AGEPRO Reference Manual

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Abstract

This reference manual describes the updated version 4.25 AGEPRO model and software to perform stochastic age-structured projections for an exploited age-structured fish stock. The AGEPRO model can be used to quantify the probable effects of alternative harvest scenarios by multiple fleets on an age-structured population over a given time horizon. Primary outputs include the projected distribution of spawning biomass, fishing mortality, recruitment, and landings by time period. This updated version allows for multiple recruitment models to account for alternative hypotheses about recruitment dynamics and applies model-averaging to predict the distribution of realized recruitment given estimates of recruitment model probabilities. The reference manual also describes the logical structure of the projection model, including program inputs, outputs, structure and usage. This includes three examples which illustrate: a standard two-fleet projection analysis projection, a stock rebuilding projection analysis, and projections to calculate the annual catch limits that produce probabilities of exceeding an overfishing level. Although all reasonable efforts have been taken to ensure the accuracy and reliability of the AGEPRO software and data, the National Oceanic and Atmospheric Administration and the U.S. Government do not and cannot warrant the performance or results that may be obtained by using this software or data.

Part I

Introduction

The AGEPRO model was initially developed in 1994 to determine optimal strategies to rebuild a depleted fish stock. The model was reviewed at the May 1994 meeting of the Northeast Fisheries Science Center Methods Working Group (Brodziak and Rago. Manuscript. 1994 ; Brodziak, Rago, and Conser 1998). Subsequently, the model was applied to groundfish stocks at the 18th SARC (Northeast Fisheries Science Center [NEFSC] 1994) to evaluate Amendment 5 harvest scenarios (New England Fishery Management Council [NEFMC] 1994) and was applied again in 1995 to assist with Amendment 7 (NEFMC 1996,). The reference manual was prepared in 1997 to provide documentation and has been updated since then to describe modifications to the model and software. The current program is written in the C language to allow for dynamic array allocation and to achieve rapid processing speeds.

The AGEPRO program can be used to perform stochastic projections of the abundance of an exploited age-structured population over a given time horizon. The primary purpose of the AGEPRO model is to produce management strategy projections that characterize the sampling distribution of key fishery system outputs such as landings, spawning stock biomass, population age structure, and fishing mortality from one or more fleets, accounting for uncertainty in initial population estimates, future recruitment, and natural mortality (Figure 1). The acronym "AGEPRO" derives from **age**-structured **pro**jections, in contrast to size- or biomass-based projections for size- or biomass-structured models. The user can evaluate alternative harvest scenarios by setting quotas or fishing mortality rates in each year of the time horizon.

Three elements of uncertainty can be included in an AGEPRO stock projection: **population recruitment**, **distribution of initial population size**, and **process error for population and fishery processes**. Recruitment is the primary stochastic element in the population model, where recruitment is typically defined as the number of age-0 or age-1 fish entering the modeled population at the beginning of each year in the time horizon. There are a total of fifteen stochastic recruitment models that can be used for population projection. It is also possible to simulate a deterministic recruitment trajectory (see recruitment model 3 below).

Initial population size is the second potential element of uncertainty for population projection (Figure 1). To include this element, a distribution of initial population sizes must be calculated a priori. This is typically done using bootstrapping, Markov chain Monte Carlo simulation, or other techniques in most age-structured assessments. Alternatively, projections can be based on a single best point estimate with no uncertainty in the initial population size.

The third element of uncertainty is process error in population and fishery processes. The user can choose to simulate the following population and fishery processes at age through time with a multiplicative lognormal process error with mean value equal to unity and a constant coefficient of variation:

1. Natural mortality at age

2. Maturation fraction at age
3. Stock weight on January 1st at age
4. Spawning stock weight at age
5. Mean population weight at age
6. Fishery selectivity at age
7. Discard fraction at age
8. Catch weight at age
9. Discard weight at age

The simulated values of each of these processes can be stored in auxiliary data files for the purpose of documenting projection results.

Age Structured Population Model

A pooled-sex, age-structured population model is the basis for the AGEPRO model and software. This model represents an iteroparous fish population whose abundance changes due to fluctuations in recruitment and natural mortality as well as fishing mortality from one or more fishing fleets. Population size at age changes continuously throughout the year due to the concurrent forces of natural and fishing mortality. Recruitment (R, number of age-r fish) to the population occurs at the beginning of each year (January 1^{st}) and is the first element in the population size at age vector (Table 1).

Population Abundance, Survival, and Spawning Biomass

The AGEPRO model calculates the number of fish alive within each age class of the population through time. Let Y denote the number of years in a projection where t indexes time for $t = 1, 2, ...Y$. The maximum number of years in the projection is a dynamic variable specified by the user and constrained by the amount of computer memory. The minimum or youngest age class comprises the recruits and the age of recruitment is set as age-1. The oldest age class is a plus-group, which consists of all fish that are at least as old as the plus group age (A). The maximum number of age classes is 100, including the plus group. For each age class, the number of fish alive at the beginning of each calendar year (January 1^{st}) is $N_j(t)$ where j indexes age class and t indexes year. The number of fish in the plus group is $N_A(t)$ which accounts for the number of fish that are age-A or older at the beginning of year t. Given this, the population abundance at the beginning of year t is the vector $\underline{N}(t)$ with $R(t)$ used as an alternate notation to emphasize that a recruitment submodel is needed to stochastically generate recruitment through time horizon.

$$\underline{N}(t) = \begin{bmatrix} R(t) \\ N_2(t) \\ N_3(t) \\ \vdots \\ N_A(t) \end{bmatrix} \tag{1}$$

Population survival at age from year $t-1$ to year t is calculated using instantaneous fishing and mortality rates at age. To describe annual survival through mortality, let $M_a(t)$ denote the instantaneous natural mortality rate on age group a and let $F_a(t)$ denote the instantaneous fishing mortality rate for age-a fish in year t where $F_a(t)$ is the sum of fleet-specific fishing mortalities at age a. Population size at age in year t for age classes indexed by $a = 1\ to\ A-1$ is given by

$$N_a(t) = N_{a-1}(t-1) \cdot e^{-M_{a-1}(t-1)-F_{a-1}(t-1)} \tag{2}$$

Similarly, population size at age in year t for the plus group of fish age-A and older is given by

$$N_a(t) = N_a(t-1) \cdot e^{-M_a(t-1)-F_a(t-1)} + N_{a-1}(t-1) \cdot e^{-M_{a-1}(t-1)-F_{a-1}(t-1)} \tag{3}$$

where survival for the plus-group involves an age-A and an age-$(A-1)$ component. Incoming recruitment is determined through a stochastic process that is either dependent or independent of spawning biomass in year t (see **Stock-Recruitment Relationship**).

Annual spawning biomass $B_s(t)$ is calculated from the population size vector $\underline{N}(t)$ and total mortality rates as well as information on sexual maturity and weight at age. The age-specific natural mortality rate is $M_a(t)$. To describe annual survival, let $F_a(t)$ be the instantaneous fishing mortality rate for age-a fish in year t where $F_a(t)$ is the sum of fleet-specific fishing mortalities at age $F_a(t) = \sum_v F_{v,a}(t)$. Further, let $P_{mature,a}(t)$ denote the average fraction of age-a fish that are sexually mature in year t and let $W_{S,a}$ denote the average spawning weight of an age-a fish in year t. Last, let $Z_{Frac}(t)$ denote the proportion of total mortality that occurs from January 1st to the mid-point of the spawning season in year t. Given this, population size at the midpoint of the spawning season in year t, $\underline{N}_s(t)$ is obtained by applying instantaneous natural and fishing mortality rates that occur prior to the spawning season to the population vector at the beginning of the year, $\underline{N}(t)$.

$$\underline{N}_S(t) = \begin{bmatrix} N_1(t) \cdot e^{-Z_{Frac}(t)[M_1(t)+F_r(t)]} \\ N_2(t) \cdot e^{-Z_{Frac}(t)[M_2(t)+F_2(t)]} \\ N_3(t) \cdot e^{-Z_{Frac}(t)[M_3(t)+F_3(t)]} \\ \vdots \\ N_A(t) \cdot e^{-Z_{Frac}(t)[M_A(t)+F_A(t)]} \end{bmatrix} \tag{4}$$

As a result, the amount of spawning biomass in year t is the sum of the weight of the mature fish alive at the midpoint of the spawning season

$$B_S(t) = \sum_{a=1}^{A} W_{S,a}(t) \cdot P_{mature,a}(t) \cdot N_a(t) \cdot e^{-Z_{Frac}(t)[M_a(t)+F_a(t)]} \tag{5}$$

Table 1: Glossary of AGEPRO variables

Table 1: Glossary of variables in the AGEPRO module.

