING BIOMASS LEVELS USED TO
C     EVALUATE AN OPTION
      INTEGER NUMSLEV
      PARAMETER (NUMSLEV=12)
C
C     DZ IS A DOUBLE PRECISION ZERO
      DOUBLE PRECISION DZ
      PARAMETER (DZ=0D0)
C
C     RZ IS A SINGLE PRECISION ZERO
      REAL RZ
      PARAMETER (RZ=0E0)
C
C     IZ IS AN INTEGER ZERO
      INTEGER IZ
      PARAMETER (IZ=0)
C
C     SMALL IS A SMALL REAL NUMBER
      REAL SMALL
      PARAMETER (SMALL=1E-20)
C
C     PI IS PI
      REAL PI
      PARAMETER (PI=3.141593)
C
C ////////////////////////FUNCTIONS//////////////////////////
C
C     NRAND GENERATES STANDARD NORMAL DEVIATES
      REAL NRAND
C
C     CTRSTR RETURNS A CENTERED STRING
      CHARACTER*79 CTRSTR
C
C     SECOND RETURNS THE NUMBER OF SECONDS SINCE MIDNIGHT
      INTEGER SECOND
C
C     GETLOG PROMPTS FOR AND RETURNS A LOGICAL VALUE
      LOGICAL GETLOG
C
C     GETINT PROMPTS FOR AND RETURNS AN INTEGER VALUE
      INTEGER GETINT
C
C     GETNUM PROMPTS FOR AND RETURNS A REAL NUMBER VALUE
      REAL GETNUM
C
C     GETFILE RETURNS A FILE NAME
      CHARACTER*12 GETFILE
C
C /////////////////// VARIABLE DECLARATIONS //////////////////
C
C     CHARACTER STRINGS----------------------------------------
C
C     INFILE IS THE BATCH INPUT FILE NAME
      CHARACTER*12 INFILE
C
C     OUTFIL IS THE OUTPUT FILE
      CHARACTER*12 OUTFIL
C
C     USERCOM A COMMENT LINE USED TO ANNOTATE DATA AND OUTPUT FILES
      CHARACTER*79 USERCOM
C
C     LOGICALS-------------------------------------------------
C
```

```
C     BATCH IS TRUE IF READING INPUT FROM A FILE
      LOGICAL BATCH
C
C     AUTO IS TRUE IF RANDOM NUMBER SEEDS ARE GENERATED FROM CLOCK
      LOGICAL AUTO
C
C     BLACK IS TRUE IF THE PROFIT FOR A FISHERY > 0.0
      LOGICAL BLACK
C
C     FILE IS TRUE IF THERE IS AN OUTPUT FILE
      LOGICAL FILE
C
C     ZLASTC IS TRUE IF THE REDUCTION CATCH WAS ZERO LAST YEAR
      LOGICAL ZLASTC
C
C     ZCLOSED IS TRUE IF THE REDUCTION CATCH IS ZERO THIS YEAR
      LOGICAL ZCLOSED
C
C     QLASTC IS TRUE IF THE QUOTA LAST YEAR WAS ZERO
      LOGICAL QLASTC
C
C     QCLOSED IS TRUE IF THE QUOTA IS ZERO THIS YEAR
      LOGICAL QCLOSED
C
C     PLASTC IS TRUE IF REDUCTION FISHING WAS POTENTIALLY UNPROFITABLE
C     LAST YEAR
      LOGICAL PLASTC
C
C     PCLOSED IS TRUE IF REDUCTION FISHING IS POTENTIALLY UNPROFITABLE
C     THIS YEAR
      LOGICAL PCLOSED
C
C     DOUBLE PRECISION----------------------------------------
C
C
C     SSBT HOLDS THE SUM OF SQUARES/VARIANCE FOR TOTAL BIOMASS
      DOUBLE PRECISION SSBT
C
C     BTBAR IS THE MEAN TOTAL BIOMASS
      DOUBLE PRECISION BTBAR
C
C     RCBAR HOLDS THE MEAN REDUCTION CATCH
      DOUBLE PRECISION RCBAR
C
C     SSRC HOLDS THE SUM OF SQUARES/VARIANCE FOR REDUCTION CATCH
      DOUBLE PRECISION SSRC
C
C     ZMEANC IS THE MEAN NUMBER OF YEARS THAT THE REDUCTION
C     CATCH WAS ZERO
      DOUBLE PRECISION ZMEANC
C
C     QMEANC IS THE MEAN NUMBER OF YEARS THAT THE QUOTA WAS ZERO
      DOUBLE PRECISION QMEANC
C
C     PMEANC IS THE MEAN NUMBER OF YEARS THAT REDUCTION FISHING
C     WAS NOT POTENTIALLY PROFITABLE
      DOUBLE PRECISION PMEANC
C
C     PELBAR IS THE MEAN REPRODUCTIVE SUCCESS OF PELICANS
      DOUBLE PRECISION PELBAR
C
C     SSPEL IS THE SUM OF SQUARES/VARIANCE FOR PELICAN REP. SUCCESS
      DOUBLE PRECISION SSPEL
C
C     SSPROF IS THE SUM OF SQUARES/VARIANCE FOR REDUCTION PROFIT
      DOUBLE PRECISION SSPROF
C
C     PROFBAR IS THE MEAN REDUCTION PROFIT
      DOUBLE PRECISION PROFBAR
C
C     REALS--------------------------------------------------
C
C
C     AMP IS THE AMPLITUDE OF THE CYCLES UNDERLYING PROCESS ERRORS
      REAL AMP
C
C     PERIOD IS THE LENGTH IN YEARS OF ONE CYCLE
      REAL PERIOD
C
C     IF THE SPAWNING BIOMASS IS <= OVERF THEN ALL FISHERIES ARE CLOSED
      REAL OVERF
C
C     SMALLF IS THE SMALLEST POSSIBLE FRACTION SPAWNING
      REAL SMALLF

C     RPROF IS NET REDUCTION PROFIT
      REAL RPROF

C     RGPROF IS GROSS REDUCTION PROFIT
      REAL RGPROF

C     BEFF IS THE FISHING EFFORT NEEDED TO TAKE THE BAIT CATCH
      REAL BEFF

C     BAITQ IS THE ANNUAL BAIT CATCH TAKEN IF IT IS PROFITABLE
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```
      REAL BAITQ
C     BCOST IS THE COST OF BAIT FISHING
      REAL BCOST
C     BPROF IS NET PROFIT FOR THE BAIT FISHERY
      REAL BPROF
C     BGPROF IS GROSS PROFIT FOR BAIT
      REAL BGPROF
C     BXVALUE IS THE BAIT EXVESSEL VALUE OF ANCHOVY
      REAL BXVALUE
C     NREFF IS THE FISHING EFFORT NEEDED TO TAKE THE NON-REDUCTION
C     COMMERCIAL (I.E. DEAD BAIT) CATCH
      REAL NREFF
C     NRCOST IS THE COST OF NON-REDUCTION COMMERCIAL FISHING
      REAL NRCOST
C     NRPROF IS NET PROFIT FOR NON-REDUCTION COMMERICAL FISHING
      REAL NRPROF
C     NRGPROF IS GROSS PROFIT FOR NON-REDUCTION COMMERCIAL FISHING
      REAL NRGPROF
C     NRXVAL IS THE NON-REDUCTION COMMERCIAL EXVESSEL VALUE
      REAL NRXVAL
C     NRQUOTA IS THE NON-REDUCTION COMMERCIAL QUOTA
      REAL NRQUOTA
C     MAXCPE IS THE MAXIMUM CPUE
      REAL MAXCPE
C
C     TBFRAC HOLDS THE FRACTION OF YEARS AT OR BELOW EACH TOTAL
C     BIOMASS CRITERIA LEVEL
      REAL TBFRAC(NUMBTLV)
C     CFRAC HOLDS THE FRACTION OF YEARS AT OR BELOW EACH REDUCTION CATCH
C     CRITERIA LEVEL
      REAL CFRAC(NUMCLEV)
C     SFRAC HOLDS THE FRACTION OF YEARS AT OR BELOW EACH SPAWNING BIOMASS
C     CRITERIA LEVEL
      REAL SFRAC(NUMSLEV)
C     DF IS DEGREES OF FREEDOM FOR VARIANCE ESTIMATES
      REAL DF
C     LOWEST IS THE MINIMUM TOTAL BIOMASS
      REAL LOWEST
C     PELP1 AND PELP2 ARE PARAMETERS THAT RELATE TOTAL ABUNDANCE OF
C     ANCHOVY TO PELICAN BREEDING SUCCESS
      REAL PELP1,PELP2
C
C     MAXPELP IS THE MAXIMUM PELICAN PRODUCTIVITY
      REAL MAXPELP
C
C     MINPELP IS THE MINIMUM VALUE FOR PELICAN PRODUCTIVITY
      REAL MINPELP
C
C     CPUE IS CATCH PER UNIT OF EFFORT FOR REDUCTION FISHING
      REAL CPUE
C
C     CPUEP1 AND CPUE2 ARE PARAMETERS USED TO CALCULATE CPUE
      REAL CPUEP1,CPUEP2
C
C     REFFORT IS REDUCTION FISHING EFFORT
      REAL REFFORT
C
C     COSTEFF IS THE COST OF A UNIT OF FISHING EFFORT
      REAL COSTEFF
C
C     RCOST IS THE TOTAL COST OF REDUCTION FISHING
      REAL RCOST
C
C     EXVALUE IS THE REDUCTION EXVESSEL VALUE OF A UNIT OF ANCHOVY
      REAL EXVALUE
C
C     PELICAN IS THE REPRODUCTIVE SUCCESS OF PELICANS
      REAL PELICAN
C
C     TBLEV HOLDS THE VALUES THAT DEFINE THE CRITERIA LEVELS FOR
C     TOTAL BIOMASS
      REAL TBLEV(NUMBTLV)
C
C     CLEV HOLDS THE VALUES THAT DEFINE CRITERIA LEVELS FOR
C     REDUCTION CATCH
      REAL CLEV(NUMCLEV)
C
```

```
C       SLEV HOLDS THE VALUES THAT DEFINE CRITERIA LEVELS FOR SPAWNING
C       BIOMASS
        REAL SLEV(NUMSLEV)
C
C       IF THE SPAWNING BIOMASS IS BEYOND CUTOFF1 THEN THE REDUCTION
C       QUOTA IS SET TO THE MAXIMUM VALUE
        REAL CUTOFF1
C
C       MAXCAT IS THE MAXIMUM REDUCTION QUOTA
        REAL MAXCAT
C
C       CUTOFF2 IS THE CURRENT MINIMUM SPAWNING BIOMASS CUTOFF LEVEL
        REAL CUTOFF2
C
C       TBCUT IS THE MINIMUM TOTAL BIOMASS LEVEL THAT ALLOWS CATCH WHEN
C       SB < CUTOFF2 (I.E. IF TOTAL BIOMASS > TBCUT THEN
C       SOME REDUCTION FISHING MAY OCCUR)
        REAL TBCUT
C
C       MINCAT IS THE MINIMUM REDUCTION QUOTA WHEN SB < CUTOFF2
C       AND TOTAL BIOMASS > TBCUT
        REAL MINCAT
C
C       RCATCH IS THE REDUCTION CATCH
        REAL RCATCH
C
C       RQUOTA IS THE REDUCTION QUOTA
        REAL RQUOTA
C
C       BAIT IS THE CATCH FOR BAIT
        REAL BAIT
C
C       NRCATCH IS THE COMMERCIAL NONREDUCTION QUOTA/CATCH
        REAL NRCATCH
C
C       BT IS THE TOTAL BIOMASS IN THE CURRENT YEAR
        REAL BT
C
C       BINIT IS THE INITIAL VALUE OF THE TOTAL BIOMASS
        REAL BINIT
C
C       FRACMAT IS THE FRACTION OF THE TOTAL BIOMASS THAT SPAWNS
        REAL FRACMAT
C
C       SDL IS THE STANDARD DEVIATION OF LOGIT(FRACTION SPAWNING)
        REAL SDL
C
C       MEANL IS THE MEAN OF LOGIT FRACTION SPAWNING
        REAL MEANL
C
C       TRUESBT IS THE TRUE SPAWNING BIOMASS IN YEAR T
        REAL TRUESBT
C
C       SDM IS THE STANDARD DEVIATION (LOG SCALE) FOR MEASUREMENT ERRORS
C       IN THE OBSERVATION OF SPAWNING BIOMASS
        REAL SDM
C
C       TEMP IS A TEMPORARY VARIABLE
        REAL TEMP
C
C       OBSSBT IS THE OBSERVED (WITH ERROR) SPAWNING BIOMASS
        REAL OBSSBT
C
C       NEXTB IS THE TOTAL BIOMASS IN THE NEXT YEAR
        REAL NEXTBT
C
C       ALPHA IS THE MULTIPLIER IN THE STOCK-STOCK MODEL
        REAL ALPHA
C
C       BETA IS THE EXPONENT IN THE STOCK-STOCK MODEL
        REAL BETA
C
C       SDB IS THE STANDARD DEVIATION FOR PROCESS ERROR IN THE
C       STOCK-STOCK MODEL
        REAL SDB
C
C       CATCH IS THE TOTAL CATCH DURING THE CURRENT YEAR
        REAL CATCH
C
C       DELTA IS THE DISCOUNT RATE FOR CATCHES
        REAL DELTA
C
C       RATIO IS USED TO COMPUTE SUMS OF SQUARES
        REAL RATIO
C
C       INTEGERS-------------------------------------------------
C
C       OUT IS THE CHANNEL FOR OUTPUT
        INTEGER OUT
C
C       IN IS THE CHANNEL FOR INPUT
        INTEGER IN
C
```