Variable	Description
A	Age of plus-group (fish age-A and older) and last index value for $\underline{N}$
$B_S(t)$	Spawning biomass in year t
$\overline{B}(t)$	Mean stock biomass in year t
B_T	Total stock biomass on January 1^{st} of year t
B	Number of input initial population vectors $\underline{N}(t)$
$C_a(t)$	Total catch number of age-a fish that are caught in year t
$C_{v,a}(t)$	Number of age-a fish caught by fleet v in year t
$D(t)$	Total weight of fish discarded fish in year t
$F(t)$	Instantaneous fully-selected fishing mortality rate in year t
$F_a(t)$	Total fishing mortality rate for age-a fish in year t
$F_{v,a}(t)$	Fishing mortality rate on age-a fish by fleet v in year t
F_B	Instantaneous fishing mortality weighted by mean biomass in year t
$I(t)$	Harvest index for year t. • If the harvest index has value $I(t) = 1$, then fishery harvest is based on a specified landings quota $Q(t) \geq 0$ with catch units of metric tons • Else if $I(t) = 0$, then fishery harvest is based on an instantaneous fishing mortality rate $F(t) \geq 0$
$L(t)$	Total weight of fish landed in year t
$M_a(t)$	Instantaneous natural mortality rate of age-a fish in year t
$N_a(t)$	Number of age-a fish alive on January 1st of year t
N_M	Number of recruitment models used in the projection
$P_{v,D,a}(t)$	Proportion of age-a fish caught and discarded in year t
$S_{v,a}(t)$	Fishery selectivity for age-a fish by fleet v in year t

Variable	Description
$P_{R,i}(t)$	Probability that the i^{th} recruitment model is applied in year t
$P_{mature,a}(t)$	Proportion of age-a fish that are sexually mature in year t
$Z_{Frac}(t)$	Proportion of total mortality occurring prior to spawning in year t
$Q_v(t)$	Landings quota (mt) for fleet v in year t
$R(t)$	Recruitment (number of age-1 fish on January 1^{st}) in year t
$W_{P,a}(t)$	Average population weight of an age-a fish on January 1^{st} in year t
$W_{v,L,a}(t)$	Average landed (catch) weight of age of an age-a fish by fleet v in year t
$W_{S,a}(t)$	Average spawning weight of an age-a fish in year t
$W_{midyear,a}(t)$	Average mid-year, or mean population weight of an age-a fish in year t
$W_{v,D,a}(t)$	Average weight of an age-a fish discarded by fleet-v in year t
Y	Number of Years in projection time horizon where $t = 1, 2, ..., Y$

Catch, Landings, and Discards

The fishery catch depends on the fraction of the population that is vulnerable to harvest or the exploitable stock size. Catch at age by fleet (fleets are indexed by v) is determined by the Baranov catch equation (e.g., Quinn II and Deriso 1999). The catch of age-a fish in year t by fleet v is $C_{V,a}(t)$.

$$C_{V,a}(t) = \frac{F_{v,a}(t)}{M_a(t) + F_{v,a}(t)} \left[1 - e^{-M_a(t) - F_{v,a}(t)}\right] \cdot N_a(t) \tag{6}$$

To account for age-specific discarding of fish, let $P_{v,D,a}(t)$ be the proportion of age-a fish that are discarded by fleet v in year t, and let $W_{v,L,a}(t)$ and $W_{v,D,a}$ be the average weight at age-a in year t for landed and discarded fish, respectively. Then, if discarding is included in the projections, the total landed weight of fish caught by fleet v in year t, denoted by $L_v(t)$, is

$$L_V(t) = \sum_{a=1}^{A} \cdot \left[1 - P_{v,D,a}(t)\right] \cdot W_{v,L,a(t)} \tag{7}$$

Similarly, the total weight of discarded fish in year t, denoted by $D_y(t)$, is

$$D_v(t) = \sum_{a=1}^{A} C_{v,a}(t) \cdot P_{v,D,a}(t) \cdot W_{v,D,a}(t) \tag{8}$$

Population Harvest

Population harvest is set in each year in the projection time horizon by setting the harvest index $I(t)$. There are two options for determining the level of population harvest in each year of the time horizon: these are the fishing mortality and the quota options. Note that catch quotas are input in units of metric tons of annual catch biomass. Under the fishing mortality option, the user-input fishing mortality rate determines the harvest level (i.e., effort-based management). Under the quota option, the user-input landings quota sets the harvest level (i.e., catch-based management). These two harvest options can be combined in any order within a given projection time horizon where, for example, effort-based management is applied in some years and quota-based management in the other years. This mixed harvest option allows the projection to start with one or more years of known catch followed by annual harvests set by fishing mortality rates. In this case, the user sets a binary harvest index $I(t)$ to determine the harvest option for each year in the projection time horizon. If $I(t) = 1$, or the quota indicator is set to be true, then quota-based harvest control is applied in year t; else if $I(t) = 0$, then the quota indicator is set to be false and fishing mortality-based harvest control is applied. A mixture of quotas and effort-based harvest can be useful when projecting forward from a previous assessment to the present when only catch is available for the intervening years.

When effort-based management is applied, catch at age is determined by setting $F_{v,a(t)}$ by fleet for each age class. In this case, the fishing mortality rate on age-a fish in year t is the product of the fully-selected fishing mortality rate by fleet, denoted by $F_v(t)$, and the fleet- and age-specific fishery selectivity of age-a fish, denoted by $S_{v,a}(t)$ as

$$F_{v,a}(t) = F_v(t) \cdot S_{v,a}(t) \tag{9}$$

Landings and discards, if applicable, are then determined from $F_{v,a}(t)$. When quota-based management is applied, however, the $F_v(t)$ that would yield the landings quota must be determined numerically.

Under quota-based management, the landings quota by fleet in year t, denoted by $Q_y(t)$, will translate into a variety of effective fishing mortality rates depending on population size, fishery selectivity, and discarding, if applicable.

Ignoring the fleet index and time dimension for simplicity, a landings quota Q can be expressed as a function of $F, Q = L(F)$, where F is the fully-selected fishing mortality and L is the landings expressed as a function of F. To see this result, observe that the catch of age-a fish can be expressed as a function of F

$$C_a(F) = \frac{F \cdot S_a(t)}{M_a(t) + F \cdot S_a(t)} \Big[1 - e^{-M_a(t) - F \cdot S_a(t)}\Big] \cdot N_a(t) \tag{10}$$

As a result, landings can also be expressed as a function of F

$$L(F) = \sum_{a=1}^{A} C_a(F) \cdot \Big[1 - P_{D,a}(t)\Big] \cdot W_{L,a}(t) \tag{11}$$

The fully-selected fishing mortality, which satisfies the equation, $Q = L(F)$ can be found using a robust root-finding algorithm and we apply the bisection method, that previous versions applied Newton's method. Quotas which exceed the exploitable biomass of the population are defined as being infeasible and simulations with infeasible quotas are also infeasible.

Initial Population Abundance

There are two ways to set the initial population abundance, defined as the vector of the absolute number of fish alive on January 1$^{\text{st}}$ of the first year ($t = 1$) of the projection time horizon $\underline{N}(1)$. The primary option is to use a set of samples from the distribution of the estimator of $\underline{N}(1)$. This approach explicitly incorporates uncertainty in the estimate of initial population abundance into the projections. Under this option, either frequentist methods such as bootstrapping or Bayesian methods such as Markov Chain Monte Carlo simulation can be applied to determine the sampling distribution of the estimator of $\underline{N}(1)$. The secondary option is to ignore uncertainty in the estimator of initial population abundance and use a single best estimate for the value of $\underline{N}(1)$. In this case, there is no uncertainty in the point estimate of $\underline{N}(1)$ used in the projections.