```
C      COUNT IS THE NUMBER OF SIMULATION STEPS
       INTEGER COUNT
C
C      IHR,IMIN, ISEC AND I100TH ARE USED TO FETCH THE TIME
       INTEGER*2 IHR,IMIN,ISEC,I100TH
C
C      IYR,IMON AND IDAY ARE USED TO FETCH THE DATE
       INTEGER*2 IYR,IMON,IDAY
C
C      ZCOUNT IS THE CURRENT NUMBER OF SEQUENTIAL YEARS THAT THE REDUCTION
C      CATCH HAS BEEN ZERO
       INTEGER ZCOUNT
C
C      QCOUNT IS THE CURRENT NUMBER OF SEQUENTIAL YEARS THAT THE REDUCTION
C      QUOTA HAS BEEN ZERO
       INTEGER QCOUNT
C
C      PCOUNT IS THE CURRENT NUMBER OF SEQUENTIAL YEARS THAT REDUCTION
C      FISHING HAS NOT BEEN POTENTIALLY PROFITABLE
       INTEGER PCOUNT
C
C      ZNCLOSE IS THE NUMBER OF INTERVALS DURING WHICH THE
C      REDUCTION CATCH WAS ZERO
       INTEGER ZNCLOSE
C
C      QNCLOSE IS THE NUMBER OF INTERVALS DURING WHICH THE REDUCTION
C      QUOTA WAS ZERO
       INTEGER QNCLOSE
C
C      PNCLOSE IS THE NUMBER OF INTERVALS DURING WHICH POTENTIAL
C      REDUCTION PROFITS HAVE BEEN ZERO
       INTEGER PNCLOSE
C
C      ZNC IS THE TOTAL NUMBER OF YEARS DURING WHICH THE REDUCTION
C      CATCH WAS ZERO
       INTEGER ZNC
C
C      QNC IS THE TOTAL NUMBER OF YEARS DURING WHICH THE QUOTA WAS
C      ZERO
       INTEGER QNC
C
C      PNC IS THE TOTAL NUMBER OF YEARS DURING WHICH THE POTENTIAL
C      REDUCTION FISHERY PROFIT WAS ZERO
       INTEGER PNC
C
C      TBCOUNT HOLDS THE NUMBER OF YEARS FOR EACH TOTAL BIOMASS
C      LEVEL CRITERIA
       INTEGER TBCOUNT(NUMBTLV)
C
C      RCOUNT HOLDS THE NUMBER OF YEARS FOR EACH REDUCTION CATCH
C      LEVEL CRITERIA
       INTEGER RCOUNT(NUMCLEV)
C
C      SCOUNT HOLDS THE NUMBER OF YEARS FOR EACH SPAWNING BIOMASS
C      CRITERIA LEVEL
       INTEGER SCOUNT(NUMSLEV)
C
C      H, I AND J ARE COUNTING VARIABLES
       INTEGER H,I,J
C
C      NUMYEAR IS THE NUMBER OF YEARS IN EACH SIMULATION
       INTEGER NUMYEAR
C
C      NUMSIM IS THE NUMBER OF SIMULATIONS
       INTEGER NUMSIM
C
C      SEED1, SEED2 AND SEED3 ARE SEEDS FOR RANDOM NUMBERS
       INTEGER SEED1,SEED2,SEED3
C
C      ASEED1,ASEED2 AND ASEED3 ARE INITIAL VALUES FOR RANDOM
C      NUMBER SEEDS
       INTEGER ASEED1,ASEED2,ASEED3
C
C ////////////////////// DATA STATEMENTS /////////////////////
C
C      LOGICALS-----------------------------------------------
C
       DATA BATCH /F/
C
C      DOUBLE PRECISION---------------------------------------
C
       DATA SSBT /DZ/,BTBAR /DZ/
       DATA RCBAR /DZ/,SSRC /DZ/
       DATA ZMEANC /DZ/
       DATA QMEANC /DZ/
       DATA PMEANC /DZ/
       DATA PELBAR /RZ/,SSPEL /RZ/
C
C      INTEGERS-----------------------------------------------
C
       DATA ZCOUNT /IZ/,ZNCLOSE /IZ/,ZNC /IZ/
       DATA QCOUNT /IZ/,QNCLOSE /IZ/,QNC /IZ/
       DATA PCOUNT /IZ/,PNCLOSE /IZ/,PNC /IZ/
```

```
      DATA TBCOUNT /NUMBTLV*IZ/
      DATA RCOUNT /NUMCLEV*IZ/
      DATA SCOUNT /NUMSLEV*IZ/
      DATA IN /DEFALT/,OUT /DEFOUT/
      DATA COUNT /IZ/
C
C ////////////////////// EXECUTABLE CODE //////////////////////
C
C     WRITE HEADER TO OUTPUT
      WRITE(*,8020)
      WRITE(*,8015)
     + CTRSTR('FMPSIM - ANCHOVY SIMULATION PROGRAM VERSION '//
     +          VERSION//'@','-')

C     WRITE MODIFICATION DATE
      WRITE(*,8015)
     + CTRSTR('DATE OF LAST MODIFICATION: '//MODDATE//'@',' ')

C
C     INPUT DATA ---------------------------------------------
C
C
C     -GET NAME OF OUTPUT FILE
      WRITE(*,8015) 'OUTPUT FILE?'
      FILE=GETLOG(IN,F,F)

      IF (FILE) THEN
C     GET THE OUTPUT FILE NAME
        OUTFIL=GETFILE(F)

C     CHANGE THE OUTPUT CHANNEL NUMBER
        OUT=10

C     OPEN THE OUTPUT FILE
        OPEN(UNIT=OUT,FILE=OUTFIL,STATUS='UNKNOWN')
      ENDIF

C     -FIND OUT IF INPUT WILL BE INTERACTIVE OR BATCH MODE
      WRITE(*,8015) 'BATCH INPUT?'
      BATCH=GETLOG(IN,F,F)

C     -IF BATCH GET NAME OF INPUT FILE AND OPEN IT
      IF (BATCH) THEN
        INFILE=GETFILE(T)
        OPEN(UNIT=INBAT,FILE=INFILE,STATUS='OLD',MODE='READ')
C       USE THE UNIT NUMBER FOR BATCH INPUT
        IN=INBAT
      ENDIF

C     -USER'S COMMENT
       WRITE(*,8015) 'COMMENT LINE? (MAX 79 CHARS)'
       READ(IN,'(/,A79)') USERCOM
       IF (BATCH) WRITE(*,'(1X,A79)') USERCOM

C     -EVALUATION CRITERIA LEVELS

C     ---CRITERIA FOR TOTAL BIOMASS
      DO 4050,J=1,NUMBTLV
        WRITE(*,4055) J
        TBLEV(J)=GETNUM(IN,BATCH,T,F,RZ,RZ,7)
4050  CONTINUE
4055  FORMAT (1X,'TOTAL BIOMASS CRITERIA LEVEL ',I2)

C     ---CRITERIA FOR SPAWNING BIOMASS
      DO 4057,J=1,NUMSLEV
        WRITE(*,4058) J
        SLEV(J)=GETNUM(IN,BATCH,T,F,RZ,RZ,7)
4057  CONTINUE
4058  FORMAT (1X,'SPAWNING BIOMASS CRITERIA LEVEL ',I2)

C     ---CRITERIA FOR REDUCTION CATCH
      DO 4090,J=1,NUMCLEV
        WRITE(*,4095) J
        CLEV(J)=GETNUM(IN,BATCH,T,F,RZ,RZ,7)
4090  CONTINUE
4095  FORMAT (1X,'REDUCTION CATCH CRITERIA LEVEL ',I2)

C     --CUTOFF LEVEL FOR ALL FISHING
      WRITE(*,8015) 'SPAWNING BIOMASS CUTOFF LEVEL FOR ALL FISHING'
      OVERF=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --WRITE PARAMETERS FOR REGULATION OF REDUCTION FISHERY

      WRITE(*,8015) 'UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA'
      CUTOFF1=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MAXIMUM REDUCTION QUOTA'
      MAXCAT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     + 'CURRENT LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA'
      CUTOFF2=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
```

```
     &'CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF'
      TBCUT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MINIMUM REDUCTION QUOTA'
      MINCAT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --WRITE BAIT COMMERCIAL NON-REDUCTION PARAMETERS

      WRITE(*,8015) 'ANNUAL CATCH FOR BAIT (ALL PROFITABLE YEARS)'
      BAITQ=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     +   'COMMERCIAL NONREDUCTION CATCH (ALL PROFITABLE YEARS)'
      NRQUOTA=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --WRITE ECONOMIC PARAMETERS

      WRITE(*,8015) 'COST OF ONE UNIT OF FISHING EFFORT'
      COSTEFF=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015) 'REDUCTION EXVESSEL VALUE'
      EXVALUE=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015) 'BAIT EXVESSEL VALUE'
      BXVALUE=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015) 'NONREDUCTION COMMERCIAL EXVESSEL VALUE'
      NRXVAL=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015)
     +   'MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS'
      CPUEP1=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'EXPONENT (BETA) FOR CPUE AND BIOMASS'
      CPUEP2=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MAXIMUM CPUE'
      MAXCPE=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --PELICAN PARAMETERS

      WRITE(*,8015)
     + 'INTERCEPT PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS'
      PELP1=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'SLOPE PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS'
      PELP2=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MAXIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)'
      MAXPELP=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MINIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)'
      MINPELP=GETNUM(IN,BATCH,T,T,RZ,MAXPELP,7)

C     --POPULATION DYNAMICS PARAMETERS

      WRITE(*,8015) 'LOWEST ATTAINABLE BIOMASS'
      LOWEST=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)'
      SDL=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MEAN VALUE FOR LOGIT(FRACTION SPAWNING)'
      MEANL=GETNUM(IN,BATCH,F,F,RZ,RZ,7)

      WRITE(*,8015) 'SMALLEST VALUE FOR FRACTION SPAWNING'
      SMALLF=GETNUM(IN,BATCH,F,F,RZ,RZ,7)

      WRITE(*,8015)
     +  'STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS'
      SDM=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL'
      ALPHA=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'EXPONENT (BETA) IN STOCK-STOCK MODEL'
      BETA=GETNUM(IN,BATCH,F,F,RZ,RZ,7)

      WRITE(*,8015) 'STANDARD DEVIATION FOR PROCESS ERROR'
      SDB=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     + 'AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)'
      AMP=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     + 'LENGTH OF CYCLES IN PROCESS ERROR (YEARS)'
      PERIOD=GETNUM(IN,BATCH,T,F,1.0,RZ,7)

      WRITE(*,8015) 'DISCOUNT RATE FOR CATCH'
      DELTA=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --SIMULATION CONTROL PARAMETERS
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```
      WRITE(*,8015) 'NUMBER OF SIMULATION RUNS'
      NUMSIM=GETINT(IN,BATCH,T,T,IZ,MAXSIM)

      WRITE(*,8015) 'NUMBER OF YEARS IN EACH RUN'
      NUMYEAR=GETINT(IN,BATCH,T,T,IZ,MAXYR)

C     --INITIAL CONDITIONS

      WRITE(*,8015) 'INITIAL BIOMASS (UNITS ARE MILLION MT)'
      BINIT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --INITIAL SEEDS FOR RANDOM NUMBER GENERATOR

      WRITE(*,8015) 'AUTOMATIC RANDOM NUMBER SEEDS?'
      AUTO=GETLOG(IN,BATCH,T)
      IF (AUTO) THEN
C     SET THE INITIAL VALUES TO SECONDS SINCE MIDNIGHT AND MAKE
C     SURE THAT THE INITIAL VALUES ARE NOT TOO LARGE FOR THE
C     RANDOM NUMBER GENERATOR
        ASEED1=SECOND()
        ASEED1=MOD(ASEED1,MAXSEED)
        ASEED2=ASEED1*3
        ASEED2=MOD(ASEED2,MAXSEED)
        ASEED3=ASEED2*1110
        ASEED3=MOD(ASEED3,MAXSEED)
      ELSE
        WRITE(*,8015) 'INITIAL VALUE FOR RANDOM NUMBER SEED 1'
        ASEED1=GETINT(IN,BATCH,T,T,IZ,MAXSEED)

        WRITE(*,8015) 'INITIAL VALUE FOR RANDOM NUMBER SEED 2'
        ASEED2=GETINT(IN,BATCH,T,T,IZ,MAXSEED)

        WRITE(*,8015) 'INITIAL VALUE FOR RANDOM NUMBER SEED 3'
        ASEED3=GETINT(IN,BATCH,T,T,IZ,MAXSEED)
      ENDIF

C     --SET RANDOM NUMBER SEEDS TO INITIAL VALUES
      SEED1=ASEED1
      SEED2=ASEED2
      SEED3=ASEED3

C
C     START LOOP OVER SIMULATION RUNS--------------------------

      DO 5100,H=1,NUMSIM

C     -SET FLAG FOR NO CATCH LAST YEAR TO FALSE
        ZLASTC=F

C     -SET FLAG FOR NO QUOTA LAST YEAR TO FALSE
        QLASTC=F

C     -SET FLAG FOR NO PROFIT LAST YEAR TO FALSE
        PLASTC=F

C     -SET BIOMASS TO INITIAL VALUES
        NEXTBT=BINIT

C     START LOOP OVER YEARS------------------------------------
C
      DO 5000,I=1,NUMYEAR
C
C     -COUNT THE STEP
        COUNT=COUNT+1
C
C     -SET CURRENT BIOMASS
        BT=NEXTBT