The primary option uses a set of B initial population vectors, denoted by $\underline{N}^{(*)}(1) = \left\{\underline{N}^{(1)}(1), \underline{N}^{(2)}(1), \ldots, \underline{N}^{(B)}(1)\right\}$ for stochastic projections. In this case, the set of B values are random samples from the distribution of the estimator of $\underline{N}(1)$ generated by the assessment model or other means. Given this, stochastic projection can be used to characterize the sampling distribution of key fishery outputs accounting for the uncertainty in the estimate of the initial population size. For each initial condition $\underline{N}^{(b)}(1)$, a set of simulations will be performed using the specified harvest strategy. Since dynamic array allocation is used to dimension the set of initial population vectors, the user may choose to input a large number of initial population vectors (e.g., $B = 10^3$) within the practical constraint of available computer memory.

The secondary option is to use a single point estimate of $\underline{N}(1)$for projection. In this case, one estimate of population abundance is assumed to characterize the initial state of the population. Since there is no uncertainty in the initial state of the population this option allows one to characterize the sampling distribution of key fishery outputs due to uncertainty in recruitment or other variables subject to process errors.

Regardless of which initial population abundance option is used, the user must also specify the units of the initial population size vector taken from the assessment model. In particular, the initial population abundance vector is specified and input in relative abundance units along with a conversion coefficient k_N to compute from relative units to absolute numbers, where the initial population abundance replicate is calculated as the conversion coefficient times the relative abundance vector via $\underline{N}^{(b)}(1) = \left(N_1^{(b)}(1),\ ...,\ N_A^{(b)}(1)\right) = k_N \cdot \underline{n}^{(b)}(1) = \left(k_N \cdot n_1^{(b)}(1),\ ...,\ k_N \cdot n_A^{(b)}(1)\right)$

Retrospective Adjustment

One can adjust the initial population numbers at age vector $\underline{N}(1)$ to reflect a retrospective pattern in calculating these estimates. In this case, the user must determine an appropriate vector of retrospective bias-correction coefficients, denoted by $\underline{C}$, to apply to the vector $\underline{N}(1)$. These multiplicative bias-correction coefficients may be age-specific or constant across age classes. The bias-corrected initial population vector $\underline{N}^*(1)$ is calculated from the element-wise product of $\underline{N}(1)$ and $\underline{C}$ as

$$\underline{N}^*(1) = \left(C_1 \cdot N_1(1),\ \ldots,\ C_a \cdot N_a(1),\ \ldots,\ C_A \cdot N_A(1)\right)^T$$

Note that the bias-correction coefficients are applied to all initial population vectors. If the bias-correction coefficients are determined to be constant across age classes then $\underline{C} = (C, C, ..., C)^T$ and the bias-corrected initial population vector is

$$\underline{N}^*(1) = \left(C \cdot N_1(1),\ \ldots,\ C \cdot N_a(1),\ \ldots,\ C \cdot N_A(1)\right)^T \ = \ C \cdot \underline{N}(1)$$

The bias-correction coefficients are only applied in the first time period of the projection time horizon to reflect uncertainty in the estimated population size at age. Mohn (1999) provides an informative presentation of the retrospective problem in sequential population analysis.

Stock Recruitment Relationship

In general, the relationship between spawning stock B_S and recruitment R is highly variable owing to intrinsic variability in factors governing early life history survival and to measurement error in the estimates of recruitment and the spawning biomass that generated it. The stock-recruitment relationship ultimately defines the sustainable yield 8 curve and its expected variability assuming that the stochastic processes of growth, maturation, and natural mortality are density-independent and stationary throughout the time horizon. Quinn and Deriso (1999) provide a useful discussion of stock-recruitment models, renewal processes, and sustainable yield. Note that the assumed stock-recruitment relationship does not affect the initial population abundance at the beginning of the time horizon (see **Initial Population Abundance**).

A total of twenty one stochastic recruitment models are available for population projection in the AGEPRO software. Thirteen of the recruitment models are functionally dependent on B_S while eight do not depend on spawning biomass. Five of the recruitment models have time-dependent parameters, twelve are time-invariant, and four may include time as a predictor, or not. The user is responsible for the choice and parameterization of the recruitment models. A description of each of the recruitment models follows. *Important: note that the absolute units for recruitment R* are numbers of age-1 fish, while for spawning biomass B_S, the absolute units are kilograms of spawning biomass in each of the recruitment models below.

Model 1. Markov Matrix

A Markov matrix approach to modeling recruitment may be useful when there is uncertainty about the functional form of the stock-recruitment relationship. A Markov matrix contains transition probabilities that define the probability of obtaining a given level of recruitment given that B_S was within a defined interval range. In particular, the distribution of recruitment is assumed to follow a multinomial distribution conditioned on the spawning biomass interval or spawning state of the stock. The Markov matrix model depends on spawning biomass and is time-invariant.

An empirical approach to estimate a Markov matrix uses stock-recruitment data to determine the parameters of a multinomial distribution for each spawning biomass state. In this case, matrix elements can be empirically determined by counting the number of times that a recruitment observation interval lies within a given spawning biomass state, defined by an interval of spawning biomass, and normalizing over all spawning states. To do this, assume that there are K recruitment values and J spawning biomass states. The spawning biomass states are defined by disjoint intervals on the spawning biomass axis

$$I_1 = [0, B_{s,1}) \; and \; for \; j = 1, ..., J-2 \;\; I_j = [B_{S,j-1}, B_{S,J}) \; and \; I_j = [B_{S,J-1}, \infty) \tag{14}$$

where the spawning biomass values $B_{S,j}$ are the input endpoints of the disjoint intervals of categories of spawning biomass (e.g., high, medium, low). Note that the spawning biomass intervals are defined by the cut points $B_{S,j}$. The conditional probability of realizing the k^{th} recruitment value given that observed spawning biomass $B_{S,Observed}$ is in the j^{th} interval is Pj, k. Here $P_{j,k}$ is the element in the j^{th} row and k^{th} column of the Markov matrix $\underline{P} = [P_{j,k}]$ of conditional recruitment probabilities with elements

$$P_{j,k} = Pr(R_k | B_{S,Observed} \in I_j) \tag{15}$$

These individual conditional probabilities can be estimated by the computing the number of points in the stock recruitment data set that fall within a selected recruitment $[O_{k-1}, O_k]$ range conditioned on the spawning biomass interval I_j. If $x_{j,k}$ represents the number of stock-recruitment observations in cell $I_j \times O_k$ and there is at least one observation in spawning state j, then the empirical maximum likelihood estimate of $P_{j,k}$ is

$$\Pr(r = O_k \mid B_S \in I_j) = \frac{x_{j,k}}{\sum_k x_{j,k}} \tag{16}$$

Here $P_{j,k} \geq 0$ and $\sum_{k=1} P_{j,k} = 1$

Up to 25 recruitment values and up to 10 spawning biomass states can be used in the Markov matrix model. For each spawning biomass interval, the user needs to specify the conditional probabilities of realizing the expected recruitment level, e.g., the $P_{j,k}$. Given the conditional probabilities $P_{j,k}$, simulated values of $\hat{R}$ are generated by randomly sampling the conditional distribution $\hat{R}(t) = Pr(R = O_k \mid B_S(t) \in I_j)$ through time.

Model 2. Empirical Recruits Per Spawning Biomass Distribution

For some stocks, the distribution of recruits per spawner may be independent of the number of spawners over the range of observed data. The recruitment per spawning biomass (R/B_s) model randomly generates recruitment under the assumption that the distribution of the R/B_s ratio is stationary and independent of stock size. *The empirical recruits per spawning biomass distribution model depends on spawning biomass and is time-invariant.*

To describe this nonparametric approach, let S_t be the R/B_s ratio for the t$^{\text{th}}$ stock recruitment data point assuming age-1 recruitment

$$S - t = \frac{R(t)}{B_s(t-1)} \tag{17}$$

and let R_S be the thS element in the ordered set of S_t. The empirical probability density function for R_S, denoted as $g(R_S)$, assigns a probability of $1/T$ to each value of R/B_S where T is the number of stock-recruitment data points. Let $G(R_S)$ denote the cumulative distribution function (cdf) for R_S. Set the values of G at the minimum and maximum observed R_S to be $G(R_{min}) = 0$ and $G(R_{max}) = 0$ so that the cdf of R_S can be written as

$$G(R_S) = \frac{s-1}{T-1} \tag{18}$$

Random values of R_S can be generated by applying the probability integral transform to the empirical cdf. To do this, let U be a uniformly distributed random variable on the interval [0,1]. The value of R_S corresponding to a randomly chosen value of U is determined by applying the inverse function of the cdf $G(R_S)$. In particular, if U is an integer multiple of $1/(T-1)$ so that $U = s/(T-1)$ then $R_S = G^{-1}(U)$. Otherwise R_S can be obtained by linear interpolation when U is not a multiple of $1/(T-1)$.