C     -DETERMINE CPUE FROM BIOMASS
        CPUE=CPUEP1*BT**CPUEP2

C     --MAKE SURE CPUE IS NIETHER TOO LOW OR TO HIGH
        IF (CPUE.LT.RZ) CPUE=RZ
        IF (CPUE.GT.MAXCPE) CPUE=MAXCPE

C
C     SPAWNING BIOMASS CALCULATIONS----------------------------
C
C     -CALCULATE THE FRACTION OF THE TOTAL BIOMASS THAT SPAWNS ON 15 FEB
C
C     --LOGIT(FRACTION SPAWNING) HAS A NORMAL DISTRIBUTION WITH
C       MEAN=MEANL AND STANDARD DEVIATION = SDL.  FETCH A STANDARD
C       NORMAL VALUE AND SCALE IT.
        FRACMAT=NRAND(SEED1,SEED2,SEED3)*SDL+MEANL

C     --CONVERT THE LOGIT TO A FRACTION
        FRACMAT=EXP(FRACMAT)/(1+EXP(FRACMAT))

C     --MAKE SURE THAT THE FRACTION IS NOT UNREASONABLY SMALL
        IF (FRACMAT.LE.SMALLF) FRACMAT=SMALLF
C
C     --CALCULATE THE TRUE SPAWNING BIOMASS
```

```
         TRUESBT=BT*FRACMAT
C
C     -CALCULATE THE APPARENT SPAWNING BIOMASS BY APPLYING A RANDOM
C      MEASUREMENT ERROR.  THE MEASUREMENT ERRORS COME FROM A LOG
C      NORMAL DISTRIBUTION WITH MEAN 0.0 AND STANDARD DEVIATION
C      = SDM.  FETCH A STANDARD NORMAL VALUE AND SCALE IT.
         TEMP=NRAND(SEED1,SEED2,SEED3)*SDM
C
C     --APPLY THE MEASUREMENT ERROR TO THE ACTUAL VALUE
         OBSSBT=TRUESBT*EXP(TEMP)
C
C     BAIT CATCH CALCULATIONS--------------------------------

         CALL GETPROF(CPUE,BAITQ,COSTEFF,BXVALUE,
     +                BPROF,BGPROF,BEFF,BCOST,BLACK)

C     -DON'T GO FISHING IF NO PROFIT CAN BE MADE OR AN OVERFISHING
C      CONDITION EXISTS
         IF (.NOT.BLACK.OR.TRUESBT.LE.OVERF) THEN
C     --NO CATCH
           BAIT=RZ
C     --NO PROFIT
           BPROF=RZ
         ELSE
           BAIT=BAITQ
         ENDIF

C     NON-REDUCTION COMMERCIAL CATCH CALCULATIONS----------------

         CALL GETPROF(CPUE,NRQUOTA,COSTEFF,NRXVAL,
     +                NRPROF,NRGPROF,NREFF,NRCOST,BLACK)

C     -DON'T GO FISHING IF NO PROFIT CAN BE MADE OR AN OVERFISHING
C      CONDITION EXISTS
         IF (.NOT.BLACK.OR.TRUESBT.LE.OVERF) THEN
C     --NO CATCH
           NRCATCH=RZ
C     --NO PROFIT
           NRPROF=RZ
         ELSE
           NRCATCH=NRQUOTA
         ENDIF

C
C     REDUCTION QUOTA/CATCH CALCULATIONS------------------------
C
C     -THE REDUCTION FISHERY IS OPEN UNTIL PROVEN OTHERWISE
         ZCLOSED=F
         QCLOSED=F
         PCLOSED=F

C     -IF THE OBS SB > CUTOFF1 THEN THE REDUCTION QUOTA
C        IS THE MAXIMUM VALUE
         IF (OBSSBT.GT.CUTOFF1) RQUOTA=MAXCAT

C     -IF CUTOFF2+MINCAT < OBS SB <= CUTOFF1 THEN THE QUOTA IS THE
C        DIFFERENCE
         IF
     +      ((OBSSBT.GT.CUTOFF2+MINCAT).AND.(OBSSBT.LE.CUTOFF1))
     +        RQUOTA=OBSSBT-CUTOFF2

C     -WHEN CUTOFF2 < OBS SB <= CUTOFF2+MINCAT THE QUOTA FORMULA
C      DEPENDS ON WHETHER TBCUT > 0.  IF TBCUT > 0 THEN
C      THE QUOTA ITSELF DEPENDS ON WHETHER THE TOTAL BIOMASS
C      <= TBCUT
           IF ((CUTOFF2.LT.OBSSBT).AND.(OBSSBT.LE.CUTOFF2+MINCAT)) THEN
             IF (TBCUT.EQ.RZ) THEN
C      --THE QUOTA FORMULA AND QUOTA DO NOT DEPEND ON THE TOTAL BIOMASS
               RQUOTA=MINCAT
             ELSE
               IF (BT.GE.TBCUT) THEN
C      --THE QUOTA IS SET TO ITS MINIMUM VALUE
                 RQUOTA=MINCAT
               ELSE
C      --THE QUOTA IS THE DIFFERENCE (AS IN THE STATUS QUO MODEL)
                 RQUOTA=OBSSBT-CUTOFF2
               ENDIF
             ENDIF
           ENDIF

C     -IF THE OBS SB <= CUTOFF2, AND MINCAT NOT EQUAL TO ZERO
C      AND TOTAL BIOMASS >= TBCUT THEN THE QUOTA IS MINCAT
           IF (OBSSBT.LE.CUTOFF2) THEN
             IF (MINCAT.GT.RZ) THEN
               IF (TBCUT.EQ.RZ) THEN
                 RQUOTA=MINCAT
               ELSE IF (BT.GE.TBCUT) THEN
                 RQUOTA=MINCAT
C     -ELSE THE REDUCTION QUOTA IS ZERO AND THE FISHERY IS CLOSED
               ELSE
                 RQUOTA=RZ
               ENDIF
```

```
          ELSE
            RQUOTA=RZ
          ENDIF
        ENDIF
C     -IF THE SPAWNING BIOMASS <= OVERF THEN AN OVERFISHING CONDITION
C     EXISTS AND THE REDUCTION FISHERY IS CLOSED
        IF (TRUESBT.LE.OVERF) RQUOTA=RZ
C     -IF THE QUOTA IS ZERO THEN SET FLAG
        IF (RQUOTA.EQ.RZ) QCLOSED=T
C     REDUCTION PROFITS------------------------------------------
C     -ESTIMATE POTENTIAL PROFITS
        CALL GETPROF(CPUE,RQUOTA,COSTEFF,EXVALUE,
     +               RPROF,RGPROF,REFFORT,RCOST,BLACK)
C     -IF NOT PROFITABLE THEN SET FLAG
        IF (.NOT.BLACK) PCLOSED=T
C     REDUCTION CATCH--------------------------------------------
C     -IF NO QUOTA OR NOT PROFITABLE THEN THE CATCH WILL BE ZERO
C      AND THE FISHERY SHUTS DOWN
        IF (PCLOSED.OR.QCLOSED) THEN
C     --NO CATCH
          RCATCH=RZ
          ZCLOSED=T
C     --NO PROFIT
          RPROF=RZ
        ELSE
          RCATCH=RQUOTA
        ENDIF
C     THE TOTAL CATCH IS REDUCTION + BAIT + COMM. NON-REDUCTION
        CATCH=RCATCH+BAIT+NRCATCH
C     CALCULATIONS FOR TOTAL BIOMASS NEXT YEAR------------------
C
C     -THE BIOMASS NEXT YEAR IS A DETERMINISTIC VALUE THAT IS
C      AFFECTED BY A LOGNORMAL PROCESS ERROR AND CATCH DURING
C      THE CURRENT YEAR
C
C     --CALCULATE THE DETERMINISTIC VALUE FOR BIOMASS NEXT YEAR
C       IN THE ABSENCE OF FISHING
        NEXTBT=BT*EXP(ALPHA+BETA*BT)
C
C     --RANDOM COMPONENT OF PROCESS ERROR IS LOGNORMAL WITH
C       MEAN ZERO AND STANDARD DEVIATION SDB.  FETCH A RANDOM NUMBER
C       AND SCALE IT.
        TEMP=NRAND(SEED1,SEED2,SEED3)*SDB
C
C     --CALCULATE THE UNDERLYING CYCLIC AFFECT ON PROCESS ERROR
        TEMP=TEMP+AMP*SIN(MOD(I,PERIOD)/PERIOD*2*PI)
C
C     --APPLY THE RANDOM ERROR
        NEXTBT=NEXTBT*EXP(TEMP)
C
C     --SUBTRACT THE DISCOUNTED CATCH FROM THE POTENTIAL BIOMASS
        NEXTBT=NEXTBT-DELTA*CATCH
C
C     --MAKE SURE THAT THE STOCK DOES NOT FALL BELOW THE MINIMUM
C       VALUE.  IF IT DOES THEN ADJUST STOCK LEVEL AND CATCHES
        TEMP=LOWEST+SMALL
        IF (NEXTBT.LE.TEMP) THEN
          PRINT *,' '
          PRINT *,' NOTE -> BIOMASS SMALLER THAN MIMIMUM'
C     ---SET NEXT YEARS BIOMASS TO THE LOWEST LEVEL
          NEXTBT=TEMP
C     ---CALCULATE THE CATCH (IF ANY) THAT COULD BE TAKEN
C        (THIS MAY BE <= ZERO)
          TEMP=(BT-NEXTBT)/DELTA
C     ---IF SOME CATCH IS POSSIBLE THEN ADJUST TOTAL CATCH
          IF (TEMP.GT.RZ) THEN
            CATCH=TEMP
C     ----ADJUST REDUCTION CATCH AND PROFITS IF NECESSARY
            IF (RCATCH.GT.RZ) THEN
              RCATCH=TEMP/CATCH*RCATCH
C     -----COMPUTE REDUCTION PROFIT ON BASIS OF REVISED CATCHES
C          (NOTE FISHING IS PROFITABLE IF RCATCH GT ZERO)
              CALL GETPROF(CPUE,RCATCH,COSTEFF,EXVALUE,
     +                     RPROF,RGPROF,REFFORT,RCOST,BLACK)
            ENDIF
C     ---IF NO CATCHES COULD BE TAKEN THEN SET THE TOTAL AND
C        REDUCTION CATCH TO ZERO
          ELSE
```

```
            CATCH=RZ
            RCATCH=RZ
C       ----NO CATCH IS TRUE
            ZCLOSED=T
          ENDIF
        ENDIF

C
C       UPDATE EVALUATION CRITERIA--------------------------------
C
C       -RATIO IS USED TO COMPUTE SUMS OF SQUARES
          RATIO=REAL(COUNT-1)/COUNT
C
C       -MEAN AND SUMS OF SQUARES FOR TOTAL BIOMASS
C
C       --TEMP IS USED IN CALCULATIONS
          TEMP=BT-BTBAR

C       --UPDATE SUM OF SQUARES
          SSBT=SSBT+RATIO*TEMP**2

C       --UPDATE MEAN
          BTBAR=BTBAR+TEMP/COUNT

C
C       -% OF YEARS TOTAL BIOMASS < TBLEV(I)
          DO 7000,J=1,NUMBTLV
            IF (BT.LE.TBLEV(J)) TBCOUNT(J)=TBCOUNT(J)+1
7000      CONTINUE

C
C       -% OF YEARS SPAWNING BIOMASS < SLEV(I)
          DO 7005,J=1,NUMSLEV
            IF (TRUESBT.LE.SLEV(J)) SCOUNT(J)=SCOUNT(J)+1
7005      CONTINUE

C
C       -MEAN AND SUMS OF SQUARES FOR REDUCTION CATCH
C
C       --TEMP IS USED IN CALCULATIONS
          TEMP=RCATCH-RCBAR

C         UPDATE SUM OF SQUARES
          SSRC=SSRC+RATIO*TEMP**2

C       --UPDATE MEAN
          RCBAR=RCBAR+TEMP/COUNT
C
C       -% OF YEARS REDUCTION CATCH < CLEV(I)
          DO 7010,J=1,NUMCLEV
            IF (RCATCH.LE.CLEV(J)) RCOUNT(J)=RCOUNT(J)+1
7010      CONTINUE

C
C       -DURATION OF PERIODS WITH NO REDUCTION CATCH
C
          CALL CLOSEM(ZCLOSED,ZLASTC,ZCOUNT,ZNCLOSE,ZMEANC,ZNC,I,NUMYEAR)

C
C       -DURATION OF PERIODS WITH ZERO QUOTA
C
          CALL CLOSEM(QCLOSED,QLASTC,QCOUNT,QNCLOSE,QMEANC,QNC,I,NUMYEAR)

C
C       -DURATION OF PERIODS WITH ZERO POTENTIAL PROFIT
C
          CALL CLOSEM(PCLOSED,PLASTC,PCOUNT,PNCLOSE,PMEANC,PNC,I,NUMYEAR)

C
C       -PELICAN REPRODUCTIVE SUCCESS
C
C       --SUCCESS IN CURRENT YEAR
          PELICAN=PELP1+PELP2*BT

C       ---MAKE SURE PELICAN PRODUCTIVITY IS NIETHER TOO HIGH OR LOW
          IF (PELICAN.LT.MINPELP) THEN
            PELICAN=MINPELP
          ELSEIF (PELICAN.GT.MAXPELP) THEN
            PELICAN=MAXPELP
          ENDIF

C       --TEMP IS USED IN CALCULATIONS
          TEMP=PELICAN-PELBAR

C       --UPDATE MEAN ANNUAL PELICAN BREEDING SUCCESS
          SSPEL=SSPEL+RATIO*TEMP**2

C       --UPDATE SUMS OF SQUARES FOR BREEDING SUCCESS
          PELBAR=PELBAR+TEMP/COUNT

C       --UPDATE SUM OF SQURARES/VARIANCE FOR PROFITS
          TEMP=RPROF-PROFBAR
          SSPROF=SSPROF+RATIO*TEMP**2
```

```
C       --UPDATE MEAN REDUCTION PROFITS
          PROFBAR=PROFBAR+TEMP/COUNT

C       ---- END OF LOOP OVER YEARS
5000    CONTINUE

C       ---- END OF LOOP OVER SIMULATION RUNS
5100    CONTINUE

C
C       CONVERT SUMS OF SQUARES TO STANDARD DEVIATIONS
C
C       -DEGREES OF FREEDOM
        DF=COUNT-1

C       -TOTAL BIOMASS
        SSBT=SQRT(SSBT/DF)

C       -REDUCTION CATCH
        SSRC=SQRT(SSRC/DF)

C       -PELICAN REPROCUCTIVE SUCCESS
        SSPEL=SQRT(SSPEL/DF)

C       -REDUCTION FISHERY PROFITS
        SSPROF=SQRT(SSPROF/DF)
C
C       CONVERT COUNTS INTO FRACTIONS
C
C       -COUNTS FOR TOTAL BIOMASS CRITERIA
        DO 5500 J=1,NUMBTLV
          TBFRAC(J)=REAL(TBCOUNT(J))/COUNT
5500    CONTINUE

C       -COUNTS FOR SPAWNING BIOMASS
        DO 5560 J=1,NUMSLEV
          SFRAC(J)=REAL(SCOUNT(J))/COUNT
5560    CONTINUE

C       -COUNTS FOR REDUCTION CATCH
        DO 5575 J=1,NUMCLEV
          CFRAC(J)=REAL(CFRAC(J))/COUNT
5575    CONTINUE

C
C       OUTPUT-----------------------------------------------------------
C
C       -WRITE HEADER TO OUTPUT FILE
        WRITE(OUT,8020)
        WRITE(OUT,8015)
       + CTRSTR('FMPSIM - ANCHOVY SIMULATION PROGRAM VERSION '//
       +         VERSION//'@','-')

C       WRITE MODIFICATION DATE
        WRITE(OUT,8015)
       +  CTRSTR('DATE OF LAST MODIFICATION: '//MODDATE//'@',' ')

C       -WRITE TIME
        CALL GETTIM(IHR,IMIN,ISEC,I100TH)
        WRITE(OUT,8020)
        WRITE(OUT,6010) ' TIME -> ',IHR,IMIN,ISEC
6010    FORMAT(A8,I2,':',I2,':',I2)

C       -WRITE THE DATE
        CALL GETDAT(IYR,IMON,IDAY)
        WRITE(OUT,6012) ' DATE -> ',IDAY,IMON,IYR
6012    FORMAT(A8,I2,'/',I2,'/',I4)

C       -WRITE INPUT FILE NAME IF IT EXISTS
        IF (BATCH) THEN
          WRITE(OUT,8020)
          WRITE(OUT,8015) 'INPUT FILE -> '//INFILE
        ENDIF
C       -WRITE INPUT PARAMETERS TO OUTPUT FILE IN SUCH A WAY THAT
C        AN OUTPUT FILE CAN BE REUSED AS AN INPUT FILE

        WRITE(OUT,8020)
        WRITE(OUT,8015) CTRSTR('INPUT PARAMETERS@','-')
        WRITE(OUT,8020)

C       -WRITE USER'S COMMENT
         WRITE(OUT,'(A12,/,A79)') 'COMMENT LINE',USERCOM

C
C       --EVALUATION CRITERIA LEVELS

C       ---CRITERIA FOR TOTAL BIOMASS
        DO 6050 J=1,NUMBTLV
          WRITE(OUT,6055) J,TBLEV(J)
6050    CONTINUE
6055    FORMAT ('TOTAL BIOMASS CRITERIA LEVEL ',I2,/,G13.6)
```

```
C      ---CRITERIA FOR SPAWNING BIOMASS
       DO 6057,J=1,NUMSLEV
         WRITE(OUT,6058) J,SLEV(J)
6057   CONTINUE
6058   FORMAT ('SPAWNING BIOMASS CRITERIA LEVEL ',I2,/,G13.6)
C      ---CRITERIA FOR REDUCTION CATCH
       DO 6090,J=1,NUMCLEV
         WRITE(OUT,6095) J,CLEV(J)
6090   CONTINUE
6095   FORMAT ('REDUCTION CATCH CRITERIA LEVEL ',I2,/,G13.6)
C      --WRITE CUTOFF LEVEL FOR ALL FISHING
       WRITE(OUT,8000) 'SPAWNING BIOMASS CUTOFF LEVEL FOR ALL FISHING',
     +          OVERF
C      --WRITE PARAMETERS FOR REGULATION OF REDUCTION FISHERY

       WRITE(OUT,8000)
     +     'UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA',
     +                CUTOFF1

       WRITE(OUT,8000) 'MAXIMUM REDUCTION QUOTA',
     +                MAXCAT

       WRITE(OUT,8000)
     +    'CURRENT LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA',
     +                CUTOFF2

       WRITE(OUT,8000)
     +'CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF',
     +                TBCUT

       WRITE(OUT,8000) 'MINIMUM REDUCTION QUOTA',
     +                MINCAT
C      --WRITE BAIT COMMERCIAL NON-REDUCTION PARAMETERS

       WRITE(OUT,8000) 'ANNUAL CATCH FOR BAIT (ALL PROFITABLE YEARS)',
     +                BAIT

       WRITE(OUT,8000)
     +    'COMMERCIAL NONREDUCTION CATCH (ALL PROFITABLE YEARS)',
     +                NRQUOTA
C      --WRITE ECONOMIC PARAMETERS

       WRITE(OUT,8000) 'COST OF ONE UNIT OF FISHING EFFORT',
     +                COSTEFF

       WRITE(OUT,8000) 'REDUCTION EXVESSEL VALUE',
     +                EXVALUE

       WRITE(OUT,8000) 'BAIT EXVESSEL VALUE',
     +                BXVALUE

       WRITE(OUT,8000) 'NONREDUCTION COMMERCIAL EXVESSEL VALUE',
     +                NRXVAL

       WRITE(OUT,8000)
     +     'MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS',
     +                CPUEP1

       WRITE(OUT,8000) 'EXPONENT (BETA) FOR CPUE AND BIOMASS',
     +                CPUEP2

       WRITE(OUT,8000) 'MAXIMUM CPUE',
     +                MAXCPE
C      --PELICAN PARAMETERS

       WRITE(OUT,8000)
     + 'INTERCEPT PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS',
     +                PELP1

       WRITE(OUT,8000)
     +  'SLOPE PARAMETER FOR PELICAN REPRODUCTIVE SUCCESS',
     +                PELP2

       WRITE(OUT,8000)
     +  'MAXIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)',
     +                MAXPELP

       WRITE(OUT,8000)
     +  'MINIMUM PELICAN PRODUCTIVITY (FLEDGLINGS/PAIR)',
     +                MINPELP
C      --POPULATION DYNAMICS PARAMETERS

       WRITE(OUT,8000) 'LOWEST ATTAINABLE BIOMASS',
     +                LOWEST

       WRITE(OUT,8000)
```

```
     +      'STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)',
     +              SDL

      WRITE(OUT,8000) 'MEAN VALUE FOR LOGIT(FRACTION SPAWNING)',
     +              MEANL

      WRITE(OUT,8000) 'SMALLEST VALUE FOR FRACTION SPAWNING',
     +              SMALLF

      WRITE(OUT,8000)
     +  'STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS',
     +              SDM

      WRITE(OUT,8000)
     +   'MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL',
     +              ALPHA

      WRITE(OUT,8000) 'EXPONENT (BETA) IN STOCK-STOCK MODEL',
     +              BETA

      WRITE(OUT,8000) 'STANDARD DEVIATION FOR PROCESS ERROR',
     +              SDB

      WRITE(OUT,8000)
     + 'AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)',
     +              AMP

      WRITE(OUT,8000)
     + 'LENGTH OF CYCLES IN PROCESS ERROR (YEARS)',
     +             PERIOD

      WRITE(OUT,8000) 'DISCOUNT RATE FOR CATCH',
     +              DELTA

C     --SIMULATION CONTROL PARAMETERS

      WRITE(OUT,8010) 'NUMBER OF SIMULATION RUNS',
     +              NUMSIM

      WRITE(OUT,8010) 'NUMBER OF YEARS IN EACH RUN',
     +              NUMYEAR

C     --INITIAL CONDITIONS

      WRITE(OUT,8000) 'INITIAL BIOMASS (UNITS ARE MILLION MT)',
     +              BINIT

C     --INITIAL SEEDS FOR RANDOM NUMBER GENERATOR

      WRITE(OUT,8015) 'AUTOMATIC RANDOM NUMBER SEEDS?'
      IF(AUTO) THEN
        WRITE(OUT,'(A3)') 'YES'
      ELSE
        WRITE(OUT,'(A2)') 'NO'
      ENDIF

      WRITE(OUT,8010) 'INITIAL VALUE FOR RANDOM NUMBER SEED 1',
     +              ASEED1

      WRITE(OUT,8010) 'INITIAL VALUE FOR RANDOM NUMBER SEED 2',
     +              ASEED2

      WRITE(OUT,8010) 'INITIAL VALUE FOR RANDOM NUMBER SEED 3',
     +              ASEED3

C     -WRITE RESULTS TO OUTPUT FILE

      WRITE(OUT,8020)
      WRITE(OUT,8015) CTRSTR('RESULTS@','-')
      WRITE(OUT,8020)

C     -- MEAN, SD AND CV FOR TOTAL BIOMASS

      WRITE(OUT,8000) 'MEAN TOTAL BIOMASS',
     +              REAL(BTBAR)

      WRITE(OUT,8000) 'STANDARD DEVIATION FOR TOTAL BIOMASS',
     +              REAL(SSBT)

      WRITE(OUT,8013) 'COEFFICIENT OF VARIATION FOR TOTAL BIOMASS',
     +              SSBT/(BTBAR+SMALL)*100

C     -- MEAN, SD AND CV FOR REDUCTION CATCH

      WRITE(OUT,8000) 'MEAN REDUCTION CATCH',
     +              REAL(RCBAR)

      WRITE(OUT,8000) 'STANDARD DEVIATION FOR REDUCTION CATCH',
     +              REAL(SSRC)

      WRITE(OUT,8013) 'COEFFICIENT OF VARIATION FOR REDUCTION CATCH',
     +              SSRC/(RCBAR+SMALL)*100
```

```
C     -- MEAN, SD AND CV FOR PELICAN REPRODUCTIVE SUCCESS

      WRITE(OUT,8000) 'MEAN PELICAN REPRODUCTIVE SUCCESS',
     +                REAL(PELBAR)

      WRITE(OUT,8000)
     +    'STANDARD DEVIATION FOR PELICAN REPRODUCTIVE SUCCESS',
     +                REAL(SSPEL)

      WRITE(OUT,8013)
     + 'COEFFICIENT OF VARIATION FOR PELICAN REPRODUCTIVE SUCCESS',
     +                SSPEL/(PELBAR+SMALL)*100

C     -- MEAN, SD AND CV FOR REDUCTION PROFITS

      WRITE(OUT,8000) 'MEAN REDUCTION PROFIT',
     +                REAL(PROFBAR)

      WRITE(OUT,8000) 'STANDARD DEVIATION FOR REDUCTION PROFITS',
     +                REAL(SSPROF)

      WRITE(OUT,8013) 'COEFFICIENT OF VARIATION FOR REDUCTION PROFITS',
     +                SSPROF/(PROFBAR+SMALL)*100

C     --REDUCTION FISHERY CLOSURES

C     ---PERIODS WITH NO CATCH
      WRITE(OUT,8013) 'PERCENTAGE OF YEARS WITH NO REDUCTION CATCH',
     +                REAL(ZNC)/COUNT*100

      WRITE(OUT,8000) 'MEAN NUMBER OF NO CATCH INTERVALS PER 100 YEARS',
     +                REAL(ZNCLOSE)/COUNT*100

      WRITE(OUT,8000)
     +    'MEAN LENGTH OF NO CATCH INTERVALS',
     +                REAL(ZMEANC)

C     ---PERIODS WITH NO QUOTA
      WRITE(OUT,8013) 'PERCENTAGE OF YEARS WITH NO QUOTA',
     +                REAL(QNC)/COUNT*100

      WRITE(OUT,8000) 'MEAN NUMBER OF NO QUOTA INTERVALS PER 100 YEARS',
     +                REAL(QNCLOSE)/COUNT*100

      WRITE(OUT,8000) 'MEAN LENGTH OF NO QUOTA INTERVALS',
     +                REAL(QMEANC)

C     ---PERIODS WITH NO POETENTIAL PROFIT
      WRITE(OUT,8013)
     +   'PERCENTAGE OF YEARS WITH NO POTENTIAL PROFIT',
     +                REAL(PNC)/COUNT*100

      WRITE(OUT,8000)
     +   'MEAN NUMBER OF NO POTENTIAL PROFIT INTERVALS PER 100 YEARS',
     +                REAL(PNCLOSE)/COUNT*100

      WRITE(OUT,8000)
     +   'MEAN LENGTH OF NO POTENTIAL PROFIT INTERVALS',
     +                REAL(PMEANC)