In particular, if $(s-1)/(T-1) < U < s/(T-1)$, then $\hat{R_S}$ is interpolated between R_S and R_{S+1} as

$$U = \left(\frac{\frac{s}{T-1} - \frac{s-1}{T-1}}{R_{s+1} - R_S} \right) (\widehat{R_S} - R_S) + \frac{s-1}{T-1} \tag{19}$$

Solving for $\widehat{R_S}$ as a function of U yields

$$\widehat{R_S} - (T-1)(R_{S+1} - R_S) \left(U - \frac{s-1}{T-1} \right) + R_S \tag{20}$$

Where the interpolation index s is determined as the greatest integer in $1 + U(T-1)$. Given the value of $\widehat{R_S}$, recruitment is generated as

$$R(t) = N_1(t) = B_S(t-1) \cdot \widehat{R_S} \tag{21}$$

The AGEPRO program can generate stochastic recruitments under model 2 based on thousands of input stock-recruitment data points (i.e., the stock-recruitment data array size is defined as a long int variable in the C language and is user specified with the input variable MaxRecObs, see Table 3, keyword RECRUIT) conditioned on available computer memory resources.

Model 3. Empirical Recruitment Distribution

Another simple model for generating recruitment is to draw randomly from the observed set of recruitments $\underline{R} = \{R(1), R(2), ..., R(T)\}$ .This may be a useful approach when the recruitment has randomly fluctuated about its mean and appears to beindependent of spawning biomass over the observed range of data. In this case, the recruitment distribution may be modeled as a multinomial random variable where the probability of randomly choosing a particular recruitment is $1/T$ given T observed recruitments. The empirical recruitment distribution model does not depend on spawning biomass and is time-invariant.

In this model, realized recruitment $\hat{R}$ is simulated from the empirical recruitment distribution as

$$Pr\left(\widehat{R} = R(t)\right) = \frac{1}{T}, for\ t \in \{1, 2, ..., T\} \tag{22}$$

The empirical recruitment distribution approach is nonparametric and assumes that future recruitment is totally independent of spawning stock biomass. When current levels of B_S are near the midrange of historical values this assumption seems reasonable. However, if contemporary S_B values are near the bottom of the range, then this approach could be overly optimistic, for it assumes that all historicallyobserved recruitment levels are possible, regardless of B_S. The AGEPRO program can generate stochastic recruitments under model 3 based on thousands of input recruitment data points. Note that the empirical recruitment distribution model can be used to make deterministic projections by specifying a single observed recruitment.

Model 4. Two-Stage Empricial Recruits Per Spwaning Biomass

The two-stage recruits per spawning biomass model is a direct generalization of the R/B_S model where the spawning stock of the population is categorized into "low" and "high" states. *The two-stage empirical recruits per spawning biomass distribution model depends on spawning biomass and is time-invariant.*

In this model, there is an R/B_S distribution for the low spawning biomass state and an R/B_S distribution for the high spawning biomass state. Let G_{Low} be the cdf and let T_Low be the number of R/B_S values for the low B_S state. Similarly, let G_{High} be the cdf and let T_{High} be the number of R/B_S values for the high B_S state. Further, let B_S^* B denote the cutoff level of B_S such that, if $B_S > B_S^*$, then B_S falls in the high state. Conversely if $B_S < B_S^*$, then B_S falls in the low state. Recruitment is stochastically generated from G_{Low} or G_{High} using equations (20) and (21) dependent on the B_S state. The AGEPRO program can generate stochastic recruitments under model 4 based on thousands of input stock recruitment data points per B_S state.

Model 5. Beverton-Holt Curve with Lognormal Error

The Beverton-Holt curve (Beverton and Holt 1957) with lognormal errors is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. *The Beverton-Holt curve with lognormal error model depends on spawning biomass and is time-invariant.*

The Beverton-Holt curve with lognormal error generates recruitment as

$$\begin{aligned} \hat{r}(t) &= \frac{\alpha \cdot b_s(t-1)}{\beta + b_s(t-1)} \cdot e^w \\ &\textit{where } w \sim N(0, \sigma_w^2), \widehat{R}(t) = c_R \cdot \hat{r}(t), \textit{and } B_S(t) = c_B \cdot b_S(t) \end{aligned} \tag{23}$$

The stock-recruitment parameters α, β, and σ_w^2 and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Beverton-Holt curve have been estimated in relative units of recruitment $r(t)$ and spawning biomass $b_s(t)$, which are converted to absolute values using the conversion coefficients. Note that the absolute value of recruitment is expressed as numbers of fish, while for spawning biomass, the absolute value is expressed as kilograms of B_S. For example, if the stock-recruitment curve was estimated with stock-recruitment data that were measured in millions of fish and thousands of metric tons of B_S, then $c_R = 10^6$ and $c_R = 10^6$. It may be important to estimate the parameters of the stock-recruitment curve in relative units to reduce the potential effects of roundoff error on parameter estimates. It is important to note that the expected value of the lognormal error term is not unity but is $exp\left(\frac{1}{2}\sigma_w^2\right)$. Therefore, in order to generate a recruitment model that has a lognormal error term that is equal to 1, one needs to multiply the parameter α by $exp\left(-\frac{1}{2}\sigma_w^2\right)$. This bias correction applies when the lognormal error used to fit the Beverton-Holt curve has a log-scale error term w with zero mean.

The Beverton-Holt curve is often reparameterized in a modified form with parameters for steepness h , unfished recruitment R_0, and unfished spawning biomass B_0. The modified Beverton-Holt curve produces $h = R_0$ recruits when $B_S = 0.2B_0$ and has the form

$$\hat{R} = \frac{4hR_0B_S}{B_0(1-h) + B_S(5h-1)} \tag{24}$$

The parameters α and β can be expressed as functions of the parameters of the modified Beverton-Holt curve as

$$\alpha = \frac{4hR_0}{5h-1} = 4B_0\frac{h}{\left(\frac{B_0}{R_0}\right)(5h-1)} \tag{25}$$

and

$$\beta = \frac{B_0(1-h)}{(5h-1)} - \frac{\alpha\left(\frac{B_0}{R_0}\right)(h^{-1}-1)}{4} \tag{26}$$

Thus, parameter estimates for the modified curve can be used to determine the Beverton-Holt parameters for the AGEPRO program.

Model 6. Ricker Curve with Lognormal Error

The Ricker curve (Ricker 1954) with lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. *The Ricker curve with lognormal error model depends on spawning biomass and is time invariant.*

The Ricker curve with lognormal error generates recruitment as

$$\begin{aligned}&\hat{r}(t) = \alpha \cdot b_S(t-1) \cdot e^{-\beta \cdot b_S(t-1)} \cdot e^w \\ &where\ w \sim N(0,\sigma_w^2), \hat{R}(t) = c_R \cdot \hat{r}(t),\ and\ B_S(t) = c_B \cdot b_S(t)\end{aligned} \tag{27}$$

The stock-recruitment parameters α, β, and σ_w^2 and the conversion coefficients for recruitment C_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Beverton-Holt curve have been estimated in relative units of recruitment $r(t)$ and spawning biomass

$b_s(t)$ which are converted to absolute values using the conversion coefficients. It is important to note that the expected value of the lognormal error term is not unity but is $exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Ricker curve has a log-scale error term w with zero mean.

Model 7. Shepherd Curve with Lognormal Error

The Shepherd curve (Shepherd 1982) with lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. *The Shepherd curve with lognormal error model depends on spawning biomass and is time-invariant.*

The Shepherd curve with lognormal error generates recruitment as

$$\hat{r}(t) = \frac{\alpha \cdot b_S(t-1)}{1 + \left(\dfrac{b_s(t-1)}{k}\right)^{\beta}} \cdot e^{w} \tag{28}$$

$$where\ w \sim N(0, \sigma_w^2), \hat{R}(t) = c_R \cdot \hat{r}(t),\ and\ B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters α, β, k, and σ_w^2 and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Beverton-Holt curve have been estimated in relative units of recruitment $r(t)$ and spawning biomass $b_S(t)$ which are converted to absolute values using the conversion coefficients. It is important to note that the expected value of the lognormal error term is not unity but is $exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Ricker curve has a log-scale error term w with zero mean.