C     --CRITERIA LEVELS FOR TOTAL BIOMASS
      WRITE(OUT,8055)
     +      ' PERCENT YEARS TOTAL BIOMASS < OR = TO CRITERIA LEVELS'
      DO 8080,J=1,NUMBTLV
        WRITE(OUT,8060) TBLEV(J),100.*REAL(TBCOUNT(J))/COUNT
8080  CONTINUE

C     --CRITERIA LEVELS FOR SPAWNING BIOMASS
      WRITE(OUT,8055)
     +      ' PERCENT YEARS SPAWNING BIOMASS < OR = TO CRITERIA LEVELS'
      DO 8085,J=1,NUMSLEV
        WRITE(OUT,8060) SLEV(J),100.*REAL(SCOUNT(J))/COUNT
8085  CONTINUE

C     --CRITERIA LEVELS FOR REDUCTION CATCH
      WRITE(OUT,8055)
     +      ' PERCENT YEARS REDUCTION CATCH < OR = TO CRITERIA LEVELS'
      DO 8090,J=1,NUMCLEV
        WRITE(OUT,8060) CLEV(J),100.*REAL(RCOUNT(J))/COUNT
8090  CONTINUE

8055  FORMAT(/,A,/,
     + '       LEVEL                          %',/,
     + ' -------------              -------------',/)

8060  FORMAT(F13.6,18X,F13.6)

C     -NOTIFY USER THAT PROGRAM HAS TERMINATED NORMALLY
      WRITE(OUT,9000)
C
C     FORMAT STATEMENTS USED THROUGHOUT
C
```

```
C     -WRITE DESCRIPTION AND REAL NUMBER
8000  FORMAT(1X,A,/,1X,G13.6)
C
C     -WRITE DESCRIPTION AND INTEGER
8010  FORMAT(1X,A,/,1X,I14)
C
C     -WRITE DESCRIPTION AND REAL AS A PERCENTAGE
8013  FORMAT(1X,A,/,1X,G13.6,'%')
C
C     -WRITE CHARACTER STRING OF INDEFINATE LENGTH
8015  FORMAT(1X,A)
C
C     -WRITE A BLANK LINE
8020  FORMAT(/)
C
C     -TERMINATION MESSAGE
9000  FORMAT(/,' -- NORMAL TERMINATION --')

      STOP
      END

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      SUBROUTINE GETPROF(CPUE,CATCH,COSTEF,EXVAL,
     +                   NPROF,GPROF,EFFORT,COST,BLACK)
      IMPLICIT NONE
C
C     LARRY JACOBSON
C        24 SEPTEMBER 1989
C
C     THIS SUBROUTINE DETERMINES IF A PROFIT COULD BE
C     MADE AT A GIVEN LEVEL OF CPUE, EXVESSEL PRICE AND
C     COST PER UNIT OF EFFORT.  IF A PROFIT IS POSSIBLE
C     AND THE QUOTA IS > 0, THEN THE GROSS PROFITS
C     AFTER TAKING THE QUOTA ARE CALCULATED.
C
C     ON ENTRY:
C      - CPUE HOLDS THE CATCH PER UNIT EFFORT
C      - CATCH HOLDS THE CATCH TO BE TAKEN
C      - COSTEF IS THE COST ON ONE UNIT OF FISHING EFFORT
C      - EXVAL IS THE EXVESSEL PRICE OF ONE UNIT CATCH
C
C     ON EXIT:
C      - NPROF HOLDS THE NET PROFIT
C      - GPROF HOLDS THE GROSS PROFIT
C      - EFFORT HOLDS THE FISHING EFFORT REQUIRED
C      - COST HOLDS THE COST OF TAKING CATCH
C      - BLACK IS TRUE IF THE POTENTIAL PROFIT IS > 0.0
C        AND FALSE OTHERWISE
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        REAL CPUE,CATCH,COSTEF,EXVAL,NPROF,GPROF,EFFORT,COST
        LOGICAL BLACK

C       DETERMINE WHETHER OR NOT A PROFIT IS POTENTIALLY POSSIBLE
        IF (EXVAL-COSTEF/CPUE.GT.0.0) THEN
          BLACK=.TRUE.
        ELSE
          BLACK=.FALSE.
        ENDIF

C       IF CATCH IS ZERO OR FISHING NOT PROFITABLE THEN NO FISHING
C       SO PROFITS AND COSTS ARE ZERO
        IF ((CATCH.EQ.0.0).OR.(.NOT.BLACK)) THEN
C       -EFFORT,COSTS,GROSS PROFIT AND NET PROFIT ARE ZERO
          EFFORT=0.0
          COST=0.0
          GPROF=0.0
          NPROF=0.0
C       -RETURN TO CALLING PROGRAM
          RETURN
        ELSE
C       -CALCULATE PROFITS AND COSTS
C       --FISHING EFFORT
          EFFORT=CATCH/CPUE
C       --COST OF FISHING
          COST=EFFORT*COSTEF
C       --GROSS PROFITS
          GPROF=CATCH*EXVAL
C       --NET PROFITS
          NPROF=GPROF-COST
        ENDIF

        RETURN
        STOP
        END

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      SUBROUTINE CLOSEM(THISYR,LASTYR,COUNT,NCLOSED,
     +                  MEANC,NC,YR,FINALY)
      IMPLICIT NONE
C
```

```
C     THIS SUBROUTINE PERFORMS ALL NECESSARY CALCULATIONS
C     IN CONNECTION WITH DETERMINING THE NUMBER OF YEARS
C     IN WHICH A FISHERY IS CLOSED AND THE MEAN DURATION
C     OF THE CLOSURES.
C
C     ON ENTRY:
C      - THISYR IS TRUE IF THE FISHERY IS CLOSED IN THE CURRENT YEAR
C      - LASTYR IS TRUE IF THE FISHERY WAS CLOSED LAST YEAR
C      - COUNT IS THE NUMBER OF CONSECUTIVE YEARS (EXCLUDING
C        CURRENT YEAR) DURING WHICH THE FISHERY HAS BEEN CLOSED
C      - NCOUNT IS THE NUMBER OF CLOSURES THAT HAVE OCCURRED
C        PRIOR TO THIS YEAR (EXCLUDING THE CLOSURE THIS YEAR
C        IF THIS YEAR IS THE FIRST YEAR OF THE CLOSURE)
C      - MEANC IS THE MEAN LENGTH OF CLOSURES (EXCLUDING THE CURRENT
C        CLOSURE IF THE FISHERY IS STILL CLOSED)
C      - NC IS THE TOTAL NUMBER OF YEARS (EXLUDING CURRENT YEAR)
C        DURING WHICH THE FISHERY WAS CLOSED
C      - YR IS THE CURRENT YEAR IN THE SIMULATION
C      - FINALY IS THE LAST YEAR IN THE SIMULATION RUN
C
C     ON EXIT:
C      - LASTYR IS TRUE IF THE FISHERY WAS CLOSED THIS YEAR
C      - COUNT IS THE NUMBER OF CONSECUTIVE YEARS (INCLUDING
C        CURRENT YEAR) DURING WHICH THE FISHERY HAS BEEN CLOSED
C      - NCOUNT IS THE NUMBER OF CLOSURES THAT HAVE OCCURRED
C      - NC IS THE TOTAL NUMBER OF YEARS (INCLUDING CURRENT)
C        DURING WHICH THE FISHERY HAS BEEN CLOSED
C      - MEANC IS THE MEAN LENGTH OF CLOSURES (INCLUDING THE
C        MOST RECENT CLOSURE IF THE FISHERY REOPENED THIS YEAR)
C
      INTEGER COUNT,NCLOSED,NC,YR,FINALY
      DOUBLE PRECISION MEANC
      LOGICAL THISYR,LASTYR

C     IF CLOSED THIS YEAR THEN INCREMENT COUNT OF TOTAL YEARS CLOSED
      IF (THISYR) NC=NC+1

C     TAKE APPROPRIATE ACTION IF CLOSED THIS YEAR
      IF (THISYR) THEN
C     -IF CLOSED LAST YEAR JUST INCREMENT COUNT
        IF (LASTYR) THEN
          COUNT=COUNT+1
        ELSE
C     IF NOT CLOSED LAST YEAR THEN SET FLAG AND START COUNTING
          LASTYR=.TRUE.
          COUNT=1
          NCLOSED=NCLOSED+1
        ENDIF
      ENDIF

C     IF FISHERY OPEN THIS YEAR BUT CLOSED LAST YEAR
C     THEN THE FISHERY HAS REOPENED
      IF ((.NOT.THISYR).AND.LASTYR) THEN
        MEANC=MEANC+(COUNT-MEANC)/NCLOSED
        LASTYR=.FALSE.
      ENDIF

C     IF CLOSED THIS YEAR AND THIS IS THE LAST
C     YEAR IN THE SIMULATION WE STILL WANT TO INCLUDE THE CURRENT
C     CLOSURE IN CALCULATION OF THE MEAN DURATION OF CLOSURES
      IF (THISYR.AND.(YR.EQ.FINALY))
     +          MEANC=MEANC+(COUNT-MEANC)/NCLOSED

      RETURN
      STOP
      END
```

Appendix F. Source code for FMPTIME. Subroutines used for 'housekeeping' tasks (e.g. opening files) not shown.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      PROGRAM FMPTIME
C
C     MODIFICATION HISTORY (PROGRAMMER / DATE / DESCRIPTION
C     ---------------------
C     7 DEC 1989 /  LARRY JACOBSON
C     THIS PROGRAM WAS CREATED FROM THE PROGRAM FMPSIM (DOS FILE
C     FMPSIM24.FOR).
C
C     PURPOSE
C     -------
C     THIS PROGRAM DETERMINES THE MEAN TIME REQUIRED FOR THE ANCHOVY
C     STOCK TO RECOVER FROM A LOW INITIAL SPAWNING BIOMASS.  RECOVERY
C     OCCURS WHEN THE SPAWNING BIOMASS INCREASES TO A SPECIFIED LEVEL.
C
C     FOR ADDITIONAL INFORMATION, SEE THE SOURCE CODE FOR THE FMPSIM
C     PROGRAM.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C ////////////////////PARAMETER DEFINITIONS ///////////////////
C
C     MODDATE IS THE LAST MODIFICATION DATE IN FORM 03/APR/89
      CHARACTER*9 MODDATE
      PARAMETER (MODDATE='08/DEC/89')
C
C     VERSION IS THE VERSION NUMBER
      CHARACTER*1 VERSION
      PARAMETER (VERSION='1')
C
C     INBAT IS THE UNIT NUMBER FOR BATCH INPUT
      INTEGER INBAT
      PARAMETER (INBAT=9)
C
C     DEFALT IS THE DEFAULT UNIT NUMBER FOR INTERACTIVE INPUT
      INTEGER DEFALT
      PARAMETER (DEFALT=5)
C
C     DEFOUT IS THE DEFAULT UNIT NUMBER FOR INTERACTIVE OUTPUT
      INTEGER DEFOUT
      PARAMETER (DEFOUT=6)
C
C     MAXSEED IS THE LARGEST ALLOWABLE VALUE FOR RANDOM NUMER SEEDS
      INTEGER MAXSEED
      PARAMETER (MAXSEED=30270)
C
C     MAXYR IS THE MAXIMUM NUMBER OF YEARS IN A SIMULATION
      INTEGER MAXYR
      PARAMETER (MAXYR=1000)
C
C     MAXSIM IS THE MAXIMUM NUMBER OF SIMULATIONS
      INTEGER MAXSIM
      PARAMETER (MAXSIM=1000000)
C
C     T AND F ARE EASIER TO SPELL THAN .TRUE. AND .FALSE.
      LOGICAL T,F
      PARAMETER (T=.TRUE.)
      PARAMETER (F=.FALSE.)
C
C     NUMSLEV IS THE NUMBER OF SPAWNING BIOMASS LEVELS USED TO
C     EVALUATE AN OPTION
      INTEGER NUMSLEV
      PARAMETER (NUMSLEV=30)
C
C     DZ IS A DOUBLE PRECISION ZERO
      DOUBLE PRECISION DZ
      PARAMETER (DZ=0D0)
C
C     RZ IS A SINGLE PRECISION ZERO
      REAL RZ
      PARAMETER (RZ=0E0)
C
C     IZ IS AN INTEGER ZERO
      INTEGER IZ
      PARAMETER (IZ=0)
C
C     SMALL IS A SMALL REAL NUMBER
      REAL SMALL
      PARAMETER (SMALL=1E-20)
C
C     PI IS PI
      REAL PI
      PARAMETER (PI=3.141593)
C
C ////////////////////////FUNCTIONS//////////////////////////
C
C     NRAND GENERATES STANDARD NORMAL DEVIATES
      REAL NRAND
C
C     CTRSTR RETURNS A CENTERED STRING
      CHARACTER*79 CTRSTR
C
```

```
C     SECOND RETURNS THE NUMBER OF SECONDS SINCE MIDNIGHT
      INTEGER SECOND
C
C     GETLOG PROMPTS FOR AND RETURNS A LOGICAL VALUE
      LOGICAL GETLOG
C
C     GETINT PROMPTS FOR AND RETURNS AN INTEGER VALUE
      INTEGER GETINT
C
C     GETNUM PROMPTS FOR AND RETURNS A REAL NUMBER VALUE
      REAL GETNUM
C
C     GETFILE RETURNS A FILE NAME
      CHARACTER*12 GETFILE
C
C ////////////////// VARIABLE DECLARATIONS //////////////////
C
C     CHARACTER STRINGS-----------------------------------------
C
C     INFILE IS THE BATCH INPUT FILE NAME
      CHARACTER*12 INFILE
C
C     OUTFIL IS THE OUTPUT FILE
      CHARACTER*12 OUTFIL
C
C     USERCOM A COMMENT LINE USED TO ANNOTATE DATA AND OUTPUT FILES
      CHARACTER*79 USERCOM
C
C     LOGICALS-------------------------------------------------
C
C     BATCH IS TRUE IF READING INPUT FROM A FILE
      LOGICAL BATCH
C
C     AUTO IS TRUE IF RANDOM NUMBER SEEDS ARE GENERATED FROM CLOCK
      LOGICAL AUTO
C
C     BLACK IS TRUE IF THE PROFIT FOR A FISHERY > 0.0
      LOGICAL BLACK
C
C     FILE IS TRUE IF THERE IS AN OUTPUT FILE
      LOGICAL FILE
C
C     QCLOSED IS TRUE IF THE REDUCTION QUOTA IS ZERO THIS YEAR
      LOGICAL QCLOSED
C
C     PCLOSED IS TRUE IF REDUCTION FISHING IS POTENTIALLY UNPROFITABLE
C     THIS YEAR
      LOGICAL PCLOSED
C
C     DOUBLE PRECISION------------------------------------------
C
C     MEANCN IS THE MEAN NUMBER OF YEARS TO RECOVERY
      DOUBLE PRECISION MEANCN
C
C     SSC IS THE SUM OF SQUARES/VARIANCE FOR YEARS TO RECOVERY
      DOUBLE PRECISION SSCN

C     REALS----------------------------------------------------
C
C     AMP IS THE AMPLITUDE OF THE CYCLES UNDERLYING PROCESS ERRORS
      REAL AMP
C
C     PERIOD IS THE LENGTH IN YEARS OF ONE CYCLE
      REAL PERIOD
C
C     IF THE SPAWNING BIOMASS IS <= OVERF THEN ALL FISHERIES ARE CLOSED
      REAL OVERF
C
C     SMALLF IS THE SMALLEST POSSIBLE FRACTION SPAWNING
      REAL SMALLF

C     RPROF IS NET REDUCTION PROFIT
      REAL RPROF

C     RGPROF IS GROSS REDUCTION PROFIT
      REAL RGPROF

C     BEFF IS THE FISHING EFFORT NEEDED TO TAKE THE BAIT CATCH
      REAL BEFF

C     BAITQ IS THE ANNUAL BAIT CATCH TAKEN IF IT IS PROFITABLE
      REAL BAITQ

C     BCOST IS THE COST OF BAIT FISHING
      REAL BCOST

C     BPROF IS NET PROFIT FOR THE BAIT FISHERY
      REAL BPROF

C     BGPROF IS GROSS PROFIT FOR BAIT
      REAL BGPROF

C     BXVALUE IS THE BAIT EXVESSEL VALUE OF ANCHOVY
```

```
      REAL BXVALUE
C     NREFF IS THE FISHING EFFORT NEEDED TO TAKE THE NON-REDUCTION
C     COMMERCIAL (I.E. DEAD BAIT) CATCH
      REAL NREFF
C     NRCOST IS THE COST OF NON-REDUCTION COMMERCIAL FISHING
      REAL NRCOST
C     NRPROF IS NET PROFIT FOR NON-REDUCTION COMMERICAL FISHING
      REAL NRPROF
C     NRGPROF IS GROSS PROFIT FOR NON-REDUCTION COMMERCIAL FISHING
      REAL NRGPROF
C     NRXVAL IS THE NON-REDUCTION COMMERCIAL EXVESSEL VALUE
      REAL NRXVAL
C     NRQUOTA IS THE NON-REDUCTION COMMERCIAL QUOTA
      REAL NRQUOTA
C     MAXCPE IS THE MAXIMUM CPUE
      REAL MAXCPE
C     DF IS DEGREES OF FREEDOM FOR VARIANCE ESTIMATES
      REAL DF
C     LOWEST IS THE MINIMUM TOTAL BIOMASS
      REAL LOWEST
C     CPUE IS CATCH PER UNIT OF EFFORT FOR REDUCTION FISHING
      REAL CPUE
C
C     CPUEP1 AND CPUE2 ARE PARAMETERS USED TO CALCULATE CPUE
      REAL CPUEP1,CPUEP2
C
C     REFFORT IS REDUCTION FISHING EFFORT
      REAL REFFORT
C
C     COSTEFF IS THE COST OF A UNIT OF FISHING EFFORT
      REAL COSTEFF
C
C     RCOST IS THE TOTAL COST OF REDUCTION FISHING
      REAL RCOST
C
C     EXVALUE IS THE REDUCTION EXVESSEL VALUE OF A UNIT OF ANCHOVY
      REAL EXVALUE
C     IF THE SPAWNING BIOMASS IS BEYOND CUTOFF1 THEN THE REDUCTION
C     QUOTA IS SET TO THE MAXIMUM VALUE
      REAL CUTOFF1
C
C     MAXCAT IS THE MAXIMUM REDUCTION QUOTA
      REAL MAXCAT
C
C     CUTOFF2 IS THE CURRENT MINIMUM SPAWNING BIOMASS CUTOFF LEVEL
      REAL CUTOFF2
C
C     TBCUT IS THE MINIMUM TOTAL BIOMASS LEVEL THAT ALLOWS CATCH WHEN
C     SB < CUTOFF2 (I.E. IF TOTAL BIOMASS > TBCUT THEN
C     SOME REDUCTION FISHING MAY OCCUR)
      REAL TBCUT
C
C     MINCAT IS THE MINIMUM REDUCTION QUOTA WHEN SB < CUTOFF2
C     AND TOTAL BIOMASS > TBCUT
      REAL MINCAT
C
C     RCATCH IS THE REDUCTION CATCH
      REAL RCATCH
C
C     RQUOTA IS THE REDUCTION QUOTA
      REAL RQUOTA
C
C     BAIT IS THE CATCH FOR BAIT
      REAL BAIT
C
C     NRCATCH IS THE COMMERCIAL NONREDUCTION QUOTA/CATCH
      REAL NRCATCH
C
C     BT IS THE TOTAL BIOMASS IN THE CURRENT YEAR
      REAL BT
C
C     SBINIT IS THE INITIAL VALUE OF THE SPAWNING BIOMASS
      REAL SBINIT
C
C     FRACMAT IS THE FRACTION OF THE TOTAL BIOMASS THAT SPAWNS
      REAL FRACMAT
C
C     SDL IS THE STANDARD DEVIATION OF LOGIT(FRACTION SPAWNING)
      REAL SDL
C
C     MEANL IS THE MEAN OF LOGIT FRACTION SPAWNING
      REAL MEANL
```

```
C
C     TRUESBT IS THE TRUE SPAWNING BIOMASS IN YEAR T
      REAL TRUESBT
C
C     SDM IS THE STANDARD DEVIATION (LOG SCALE) FOR MEASUREMENT ERRORS
C     IN THE OBSERVATION OF SPAWNING BIOMASS
      REAL SDM
C
C     TEMP IS A TEMPORARY VARIABLE
      REAL TEMP
C
C     OBSSBT IS THE OBSERVED (WITH ERROR) SPAWNING BIOMASS
      REAL OBSSBT
C
C     NEXTBT IS THE TOTAL BIOMASS IN THE NEXT YEAR
      REAL NEXTBT
C
C     ALPHA IS THE MULTIPLIER IN THE STOCK-STOCK MODEL
      REAL ALPHA
C
C     BETA IS THE EXPONENT IN THE STOCK-STOCK MODEL
      REAL BETA
C
C     SDB IS THE STANDARD DEVIATION FOR PROCESS ERROR IN THE
C     STOCK-STOCK MODEL
      REAL SDB
C
C     CATCH IS THE TOTAL CATCH DURING THE CURRENT YEAR
      REAL CATCH
C
C     DELTA IS THE DISCOUNT RATE FOR CATCHES
      REAL DELTA
C
C     RATIO IS USED TO COMPUTE SUMS OF SQUARES
      REAL RATIO
C
C     OKSBT IS THE SPAWNING BIOMASS LEVEL FOR RECOVERY
      REAL OKSBT
C
C     INTEGERS--------------------------------------------------
C
C
C     SHIST HOLDS THE FREQUENCY DISTRIBUTION OF RECOVERY TIMES
      INTEGER SHIST(NUMSLEV)

C     YEARS COUNTS YEARS TO RECOVERY
      INTEGER YEARS

C     OUT IS THE CHANNEL FOR OUTPUT
      INTEGER OUT
C
C     IN IS THE CHANNEL FOR INPUT
      INTEGER IN
C
C     IHR,IMIN, ISEC AND I100TH ARE USED TO FETCH THE TIME
      INTEGER*2 IHR,IMIN,ISEC,I100TH
C
C     IYR,IMON AND IDAY ARE USED TO FETCH THE DATE
      INTEGER*2 IYR,IMON,IDAY
C
C     H, I ARE COUNTING VARIABLES
      INTEGER H,I
C
C     NUMYEAR IS THE MAXIMUM NUMBER OF YEARS IN EACH SIMULATION
      INTEGER NUMYEAR
C
C     NUMSIM IS THE NUMBER OF SIMULATIONS
      INTEGER NUMSIM
C
C     SEED1, SEED2 AND SEED3 ARE SEEDS FOR RANDOM NUMBERS
      INTEGER SEED1,SEED2,SEED3
C
C     ASEED1,ASEED2 AND ASEED3 ARE INITIAL VALUES FOR RANDOM
C     NUMBER SEEDS
      INTEGER ASEED1,ASEED2,ASEED3
C
C ////////////////////// DATA STATEMENTS /////////////////////
C
C
C     LOGICALS--------------------------------------------------
C
      DATA BATCH /F/
C
C     DOUBLE PRECISION------------------------------------------
      DATA MEANCN /DZ/,SSCN /DZ/
C
C     INTEGERS--------------------------------------------------
C
      DATA IN /DEFALT/,OUT /DEFOUT/
      DATA SHIST /NUMSLEV*IZ/
C
C ////////////////////// EXECUTABLE CODE /////////////////////
C
C
C     WRITE HEADER TO OUTPUT
      WRITE(*,8020)
```

```
      WRITE(*,8015)
     + CTRSTR('FMPTIME - ANCHOVY RECOVERY TIME PROGRAM VERSION '//
     +        VERSION//'@','-')
C     WRITE MODIFICATION DATE
      WRITE(*,8015)
     + CTRSTR('DATE OF LAST MODIFICATION: '//MODDATE//'@',' ')
C
C     INPUT DATA -----------------------------------------------------
C
C     -GET NAME OF OUTPUT FILE
      WRITE(*,8015) 'OUTPUT FILE?'
      FILE=GETLOG(IN,F,F)

      IF (FILE) THEN
C     GET THE OUTPUT FILE NAME
        OUTFIL=GETFILE(F)

C     CHANGE THE OUTPUT CHANNEL NUMBER
        OUT=10

C     OPEN THE OUTPUT FILE
        OPEN(UNIT=OUT,FILE=OUTFIL,STATUS='UNKNOWN')
      ENDIF

C     -FIND OUT IF INPUT WILL BE INTERACTIVE OR BATCH MODE