Model 8. Lognormal Distribution

The lognormal distribution provides a parametric model for stochastic recruitment generation. *The lognormal distribution model does not depend on spawning biomass and is time-invariant.*

The lognormal distribution generates recruitment as

$$\begin{aligned}
&\hat{r}(t) = e^{w} \\
&\textit{where } w \sim N(\mu_{log(r)}, \sigma^2_{log(r)}) \textit{ and } \hat{R}(t) = c_R \cdot \hat{r}(t)
\end{aligned} \tag{29}$$

The lognormal distribution parameters $\mu_{log(r)}$ and $\sigma^2_{log(r)}$ as well as the conversion coefficient for recruitment C_R are specified by the user. It is assumed that the parameters of the lognormal distribution have been estimated in relative units $r(t)$ and then converted to absolute values with the conversion coefficients.

Model 9. [DEPRECATED] Time-Varying Empirical Recruitment Distribution

This recruitment model has been deprecated. The model for a time-varying empirical recruitment distribution can be fully implemented using model 3.

Model 10. Beverton-Holt Curve with Autocorrelated Lognormal Error

The Beverton-Holt curve with autocorrelated lognormal errors is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially-correlated stochastic variation. *The Beverton-Holt curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.*

The Beverton-Holt curve with autocorrelated lognormal error generates recruitment as

$$\begin{aligned}
\hat{r}(t) = &\frac{\alpha \cdot b_s(t-1)}{\beta + b_s(t-1)} \cdot e^{\varepsilon_t} \\
&\textit{where } \varepsilon_t = \phi\varepsilon_{t-1} + w_t \quad \textit{with } w_t \sim N(0, \sigma^2_w), \\
&\hat{R}(t) = c_r \cdot \hat{r}(t), \textit{and } B_s(t) = c_B \cdot b_S(t)
\end{aligned} \tag{30}$$

The stock-recruitment parameters α, β, ϕ, ε_0, and σ^2_w and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the time prior to the projection. If this value is not known, the default is to set $\varepsilon_0 = 0$.

Model 11. Ricker Curve with Autocorrelated Lognormal Error

The Ricker curve with autocorrelated lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially correlated stochastic variation. *The Ricker curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.*

The Ricker curve with autocorrelated lognormal error generates recruitment as

$$\begin{aligned}\hat{r}(t) = \alpha \cdot b_S(t-1) \cdot e^{-\beta \cdot b_S(t-1)} \cdot e^{\varepsilon_t} \\ \quad \textit{where } \varepsilon_t = \phi\varepsilon_{t-1} + w_t \ \ \textit{with } w_t \sim N(0, \sigma_w^2), \\ \quad \hat{R}(t) = c_r \cdot \hat{r}(t), \textit{and } B_s(t) = c_B \cdot b_S(t)\end{aligned} \tag{31}$$

The stock-recruitment parameters α, β, ϕ, ε_0, and σ_w^2 and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the time prior to the projection. If this value is not known, the default is to set $\varepsilon_0 = 0$.

Model 12. Shepherd Curve with Autocorrelated Lognormal Error

The Shepherd curve with autocorrelated lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially-correlated stochastic variation. *The Shepherd curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.*

The Shepherd curve with autocorrelated lognormal error generates recruitment as

$$\begin{aligned}\hat{r}(t) = \frac{\alpha \cdot b_S(t-1)}{1 + \left(\dfrac{b_s(t-1)}{k}\right)^{\beta}} \cdot e^{\varepsilon_t} \\ \textit{where } \varepsilon_t = \phi\varepsilon_{t-1} + w_t \ \ \textit{with } w_t \sim N(0, \sigma_w^2), \\ \hat{R}(t) = c_r \cdot \hat{r}(t), \textit{and } B_s(t) = c_B \cdot b_S(t)\end{aligned} \tag{32}$$

The stock-recruitment parameters α, β, k, ϕ, ε_0, and σ_w^2 and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the time prior to the projection. If this value is not known, the default is to set $\varepsilon_0 = 0$.

Model 13. Autocorrelated Lognormal Distribution

The autocorrelated lognormal distribution provides a parametric model for stochastic recruitment generation with serial correlation. *The autocorrelated lognormal distribution model does not depend on spawning biomass and is time-dependent.*

The autocorrelated lognormal distribution is

$$
\begin{aligned}
&n_r(t) = e^{s_t} \\
&\textit{where } \varepsilon_t = \phi\varepsilon_{t-1} + w_t \textit{ with } w_t \sim N\left(\mu_{log(r)} \cdot \sigma^2_{log(r)}\right) \\
&\textit{and } R(t) = c_R \cdot n_r(t)
\end{aligned}
\tag{33}
$$

The lognormal distribution parameters $\mu_{log(r)} \cdot \sigma^2_{log(r)}$,$\phi$, ε_0 as well as the conversion coefficient for recruitment C_R are specified by the user. It is assumed that the parameters of the lognormal distribution have been estimated in relative units $r(t)$ and then converted to absolute values with the conversion coefficient.

Model 14. Empirical Cumulative Distribution Function of Recruitment

The empirical cumulative distribution function of recruitment can be used to randomly generates recruitment under the assumption that the distribution of R is stationary and independent of stock size. *The empirical cumulative distribution function of recruitment model does not depend on spawning biomass and is time-invariant.*

To describe this nonparametric approach, let R_S denote the S^{th} element in the ordered set of observed recruitment values. The empirical probability density function for R_S, denoted as $g(R_s)$, assigns a probability of $1/T$ to each value of $R(t)$ where T is the number of stock-recruitment data points. Let $G(R_S)$ denote the cumulative distribution function (cdf) for R_S. Set the values of G at the minimum and maximum observed R_S to be $G(R_{min}) = 0$ and $G(R_{max}) = 0$ so that the cdf of R_S can be written as

$$G(R_S) = \frac{s-1}{T-1} \tag{34}$$

Random values of R_S can be generated by applying the probability integral transform to the empirical cdf. To do this, let U be a uniformly distributed random variable on the interval [0,1]. The value of R_S corresponding to a randomly chosen value of U is determined by applying the inverse function of the cdf $G(R_S)$. In particular, if U is an integer multiple of $1/(T-1)$ so that $U = s/(T-1)$ then $\widehat{R_s} = G^{-1}(U)$. Otherwise $\widehat{R_s}$ can be obtained by linear interpolation when U is not a multiple of $1/(T-1)$.

In particular, if $(s-1)/(T-1) < U < s/(T-1)$, then $\widehat{R_s}$ is interpolated between R_S and R_{S+1} as

$$U = \left(\frac{\frac{s}{T-1} - \frac{s-1}{T-1}}{R_{S+1} - R_S} \right) \left(\widehat{R_S} - R_S \right) + \frac{s-1}{T-1} \tag{35}$$

Solving for $\widehat{R_s}$ as a function of U yields

$$\widehat{R_S} = (T-1)(R_{S+1} - R_S) \left(U - \frac{s-1}{T-1} \right) + R_S \tag{36}$$

where the interpolation index s is determined as the greatest integer in $1 + U(T-1)$. Given the value of R_S, recruitment is set to be

$$\widehat{R}(t) = \widehat{R_S} \tag{37}$$

The AGEPRO program can generate stochastic recruitments under model 14 based on thousands of input recruitment data points.

Model 15. Two Stage Empirical Cumulative Distribution Function of Recruitment

The two-stage empirical cumulative distribution function of recruitment model is an extension of Model 14 where the spawning stock of the population is categorized into low and high states. *The two-stage empirical cumulative distribution function of recruitment model depends on spawning biomass and is time-invariant.*

In this model, there is an empirical recruitment distribution R_{Low} for the low spawning biomass state and an empirical recruitment distribution R_{High} for the high spawning biomass state. Let G_{Low} be the cdf and let T_{Low} be the number of R values for the low B_S state. Similarly, let G_{High} be the cdf and let T_{High} be the number of R values for the high B_S state. Further, let B_S^* denote the cutoff level of B_S such that, if $B_S > B_S^*$, then B_S falls in the high state. Conversely if $B_S < B_S^*$, then B_S falls in the low state. Recruitment is stochastically generated from G_{Low} or G_{High} using equations (36) and (37) dependent on the B_S state. The AGEPRO program can generate stochastic recruitments under model 15 based on thousands of input stock-recruitment data points per B_S state.