      WRITE(*,8015) 'BATCH INPUT?'
      BATCH=GETLOG(IN,F,F)

C     -IF BATCH GET NAME OF INPUT FILE AND OPEN IT
      IF (BATCH) THEN
        INFILE=GETFILE(T)
        OPEN(UNIT=INBAT,FILE=INFILE,STATUS='OLD',MODE='READ')
C       USE THE UNIT NUMBER FOR BATCH INPUT
        IN=INBAT
      ENDIF

C     -USER'S COMMENT
       WRITE(*,8015) 'COMMENT LINE? (MAX 79 CHARS)'
       READ(IN,'(/,A79)') USERCOM
       IF (BATCH) WRITE(*,'(1X,A79)') USERCOM

C     --CUTOFF LEVEL FOR ALL FISHING
      WRITE(*,8015) 'SPAWNING BIOMASS CUTOFF LEVEL FOR ALL FISHING'
      OVERF=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --WRITE PARAMETERS FOR REGULATION OF REDUCTION FISHERY

      WRITE(*,8015) 'UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA'
      CUTOFF1=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MAXIMUM REDUCTION QUOTA'
      MAXCAT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     + 'CURRENT LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA'
      CUTOFF2=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     &'CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF'
      TBCUT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MINIMUM REDUCTION QUOTA'
      MINCAT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --WRITE BAIT COMMERCIAL NON-REDUCTION PARAMETERS

      WRITE(*,8015) 'ANNUAL CATCH FOR BAIT (ALL PROFITABLE YEARS)'
      BAITQ=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     +   'COMMERCIAL NONREDUCTION CATCH (ALL PROFITABLE YEARS)'
      NRQUOTA=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --WRITE ECONOMIC PARAMETERS

      WRITE(*,8015) 'COST OF ONE UNIT OF FISHING EFFORT'
      COSTEFF=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015) 'REDUCTION EXVESSEL VALUE'
      EXVALUE=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015) 'BAIT EXVESSEL VALUE'
      BXVALUE=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015) 'NONREDUCTION COMMERCIAL EXVESSEL VALUE'
      NRXVAL=GETNUM(IN,BATCH,T,F,RZ,RZ,1)

      WRITE(*,8015)
     +   'MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS'
      CPUEP1=GETNUM(IN,BATCH,T,F,RZ,RZ,7)
```

```
      WRITE(*,8015) 'EXPONENT (BETA) FOR CPUE AND BIOMASS'
      CPUEP2=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MAXIMUM CPUE'
      MAXCPE=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --POPULATION DYNAMICS PARAMETERS

      WRITE(*,8015) 'LOWEST ATTAINABLE BIOMASS'
      LOWEST=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)'
      SDL=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MEAN VALUE FOR LOGIT(FRACTION SPAWNING)'
      MEANL=GETNUM(IN,BATCH,F,F,RZ,RZ,7)

      WRITE(*,8015) 'SMALLEST VALUE FOR FRACTION SPAWNING'
      SMALLF=GETNUM(IN,BATCH,F,F,RZ,RZ,7)

      WRITE(*,8015)
     +  'STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS'
      SDM=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL'
      ALPHA=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'EXPONENT (BETA) IN STOCK-STOCK MODEL'
      BETA=GETNUM(IN,BATCH,F,F,RZ,RZ,7)

      WRITE(*,8015) 'STANDARD DEVIATION FOR PROCESS ERROR'
      SDB=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     + 'AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)'
      AMP=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015)
     + 'LENGTH OF CYCLES IN PROCESS ERROR (YEARS)'
      PERIOD=GETNUM(IN,BATCH,T,F,1.0,RZ,7)

      WRITE(*,8015) 'DISCOUNT RATE FOR CATCH'
      DELTA=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

C     --SIMULATION CONTROL PARAMETERS

      WRITE(*,8015) 'NUMBER OF SIMULATION RUNS'
      NUMSIM=GETINT(IN,BATCH,T,T,IZ,MAXSIM)

      WRITE(*,8015) 'MAXIMUM NUMBER OF YEARS IN EACH RUN'
      NUMYEAR=GETINT(IN,BATCH,T,T,IZ,MAXYR)

C     --INITIAL AND RECOVERY CONDITIONS

      WRITE(*,8015) 'INITIAL SPAWNING BIOMASS (MILLION MT)'
      SBINIT=GETNUM(IN,BATCH,T,F,RZ,RZ,7)

      WRITE(*,8015) 'SPAWNING STOCK BIOMASS RECOVERY LEVEL'
      OKSBT=GETNUM(IN,BATCH,T,F,SBINIT,RZ,7)

C     --INITIAL SEEDS FOR RANDOM NUMBER GENERATOR

      WRITE(*,8015) 'AUTOMATIC RANDOM NUMBER SEEDS?'
      AUTO=GETLOG(IN,BATCH,T)
      IF (AUTO) THEN
C     SET THE INITIAL VALUES TO SECONDS SINCE MIDNIGHT AND MAKE
C     SURE THAT THE INITIAL VALUES ARE NOT TOO LARGE FOR THE
C     RANDOM NUMBER GENERATOR
        ASEED1=SECOND()
        ASEED1=MOD(ASEED1,MAXSEED)
        ASEED2=ASEED1*3
        ASEED2=MOD(ASEED2,MAXSEED)
        ASEED3=ASEED2*1110
        ASEED3=MOD(ASEED3,MAXSEED)
      ELSE
        WRITE(*,8015) 'INITIAL VALUE FOR RANDOM NUMBER SEED 1'
        ASEED1=GETINT(IN,BATCH,T,T,IZ,MAXSEED)

        WRITE(*,8015) 'INITIAL VALUE FOR RANDOM NUMBER SEED 2'
        ASEED2=GETINT(IN,BATCH,T,T,IZ,MAXSEED)

        WRITE(*,8015) 'INITIAL VALUE FOR RANDOM NUMBER SEED 3'
        ASEED3=GETINT(IN,BATCH,T,T,IZ,MAXSEED)
      ENDIF

C     --SET RANDOM NUMBER SEEDS TO INITIAL VALUES
      SEED1=ASEED1
      SEED2=ASEED2
      SEED3=ASEED3

C
C     START LOOP OVER SIMULATION RUNS--------------------------
```

```
      DO 5100,H=1,NUMSIM
C     -CONVERT INITIAL SPAWNING BIOMASS TO TOTAL BIOMASS
C     --LOGIT(FRACTION SPAWNING) HAS A NORMAL DISTRIBUTION WITH
C       MEAN=MEANL AND STANDARD DEVIATION = SDL.  FETCH A STANDARD
C       NORMAL VALUE AND SCALE IT.
        FRACMAT=NRAND(SEED1,SEED2,SEED3)*SDL+MEANL
C     --CONVERT THE LOGIT TO A FRACTION
        FRACMAT=EXP(FRACMAT)/(1+EXP(FRACMAT))
C    --MAKE SURE THAT THE FRACTION IS NOT UNREASONABLY SMALL
        IF (FRACMAT.LE.SMALLF) FRACMAT=SMALLF
C
C     --CALCULATE THE TOTAL BIOMASS FROM SPAWNING BIOMASS AND FRACMAT
       NEXTBT=SBINIT/FRACMAT
C     SET YEARS TO A NEGATIVE NUMBER
      YEARS=-1
C     START LOOP OVER YEARS-----------------------------------
C
      DO 5000,I=1,NUMYEAR
C
C     -SET CURRENT BIOMASS
        BT=NEXTBT
C     -DETERMINE CPUE FROM BIOMASS
        CPUE=CPUEP1*BT**CPUEP2
C     --MAKE SURE CPUE IS NIETHER TOO LOW OR TO HIGH
        IF (CPUE.LT.RZ) CPUE=RZ
        IF (CPUE.GT.MAXCPE) CPUE=MAXCPE
C
C     SPAWNING BIOMASS CALCULATIONS-----------------------------
C
C     -CALCULATE THE FRACTION OF THE TOTAL BIOMASS THAT SPAWNS ON 15 FEB
C
C     --LOGIT(FRACTION SPAWNING) HAS A NORMAL DISTRIBUTION WITH
C       MEAN=MEANL AND STANDARD DEVIATION = SDL.  FETCH A STANDARD
C       NORMAL VALUE AND SCALE IT.
        FRACMAT=NRAND(SEED1,SEED2,SEED3)*SDL+MEANL
C     --CONVERT THE LOGIT TO A FRACTION
        FRACMAT=EXP(FRACMAT)/(1+EXP(FRACMAT))
C    --MAKE SURE THAT THE FRACTION IS NOT UNREASONABLY SMALL
        IF (FRACMAT.LE.SMALLF) FRACMAT=SMALLF
C
C     --CALCULATE THE TRUE SPAWNING BIOMASS
        TRUESBT=BT*FRACMAT
C
C     -CALCULATE THE APPARENT SPAWNING BIOMASS BY APPLYING A RANDOM
C      MEASUREMENT ERROR.  THE MEASUREMENT ERRORS COME FROM A LOG
C      NORMAL DISTRIBUTION WITH MEAN 0.0 AND STANDARD DEVIATION
C      = SDM.  FETCH A STANDARD NORMAL VALUE AND SCALE IT.
        TEMP=NRAND(SEED1,SEED2,SEED3)*SDM
C
C     --APPLY THE MEASUREMENT ERROR TO THE ACTUAL VALUE
        OBSSBT=TRUESBT*EXP(TEMP)
C
C     TEST FOR STOCK RECOVERY------------------------------------------
      IF (OBSSBT.GE.OKSBT) THEN
C     -SAVE CURRENT YEAR
        YEARS=I
C     -UPDATE FREQUENCY DISTRIBUTION
        IF (YEARS.GE.NUMSLEV) THEN
          SHIST(NUMSLEV)=SHIST(NUMSLEV)+1
        ELSE
          SHIST(YEARS)=SHIST(YEARS)+1
        ENDIF
C     -SKIP OUT OF LOOP
C           print *,'recovery at year ',years,' in cycle ',h
        GOTO 9876
      ENDIF
C     BAIT CATCH CALCULATIONS--------------------------------
        CALL GETPROF(CPUE,BAITQ,COSTEFF,BXVALUE,
     +               BPROF,BGPROF,BEFF,BCOST,BLACK)
C     -DON'T GO FISHING IF NO PROFIT CAN BE MADE OR AN OVERFISHING
C      CONDITION EXISTS
        IF (.NOT.BLACK.OR.TRUESBT.LE.OVERF) THEN
C     --NO CATCH
          BAIT=RZ
        ELSE
          BAIT=BAITQ
        ENDIF
C     NON-REDUCTION COMMERCIAL CATCH CALCULATIONS---------------
```

```
         CALL GETPROF(CPUE,NRQUOTA,COSTEFF,NRXVAL,
     +               NRPROF,NRGPROF,NREFF,NRCOST,BLACK)
C       -DON'T GO FISHING IF NO PROFIT CAN BE MADE OR AN OVERFISHING
C        CONDITION EXISTS
         IF (.NOT.BLACK.OR.TRUESBT.LE.OVERF) THEN
C       --NO CATCH
           NRCATCH=RZ
         ELSE
           NRCATCH=NRQUOTA
         ENDIF
C
C       REDUCTION QUOTA/CATCH CALCULATIONS------------------------
C
C       -THE REDUCTION FISHERY IS OPEN UNTIL PROVEN OTHERWISE
         QCLOSED=F
         PCLOSED=F
C       -IF THE OBS SB > CUTOFF1 THEN THE REDUCTION QUOTA
C          IS THE MAXIMUM VALUE
         IF (OBSSBT.GT.CUTOFF1) RQUOTA=MAXCAT
C       -IF CUTOFF2+MINCAT < OBS SB <= CUTOFF1 THEN THE QUOTA IS THE
C         DIFFERENCE
         IF
     +      ((OBSSBT.GT.CUTOFF2+MINCAT).AND.(OBSSBT.LE.CUTOFF1))
     +        RQUOTA=OBSSBT-CUTOFF2
C       -WHEN CUTOFF2 < OBS SB <= CUTOFF2+MINCAT THE QUOTA FORMULA
C        DEPENDS ON WHETHER TBCUT > 0.  IF TBCUT > 0 THEN
C        THE QUOTA ITSELF DEPENDS ON WHETHER THE TOTAL BIOMASS
C        <= TBCUT
           IF ((CUTOFF2.LT.OBSSBT).AND.(OBSSBT.LE.CUTOFF2+MINCAT)) THEN
             IF (TBCUT.EQ.RZ) THEN
C        --THE QUOTA FORMULA AND QUOTA DO NOT DEPEND ON THE TOTAL BIOMASS
               RQUOTA=MINCAT
             ELSE
               IF (BT.GE.TBCUT) THEN
C        --THE QUOTA IS SET TO ITS MINIMUM VALUE
                 RQUOTA=MINCAT
               ELSE
C        --THE QUOTA IS THE DIFFERENCE (AS IN THE STATUS QUO MODEL)
                 RQUOTA=OBSSBT-CUTOFF2
               ENDIF
             ENDIF
           ENDIF
C       -IF THE OBS SB <= CUTOFF2, AND MINCAT NOT EQUAL TO ZERO
C        AND TOTAL BIOMASS >= TBCUT THEN THE QUOTA IS MINCAT
           IF (OBSSBT.LE.CUTOFF2) THEN
             IF (MINCAT.GT.RZ) THEN
               IF (TBCUT.EQ.RZ) THEN
                 RQUOTA=MINCAT
               ELSE IF (BT.GE.TBCUT) THEN
                 RQUOTA=MINCAT
C       -ELSE THE REDUCTION QUOTA IS ZERO AND THE FISHERY IS CLOSED
               ELSE
                 RQUOTA=RZ
               ENDIF
             ELSE
               RQUOTA=RZ
             ENDIF
           ENDIF
C       -IF THE SPAWNING BIOMASS <= OVERF THEN AN OVERFISHING CONDITION
C        EXISTS AND THE REDUCTION FISHERY IS CLOSED
           IF (TRUESBT.LE.OVERF) RQUOTA=RZ
C       -IF THE QUOTA IS ZERO THEN SET FLAG
          IF (RQUOTA.EQ.RZ) QCLOSED=T
C        REDUCTION PROFITS-----------------------------------------
C       -ESTIMATE POTENTIAL PROFITS
          CALL GETPROF(CPUE,RQUOTA,COSTEFF,EXVALUE,