Model 16. Linear Recruits Per Spawning Biomass Predictor with Normal Error

The linear recruits per spawning biomass predictor with normal error is a parametric model to simulate random values of recruits per spawning biomass $\frac{R}{B_S}$ and realized recruitment values. The predictors in the linear model $X_p(t)$ can be any continuous variable and may typically be survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. Similarly, if this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of $\frac{R}{B_S}$ is generated using the linear model

$$\frac{R}{B_S} = \beta_0 + \sum_{p=1}^{N_P} \beta_p \cdot X_p(t) + \varepsilon \tag{38}$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient of the p^{th} predictor and ε is a normal distribution with zero mean and constant variance σ^2. It is possible negative values of $\frac{R}{B_S}$ to be generated using this formulation; such values are excluded from the set of simulated values of $\frac{R}{B_S}$ from equation (35) by testing if $\frac{R}{B_S} < 0$ repeating the random sampling until an feasible positive value of $\frac{R}{B_S}$ is obtained. This model randomly generates $\frac{R}{B_S}$ values under the assumption that the linear predictor of the $\frac{R}{B_S}$ ratio is stationary and independent of stock size. Random values of $\frac{R}{B_S}$ are multiplied by realized spawning biomass to generate recruitment in each time period. *The linear recruits per spawning biomass predictor with normal error depends on spawning biomass and is time-invariant unless time is used as a predictor.*

Model 17. Loglinear Recruits Per Spawning Biomass Predictor with Lognormal Error

The loglinear recruits per spawning biomass predictor with lognormal error is a parametric model to simulate random values of recruits per spawning biomass $\frac{R}{B_S}$ and associated random recruitments. Predictors for the loglinear model $X_p(t)$ can be any continuous variable and could include survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. If this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of the natural logarithm of $\frac{R}{B_S}$ is generated using the loglinear model

$$\log\left(\frac{R}{B_s}\right) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon \tag{39}$$

where N_P is the number of predictors, β_0 is the intercept, β_p is the linear coefficient of the p^{th} predictor and ε is a normal distribution with constant variance σ^2 and mean equal to $-0.5\sigma^2$. In this case, the mean of ε implies that the expected value of the lognormal error term is unity. This model generates positive random values of $\frac{R}{B_S}$ under the assumption that the linear predictor of the $\frac{R}{B_S}$ ratio is stationary and independent of stock size. Simulated values of $\frac{R}{B_S}$ are multiplied by realized spawning biomass to generate recruitment in each time period. *The loglinear recruits per spawning biomass predictor with lognormal error depends on spawning biomass and is time-invariant unless time is used as a predictor.*

Model 18. Linear Recruitment Predictor with Normal Error

The linear recruitment predictor with normal error is a parametric model to simulate representative random values of recruitment. The predictors in the linear model $X_p(t)$ can be any continuous variable and could represent survey indices of cohort abundance or environmental covariates correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. Similarly, if this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of R is generated using the linear model

$$
\begin{aligned}
&n_r(t) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \ \cdot X_p(t) + \varepsilon \\
&with\ R(t) = c_r \cdot n_r(t)
\end{aligned}
\tag{40}
$$

here N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient of the p^{th} predictor and ε is a normal distribution with zero mean and constant variance σ^2 and the conversion coefficients for recruitment is c_R. It is possible that negative values of R can be generated using this formulation; such values are excluded from the set of simulated values of R from equation (37) by testing if R repeating the random sampling until an feasible positive value of R is obtained. This model randomly generates R values under the assumption that the linear predictor of R is stationary and independent of stock size. *The linear recruitment predictor with normal error does not depend on spawning biomass and is time-invariant unless time is used as a predictor.*

Model 19. Loglinear Recruitment Predictor with Lognormal Error

The loglinear recruitment predictor with lognormal error is a parametric model to simulate random values of recruitment R. Predictors for the loglinear model $X_p(t)$ can be any continuous variable such as survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. If this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of the natural logarithm of R is generated using the loglinear model

$$\begin{aligned} &\log\left(n_r(t)\right) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \ \cdot X_p(t) + \varepsilon \\ &with\ R(t) = c_r \cdot n_r(t) \end{aligned} \tag{41}$$

here N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient of the p^{th} predictor and ε is a normal distribution with constant variance σ^2 and and mean equal to $-0.5\sigma^2$, and the conversion coefficients for recruitment is c_R. In this case, the mean of ε implies that the expected value if the lognormal error term is unity. This model generates positive random values of R under the assumption that the linear predictor of R is stationary and independent of stock size. *The loglinear recruitment predictor with lognormal error does not depend on spawning biomass and is time-invariant unless time is used as a predictor.*

Model 20. Fixed Recruitment

The fixed recruitment predictor applies a specified value of recruitment for each year of the time horizon. The vector of input recruitment values in relative units is $\underline{n}_r = \left[n_r(1), n_r(2, ..., n_r(Y)\right]$ for projections years 1 through Y. The fixed recruitment model predicts recruitment as

$$R(t) = c_r \cdot n_r(t) \tag{42}$$

where the conversion coefficient for input recruitment to absolute numbers is c_R. *The fixed recruitment model does not depend on spawning biomass and is time-invariant.*

Model 21. Empirical Cumulative Distribution Function of Recruitment with Linear Decline to Zero

The empirical cumulative distribution function of recruitment with linear decline to zero model is an extension of the empirical cumulative distribution function of recruitment (Model 14) in which recruitment strength declines when the spawning stock biomass falls below a threshold B_S^*. The decline in recruitment randomly generated from the empirical cdf of the observed recruitment is proportional to the ratio of current spawning stock biomass to the threshold $\frac{B_S}{B_S^*}$ when $B_S < B_S^*$. In particular, predicted recruitment values are randomly generated using equation (37) given the input time series of observed recruitment. That is, if the current spawning biomass is at or above the threshold with $B_S \geq B_S^*$ then the predicted recruitment is

$$R = c_R \cdot \left[(T-1)(R_{S+1} - R_S)\left(U - \frac{s-1}{T-1}\right) + R_S\right] \tag{43}$$

where the conversion coefficient for input recruitment to absolute numbers is c_R.

Otherwise, if the current spawning biomass falls below the threshold with $B_S < B_S^*$ then the predicted recruitment is reduced to be

$$R = c_R \cdot \frac{B_S}{B_S^*}\left[\,(T-1)(R_{S+1} - R_S)\left(U - \frac{s-1}{T-1}\right) + R_S\right] \tag{44}$$

where the conversion coefficient for input recruitment to absolute numbers is c_R. *The empirical cumulative distribution function of recruitment with linear decline to zero model depends on spawning biomass and is time-invariant.*

Recruitment Model Probabilities

Model uncertainty about the appropriate stock-recruitment model can be directly incorporated into AGEPRO projections. Using a set of recruitment models may be appropriate when each model provides a similar statistical fit to a set of stock-recruitment data, where similarity can be measured using Akaike information criterion, deviance information criterion, widely applicable information criterion, or other goodness-of-fit measures. Given a measure of a stock-recruitment model's relative likelihood compared to a set of alternative models, one can use information criteria to calculate an individual model's probability of best representing the true state of nature. Alternatively, one can assign model probabilities based on judgment of other measures of goodness of fit or use the principle of indifference to assign equal probabilities in the absence of compelling information.

Regardless of the approach used to estimate them, the recruitment model probabilities are used to generate stochastic recruitment dynamics in a straightforward manner. Suppose there are a total of N_M probable recruitment models, as determined by the user. The probability that recruitment model m is realized in year t is denoted by $P_{R,m}(t) > 0$. Conservation of total probability implies that the sum of model probabilities over the set of probable models in each year is unity

$$\sum_{m=1}^{N_M} P_{R,m}(t) = 1 \tag{45}$$

This gives a conditional probability distribution for randomly sampling recruitment submodels in each year of the projection time horizon. As in previous versions of AGEPRO, a single recruitment model can be used for the entire projection time horizon by setting $N_M - 1$.