     +                RPROF,RGPROF,REFFORT,RCOST,BLACK)
C       -IF NOT PROFITABLE THEN SET FLAG
          IF (.NOT.BLACK) PCLOSED=T
C        REDUCTION CATCH-------------------------------------------
C       -IF NO QUOTA OR NOT PROFITABLE THEN THE CATCH WILL BE ZERO
C         AND THE FISHERY SHUTS DOWN
          IF (PCLOSED.OR.QCLOSED) THEN
C       --NO CATCH
            RCATCH=RZ
          ELSE
            RCATCH=RQUOTA
          ENDIF
```

```
C      THE TOTAL CATCH IS REDUCTION + BAIT + COMM. NON-REDUCTION
         CATCH=RCATCH+BAIT+NRCATCH

C      CALCULATIONS FOR TOTAL BIOMASS NEXT YEAR-------------------
C
C      -THE BIOMASS NEXT YEAR IS A DETERMINISTIC VALUE THAT IS
C       AFFECTED BY A LOGNORMAL PROCESS ERROR AND CATCH DURING
C       THE CURRENT YEAR
C
C      --CALCULATE THE DETERMINISTIC VALUE FOR BIOMASS NEXT YEAR
C        IN THE ABSENCE OF FISHING
         NEXTBT=BT*EXP(ALPHA+BETA*BT)
C
C      --RANDOM COMPONENT OF PROCESS ERROR IS LOGNORMAL WITH
C        MEAN ZERO AND STANDARD DEVIATION SDB.  FETCH A RANDOM NUMBER
C        AND SCALE IT.
          TEMP=NRAND(SEED1,SEED2,SEED3)*SDB
C
C      --CALCULATE THE UNDERLYING CYCLIC AFFECT ON PROCESS ERROR
          TEMP=TEMP+AMP*SIN(MOD(I,PERIOD)/PERIOD*2*PI)
C
C      --APPLY THE RANDOM ERROR
          NEXTBT=NEXTBT*EXP(TEMP)
C
C      --SUBTRACT THE DISCOUNTED CATCH FROM THE POTENTIAL BIOMASS
          NEXTBT=NEXTBT-DELTA*CATCH
C
C      --MAKE SURE THAT THE STOCK DOES NOT FALL BELOW THE MINIMUM
C        VALUE.  IF IT DOES THEN ADJUST STOCK LEVEL AND CATCHES
          TEMP=LOWEST+SMALL
          IF (NEXTBT.LE.TEMP) THEN
            PRINT *,' '
            PRINT *,' NOTE -> BIOMASS SMALLER THAN MIMIMUM'

C      ---SET NEXT YEARS BIOMASS TO THE LOWEST LEVEL
            NEXTBT=TEMP

          ENDIF

C      ---- END OF LOOP OVER YEARS
5000   CONTINUE

9876   IF (YEARS.GE.1) THEN
         RATIO=REAL(H-1)/H
         TEMP=YEARS-MEANCN
         SSCN=SSCN+RATIO*TEMP**2
         MEANCN=MEANCN+TEMP/H
       ELSE
         WRITE(*,5015) NUMYEAR,H
         STOP
       ENDIF

5015   FORMAT(1X,'ERROR...MAXIMUM NUMBER OF YEARS = ',I8,/
     +        1X,'            REACHED IN INTERATION = ',I8,/)

C      ---- END OF LOOP OVER SIMULATION RUNS
5100   CONTINUE

C
C      CONVERT SUMS OF SQUARES TO STANDARD DEVIATIONS
C
C      -DEGREES OF FREEDOM
       DF=NUMSIM-1

C      -STANDARD DEVIATION FOR YEARS TO RECOVERY
       SSCN=SQRT(SSCN/DF)

C
C      OUTPUT------------------------------------------------------
C
C      -WRITE HEADER TO OUTPUT FILE
       WRITE(OUT,8020)
       WRITE(OUT,8015)
     + CTRSTR('FMPTIME - ANCHOVY RECOVERY TIME PROGRAM VERSION '//
     +          VERSION//'@','-')

C      WRITE MODIFICATION DATE
       WRITE(OUT,8015)
     +  CTRSTR('DATE OF LAST MODIFICATION: '//MODDATE//'@',' ')

C      -WRITE TIME
       CALL GETTIM(IHR,IMIN,ISEC,I100TH)
       WRITE(OUT,8020)
       WRITE(OUT,6010) ' TIME -> ',IHR,IMIN,ISEC
6010   FORMAT(A8,I2,':',I2,':',I2)

C      -WRITE THE DATE
       CALL GETDAT(IYR,IMON,IDAY)
       WRITE(OUT,6012) ' DATE -> ',IDAY,IMON,IYR
6012   FORMAT(A8,I2,'/',I2,'/',I4)

C      -WRITE INPUT FILE NAME IF IT EXISTS
```

```
      IF (BATCH) THEN
        WRITE(OUT,8020)
        WRITE(OUT,8015) 'INPUT FILE -> '//INFILE
      ENDIF
C     -WRITE INPUT PARAMETERS TO OUTPUT FILE IN SUCH A WAY THAT
C      AN OUTPUT FILE CAN BE REUSED AS AN INPUT FILE

      WRITE(OUT,8020)
      WRITE(OUT,8015) CTRSTR('INPUT PARAMETERS@','-')
      WRITE(OUT,8020)

C     -WRITE USER'S COMMENT
       WRITE(OUT,'(A12,/,A79)') 'COMMENT LINE',USERCOM

C     --WRITE CUTOFF LEVEL FOR ALL FISHING
      WRITE(OUT,8000) 'SPAWNING BIOMASS CUTOFF LEVEL FOR ALL FISHING',
     +         OVERF

C     --WRITE PARAMETERS FOR REGULATION OF REDUCTION FISHERY

      WRITE(OUT,8000)
     +    'UPPER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA',
     +              CUTOFF1

      WRITE(OUT,8000) 'MAXIMUM REDUCTION QUOTA',
     +              MAXCAT

      WRITE(OUT,8000)
     +    'CURRENT LOWER SPAWNING BIOMASS CUTOFF FOR REDUCTION QUOTA',
     +              CUTOFF2

      WRITE(OUT,8000)
     +'CUTOFF LEVEL FOR TOTAL BIOMASS ALLOWING QUOTA WHEN SB < CUTOFF',
     +              TBCUT

      WRITE(OUT,8000) 'MINIMUM REDUCTION QUOTA',
     +              MINCAT

C     --WRITE BAIT COMMERCIAL NON-REDUCTION PARAMETERS

      WRITE(OUT,8000) 'ANNUAL CATCH FOR BAIT (ALL PROFITABLE YEARS)',
     +              BAIT

      WRITE(OUT,8000)
     +    'COMMERCIAL NONREDUCTION CATCH (ALL PROFITABLE YEARS)',
     +              NRQUOTA

C     --WRITE ECONOMIC PARAMETERS

      WRITE(OUT,8000) 'COST OF ONE UNIT OF FISHING EFFORT',
     +              COSTEFF

      WRITE(OUT,8000) 'REDUCTION EXVESSEL VALUE',
     +              EXVALUE

      WRITE(OUT,8000) 'BAIT EXVESSEL VALUE',
     +              BXVALUE

      WRITE(OUT,8000) 'NONREDUCTION COMMERCIAL EXVESSEL VALUE',
     +              NRXVAL

      WRITE(OUT,8000)
     +    'MULTIPLIER (ALPHA) FOR CPUE AND BIOMASS',
     +              CPUEP1

      WRITE(OUT,8000) 'EXPONENT (BETA) FOR CPUE AND BIOMASS',
     +              CPUEP2

      WRITE(OUT,8000) 'MAXIMUM CPUE',
     +              MAXCPE

C     --POPULATION DYNAMICS PARAMETERS

      WRITE(OUT,8000) 'LOWEST ATTAINABLE BIOMASS',
     +              LOWEST

      WRITE(OUT,8000)
     +      'STANDARD DEVIATION FOR LOGIT(FRACTION SPAWNING)',
     +              SDL

      WRITE(OUT,8000) 'MEAN VALUE FOR LOGIT(FRACTION SPAWNING)',
     +              MEANL

      WRITE(OUT,8000) 'SMALLEST VALUE FOR FRACTION SPAWNING',
     +              SMALLF

      WRITE(OUT,8000)
     +  'STANDARD DEVIATION OF MEASUREMENT ERROR FOR SPAWNING BIOMASS',
     +              SDM

      WRITE(OUT,8000)
     +    'MULTIPLIER (ALPHA) IN STOCK-STOCK MODEL',
     +              ALPHA
```

```
      WRITE(OUT,8000) 'EXPONENT (BETA) IN STOCK-STOCK MODEL',
     +                BETA

      WRITE(OUT,8000) 'STANDARD DEVIATION FOR PROCESS ERROR',
     +                SDB

      WRITE(OUT,8000)
     + 'AMPLITUDE OF CYCLES IN PROCESS ERROR (SAME UNITS AS S.D.)',
     +                AMP

      WRITE(OUT,8000)
     + 'LENGTH OF CYCLES IN PROCESS ERROR (YEARS)',
     +               PERIOD

      WRITE(OUT,8000) 'DISCOUNT RATE FOR CATCH',
     +                DELTA

C     --SIMULATION CONTROL PARAMETERS

      WRITE(OUT,8010) 'NUMBER OF SIMULATION RUNS',
     +                NUMSIM

      WRITE(OUT,8010) 'MAXIMUM NUMBER OF YEARS IN EACH RUN',
     +                NUMYEAR

C     --INITIAL AND RECOVERY CONDITIONS

      WRITE(OUT,8000) 'INITIAL SPAWNING BIOMASS (MILLION MT)',
     +                SBINIT

      WRITE(OUT,8000) 'SPAWNING STOCK BIOMASS RECOVERY LEVEL',
     +                OKSBT

C     --INITIAL SEEDS FOR RANDOM NUMBER GENERATOR

      WRITE(OUT,8015) 'AUTOMATIC RANDOM NUMBER SEEDS?'
      IF(AUTO) THEN
        WRITE(OUT,'(A3)') 'YES'
      ELSE
        WRITE(OUT,'(A2)') 'NO'
      ENDIF

      WRITE(OUT,8010) 'INITIAL VALUE FOR RANDOM NUMBER SEED 1',
     +                ASEED1

      WRITE(OUT,8010) 'INITIAL VALUE FOR RANDOM NUMBER SEED 2',
     +                ASEED2

      WRITE(OUT,8010) 'INITIAL VALUE FOR RANDOM NUMBER SEED 3',
     +                ASEED3

C     -WRITE RESULTS TO OUTPUT FILE

      WRITE(OUT,8020)
      WRITE(OUT,8015) CTRSTR('RESULTS@','-')
      WRITE(OUT,8020)


      WRITE(OUT,8000) 'MEAN NUMBER OF YEARS TO RECOVERY',
     +                REAL(MEANCN)

      WRITE(OUT,8000) 'STANDARD DEVIATION',
     +                REAL(SSCN)

      WRITE(OUT,8013) 'COEFFICIENT OF VARIATION',
     +                SSCN/(MEANCN+SMALL)*100

      WRITE(OUT,8020)
      WRITE(OUT,7997)
7997  FORMAT(1X, 'FREQUENCY DISTRIBUTION FOR RECOVERY TIMES',/,/,
     + 3X,'  YEARS   ',3X,' FREQUENCY',3X,'PERCENTAGE',/,
     + 3(3X,'----------'))
      DO 7998 H=1,NUMSLEV
        WRITE(OUT,7999) H,SHIST(H),REAL(SHIST(H))/NUMSIM*100.
7998  CONTINUE
7999  FORMAT(10X,I3,4X,I9,3X,F10.4,'%')

C     -NOTIFY USER THAT PROGRAM HAS TERMINATED NORMALLY
      WRITE(OUT,9000)
C
C     FORMAT STATEMENTS USED THROUGHOUT
C
C     -WRITE DESCRIPTION AND REAL NUMBER
8000  FORMAT(1X,A,/,1X,G13.6)
C
C     -WRITE DESCRIPTION AND INTEGER
8010  FORMAT(1X,A,/,1X,I14)
C
C     -WRITE DESCRIPTION AND REAL AS A PERCENTAGE
8013  FORMAT(1X,A,/,1X,G13.6,'%')
C
C     -WRITE CHARACTER STRING OF INDEFINATE LENGTH
```

```
8015  FORMAT(1X,A)
C
C     -WRITE A BLANK LINE
8020  FORMAT(/)
C
C     -TERMINATION MESSAGE
9000  FORMAT(/,' -- NORMAL TERMINATION --')

      STOP
      END

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      SUBROUTINE GETPROF(CPUE,CATCH,COSTEF,EXVAL,
     +                   NPROF,GPROF,EFFORT,COST,BLACK)
      IMPLICIT NONE
C
C     LARRY JACOBSON
C        24 SEPTEMBER 1989
C
C     THIS SUBROUTINE DETERMINES IF A PROFIT COULD BE
C     MADE AT A GIVEN LEVEL OF CPUE, EXVESSEL PRICE AND
C     COST PER UNIT OF EFFORT.  IF A PROFIT IS POSSIBLE
C     AND THE QUOTA IS > 0, THEN THE GROSS PROFITS
C     AFTER TAKING THE QUOTA ARE CALCULATED.
C
C     ON ENTRY:
C       - CPUE HOLDS THE CATCH PER UNIT EFFORT
C       - CATCH HOLDS THE CATCH TO BE TAKEN
C       - COSTEF IS THE COST ON ONE UNIT OF FISHING EFFORT
C       - EXVAL IS THE EXVESSEL PRICE OF ONE UNIT CATCH
C
C     ON EXIT:
C       - NPROF HOLDS THE NET PROFIT
C       - GPROF HOLDS THE GROSS PROFIT
C       - EFFORT HOLDS THE FISHING EFFORT REQUIRED
C       - COST HOLDS THE COST OF TAKING CATCH
C       - BLACK IS TRUE IF THE POTENTIAL PROFIT IS > 0.0
C         AND FALSE OTHERWISE
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        REAL CPUE,CATCH,COSTEF,EXVAL,NPROF,GPROF,EFFORT,COST
        LOGICAL BLACK

C       DETERMINE WHETHER OR NOT A PROFIT IS POTENTIALLY POSSIBLE
        IF (EXVAL-COSTEF/CPUE.GT.0.0) THEN
          BLACK=.TRUE.
        ELSE
          BLACK=.FALSE.
        ENDIF

C       IF CATCH IS ZERO OR FISHING NOT PROFITABLE THEN NO FISHING
C       SO PROFITS AND COSTS ARE ZERO
        IF ((CATCH.EQ.0.0).OR.(.NOT.BLACK)) THEN
C       -EFFORT,COSTS,GROSS PROFIT AND NET PROFIT ARE ZERO
          EFFORT=0.0
          COST=0.0
          GPROF=0.0
          NPROF=0.0
C       -RETURN TO CALLING PROGRAM
          RETURN
        ELSE
C       -CALCULATE PROFITS AND COSTS
C       --FISHING EFFORT
          EFFORT=CATCH/CPUE
C       --COST OF FISHING
          COST=EFFORT*COSTEF
C       --GROSS PROFITS
          GPROF=CATCH*EXVAL
C       --NET PROFITS
          NPROF=GPROF-COST
        ENDIF

        RETURN
        STOP
        END
```