One advantage of including multiple recruitment models with time-varying probabilities is that one can use auxiliary information on recruitment strength, such as environmental covariates, to make short-term recruitment predictions (1-2 years) and then change to a less informative set of medium-term recruitment models for medium-term recruitment predictions (3-5 years). Another advantage of including multiple recruitment models is to account for model selection uncertainty, which can be a substantial source of uncertainty for some fishery systems.

Process Errors for Population and Fishery Processes

Process errors to generate time-varying dynamics of population and fishery processes can be included in stock projections using AGEPRO. These process errors are defined as independent multiplicative lognormal error distributions for each life history and fishery process.

The general form for a lognormal multiplicative process error term in year t, denoted by ε_i, is

$$\begin{aligned} &\varepsilon_i \sim \exp(w) \\ &where\ w \sim N(-0.5\sigma^2, \sigma^2) \end{aligned} \tag{46}$$

And where the user specifies the coefficient of variation of the lognormal process error as $CV = \sqrt{\exp(\sigma^2) - 1}$ which sets the value of σ as $\sigma = \sqrt{\log(CV^2 + 1)}$.

The five population processes and four fishery processes that can include process error along with the input file keyword to specify the process are (keyword):

- Natural mortality at age (`NATMORT`) $M_a(t)$
- Maturation fraction at age (`MATURITY`) $P_{mature,a}(t)$
- Stock weight on January 1st at age (`STOCK_WEIGHT`) $W_{P,a}(t)$
- Spawning stock weight at age (`SSB_WEIGHT`) $W_{S,a}(t)$
- Midyear mean population weight at age (`MEAN_WEIGHT`) $W_{midyear,a}(t)$
- Fishery selectivity at age by fleet (`FISHERY`) $S_{v,a}(t)$
- Discard fraction at age by fleet (`DISCARD`) $P_{y,D,a}(t)$
- Landed catch weight at age by fleet (`CATCH_WEIGHT`) $W_{y,L,a}(t)$
- Discard weight at age by fleet (`DISC_WEIGHT`) $W_{v,D,a}(t)$

For detailed documentation of projection results, the user can choose to store individual simulated values of these processes through time in auxiliary data files by setting the value of the DataFlag=1 under the keyword `OPTIONS` (Table 3). The auxiliary file names are constructed from the AGEPRO input filename with file extensions ranging from `.xxx1` to `.xxx9` for the nine processes in the bullet list above, noting that not all processes may be used in a given projection, e.g., discarding. For processes that are used, the auxiliary file names are assigned in the order in which the process parameters are set in the AGEPRO input file. For example, if the spawning stock weight at age process parameters appeared fifth in the ordering of keywords to specify these nine processes in the AGEPRO input file, then the time series of simulated spawning stock weights at age would be store in the auxiliary output file name `input_filename.xxx5`. Each row in this file would be the spawning weights at age for one year, in sequence, for each bootstrap replicate and simulation.

Total Stock Biomass

Total stock biomass B_T is the sum over the recruitment age (r) to the plus-group age (A) of stock biomass at age on January 1$^{\text{st}}$. The computational formula for B_T in year t is

$$B_T(t) = \sum_{a=r}^{A} W_{P,a}(t) \cdot N_a(t) \tag{47}$$

where $W_{P,a}(t)$ is the population mean weight of age-a fish on January 1$^{\text{st}}$ in year t.

Mean Biomass

Mean stock biomass $\overline{B}$ is the average biomass of the stock over a given year. In particular, mean stock biomass depends on the total mortality rate experienced by the stock in each year. In the AGEPRO model, the user selects the range of ages to be used for calculating mean biomass. One can choose the full range of ages in the model (age-r through age-A) or alternatively select a smaller age range if desired. In this case, the upper age A_U for mean biomass calculations must be less than or equal to the plus group age A. Similarly, the lower age A_L must be greater than or equal to the recruitment age r. If $W_{midyear,a}(t)$ denotes the mean weight of age-a fish at the mid-point of year t then the computational formula for $\overline{B}$ in year t is

$$\overline{B}(t) = \sum_{a=A_L}^{A_U} W_{midyear,a}(t) \cdot N_a(t) \cdot \frac{(1 - \exp(-M_a(t) - F_a(t)))}{(M_a(t) + F_a(t))} \tag{48}$$

where $F_a(t)$ is the total fishing mortality on age-a fish calculated across all fleets.

Fishing Mortality Weighted by Mean Biomass

Fishing mortality weighted by mean biomass $F_{\overline{B}}(t)$ in year t is the mean-biomass weighted sum of fishing mortality at age over the age range of A_L to A_U (see Mean Biomass above). This quantity may be useful for equilibrium comparisons with fishing mortality reference points developed from surplus production models. The computational formula for fishing mortality weighted by mean biomass is

$$F_{\overline{B}}(t) = \frac{\sum_{a=A_L}^{A_u} \overline{B}_a(t) \cdot F_a(t)}{\overline{B}(t)}$$

$$where\ \overline{B}_a(t) = W_{midyear,a}(t) \cdot N_a(t) \cdot \frac{(1 - \exp(-M_a(t) - F_a(t)))}{(M_a(t) + F_a(t))} \tag{49}$$

where $F_a(t)$ is the total fishing mortality on age-a fish calculated across all fleets.

Reference Point Thresholds

Feasible Simulations

A feasible simulation is defined as one where the all landings quotas by fleet can be harvested in each year of the projection time horizon. An infeasible simulation is one where the exploitable biomass is insufficient to harvest at least one landings quota in one or more years of the time horizon. All simulations are feasible for projections where population harvest is based solely on fishing mortality values. For projections that specify landings quotas by fleet in one or more years, the feasibility of harvesting the landings quota is evaluated using an upper bound on F that defines infeasible quotas relative to the exploitable biomass (Appendix). For purposes of summarizing projection results, the total number of simulations is denoted as K_{TOTAL} and the total number of feasible simulations is denoted as $K_{FEASIBLE}$.

Biomass Thresholds

The user can specify biomass thresholds for spawning biomass ($B_{S,THRESHOLD}$), mean biomass ($\overline{B}_{THRESHOLD}$), and total stock biomass ($B_{T,THRESHOLD}$) for Sustainable Fisheries Act (SFA) policy evaluation. These biomass thresholds can be specified using the input keyword REFPOINT (Tables 2 and 3). If the REFPOINT keyword is used in an AGEPRO model, then projected biomass values are compared to the input thresholds through time. Probabilities that biomasses meet or exceed threshold values are computed for each year. In addition, the probability that biomass thresholds were exceeded in at least one year within a single simulated population trajectory is computed. If the user specifies fishing mortality-based harvesting with no landings quotas, then the SFA-threshold probabilities are computed over the entire set of simulations. Let $K_B(t)$ be the number of times that projected biomass $B(t)$ meets or exceeds a threshold biomass $B_{THRESHOLD}$ in year t. The counter $K_B(t)$ is evaluated for each year and biomass series (spawning, mean, or total stock). Given that

K_{TOTAL} is the total number of feasible simulation runs, the estimate of the annual probability that $B_{THRESHOLD}$ would be met or exceeded in year t is

$$\Pr(B(t)) \geq B_{THRESHOLD} = \frac{K_B(t)}{K_{TOTAL}} \tag{50}$$

Note that this also provides an estimate of the probability of the complementary event that biomass does not exceed the threshold via

$$\Pr(B(t) < B_{THRESHOLD}) = 1 - \Pr(B(t) \geq B_{THRESHOLD}) = 1 - \frac{K_B(t)}{K_{TOTAL}} \tag{51}$$

Next, if $K_{THRESHOLD}$ denotes the number of simulations where biomass exceeded its threshold at least once, then the probability that $K_{THRESHOLD}$ would be met or exceeded at least

$$\Pr(\exists t \in [1, 2, \ldots, Y] \ \textit{such that} \ B(t) \geq B_{THRESHOLD}) = \frac{K_{THRESHOLD}}{K_{TOTAL}} \tag{52}$$

If the user specifies landings quota-based harvesting in one or more years, then the SFA-threshold probabilities can be computed over the set of feasible simulations. In this case, the year-specific conditional probability that $B_{THRESHOLD}$ would be met or exceeded for feasible simulations is

$$\Pr(B(t)) \geq B_{THRESHOLD} = \frac{K_B(t)}{K_{FEASIBLE}} \tag{53}$$

Note that the counter $K_B(t)$ can only be incremented in a feasible simulation. In contrast, the joint probability that $B_{THRESHOLD}$ would be met or exceeded for the entire set of simulations is given by (52) and the probability that $B_{THRESHOLD}$ would be met or exceeded at least once during the projection time horizon is given by (53).

Fishing Mortality Thresholds

The user can specify the fishing mortality rate threshold for annual total fishing mortality ($F_{THRESHOLD}$) calculated across all fleets using the keyword REFPOINT. In this case, projected total F values are compared to the $F_{THRESHOLD}$ through time. Probabilities that fishing mortalities exceed threshold values are computed for each year in the same manner as for biomass thresholds (see Biomass Thresholds). In particular, if $K_F(t)$ is the number of times that fishing mortality $F(t)$ exceeds the threshold fishing mortality $F_{THRESHOLD}$ in year t, then the annual probability that the fishing mortality threshold is exceeded is

$$\Pr(F(t) > F_{THRESHOLD}) = \frac{K_F(t)}{K_{TOTAL}} \tag{54}$$

and the complementary probability that the fishing mortality threshold is not exceeded is

$$\Pr(F(t) \leq F_{THRESHOLD}) = 1 - \frac{K_F(t)}{K_{TOTAL}} \tag{55}$$

Types of Projection Analyses

The AGEPRO module can perform three types of projection analyses. These are: standard, rebuilding and PStar projection analyses.

Standard Projection

The standard projection analysis is the most flexible and can be used to apply mixtures of quota and fishing mortality based harvest by multiple fleets to the age-structured population. For a standard projection, alternative models can be setup and evaluated using any of the keyword options (Tables 2 and 3) except the REBUILD keyword.

Rebuilding Projection

The rebuilding type of projection analysis is focused on the calculation of the constant total fishing mortality calculated across all fleets that will rebuild the population, denoted as $F_{REBUILD}$. In this case, the user needs to specify the target year (TargetYear, see keyword REBUILD in Table 3) in which the population is to be rebuilt, the target biomass value (TargetType), the type of biomass being rebuilt (TargetType, e.g., spawning stock biomass), and the target percentage for achieving the rebuilding target expressed in terms of the fraction of simulations that achieve the rebuilding target (TargetPercent). Note that in cases where the rebuilding target is not achievable, the summary output of the rebuilding analysis will report that the combined catch, total fishing mortality and landings distributions are zero throughout the projection time horizon. For a rebuilding projection, the user needs to specify an initial harvest scenario of total fishing mortality values by year using the keyword HARVEST. The value of $F_{REBUILD}$ will then be iteratively calculated and the model results will be reported for the projection using the calculated value of $F_{REBUILD}$. For a rebuilding projection, the model can be setup and evaluated using any of the keyword options (Tables 2 and 3) except the PSTAR keyword.

PStar Projection

The acronym PStar stands for the probability of exceeding the overfishing threshold in a target year. The PStar type of projection analysis is focused on the calculation of the total allowable catch TAC_{PStar} that will achieve the specified probability of overfishing in the target year. In this case, the user needs to specify the target year (**TargetYear**, see keyword PSTAR in Table 3) in which the total annual catch to achieve PStar is calculated, the number of PStar values to be evaluated (**KPStar**), the vector of probabilities of overfishing or PStar values to be used (**PStar**), and the fishing mortality rate that defines the overfishing level (**PStarF**. For a PSTAR projection, the model can be setup and evaluated using any of the keyword options (Tables 2 and 3) except the REBUILD keyword.

Part II

Age-Structured Projection Software

This section covers operational details for using the AGEPRO software and is organized into three sections. First, input data requirements and projection options are covered and the structure of an input file is described. Second, projection model outputs are described in relation to keywords in the input file and the structure of the standard output file is described. Third, a set of examples are provided to illustrate projection options and features of the software.

Input Data

There are four categories of input data for an AGEPRO projection run: system, simulation, biological, and fishery (Figure 2). The system data consists of the input filename and this information is read from standard input (e.g., from the command line or via the AGEPRO GUI). The simulation, biological and fishery data are read from the text input file and the associated text bootstrap file containing the initial population numbers at age data.

The AGEPRO input file is structured by keywords. Each keyword identifies a set of related inputs for the projection run in a single section of the input file (Table 2). The table of AGEPRO input keywords below lists the 23 possible keywords in the sequential order that the information is read into the program.

Each keyword specifies a projection model attribute and the associated set of inputs that are required to implement it (Table 3). This includes a detailed listing of the AGEPRO input file structure showing the sequence of inputs by keyword. Here the input data type is shown in parentheses, where the types are: **I=integer**, **S=string**, **F=floating point** (Table 3). For data that are input as an array, the array dimensions are listed in order as [0: Dimension1] [0: Dimension2] and so on (Table 3).

The system data consists of the input file name for the projection run (Figure 2). The input file name can be any text string with the file extension `inp`. For example, a valid input file name is `GB cod 2017 FMSY projection.inp`.

Within the input file, the simulation data are specified (Tables 2 and 3) within the keyword sections named: GENERAL, CASEID, BOOTSTRAP, RETROADJUST, BOUNDS, OPTIONS, SCALE, PERC, REFPOINT, REBUILD, and PSTAR.

The biological data are specified (Tables 2 and 3) within the keyword sections of the input file named: NATMORT, BIOLOGICAL, MATURITY, STOCK_WEIGHT, SSB_WEIGHT, MEAN_WEIGHT, and RECRUIT. The recruitment models are specified in the RECRUIT keyword section and the specific inputs needed for each recruitment model are listed in Table 4.

The fishery data are specified (Tables 2 and 3) within the keyword sections of the input file named: HARVEST, FISHERY, DISCARD, CATCH_WEIGHT, and DISC_WEIGHT.

To run the AGEPRO program using the AGEPRO GUI, do the following:

- Start the AGEPRO program (double left click on the program icon)
- Under the File menu tab, select either "Create a New Case" or "Select Existing AGEPRO Input Data File" to set the input data file For the selected input file, click on the Run menu tab and select "Launch AGEPRO model …".
- When the projection run is completed, the AGEPRO output files are written to a new folder. The new folder is created in the folder `~/Username/Documents/AGEPRO/New_Folder_Name` where the New_Folder_Name is the input data file name with the time stamp of the run appended to it.

To run the AGEPRO program from the command line, enter `agepro.exe inputfilename`. The software first checks whether the input file exists and will stop if the input file does not exist. If the input file exists and is successfully read, you will see the following output in the command line screen:

```
>agepro.exe inputfilename
> Bootstrap Iteration: 1
> Bootstrap Iteration: 2
...
> Bootstrap Iteration: NBootstrap
> Summary Reports …
```

Table 2: AGEPRO Keyword Parameters

Table 2: Table of AGEPRO input file keywords.

Keyword	Purpose
GENERAL	Input general model parameters
CASEID	Input title identifying model attributes
BOOTSTRAP	Input information for bootstrap numbers at age file
HARVEST	Input information for harvest intensity (F or Q) by fleet
RETROADJUST	Input information for retrospective bias adjustment
NATMORT	Input information for natural mortality rate (M) at age
BIOLOGICAL	Input information on seasonal spawning timing for F and M
MATURITY	Input information on maturity at age
STOCK_WEIGHT	Input information on stock weights (Jan 1^{st}) at age
SSB_WEIGHT	Input information on spawning biomass weights at age
MEAN_WEIGHT	Input information on mean weights at age
FISHERY	Input information on fishery selectivity at age by fleet
DISCARD	Input information on discard fraction of numbers at age
CATCH_WEIGHT	Input information on catch weights at age
DISC_WEIGHT	Input information on discard weights at age
RECRUIT	Input information on recruitment model
BOUNDS	Input bounds on simulated fish weights and natural mortality rates
OPTIONS	Input information on projection output
SCALE	Input information on scaling factors for biomass, recruitment, and stock size
PERC	Input information for setting a specific percentile for the distributions of outputs
REFPOINT	Input information for reference points
REBUILD	Input information for calculating F to rebuild spawning biomass

Keyword	Purpose
PSTAR	Input information for calculating TAC to produce $P*$ which is the probability of overfishing in the target projection year.

Table 3: AGEPRO Keyword structure

Table 3: Structure of AGEPRO VERSION 4.25 input file by keyword.

Keyword	Input Variable
`GENERAL`	1. **NFyear** (I) - this is the first year of the projection 2. **NXYear** (I) - this is the last year of the projection 3. **NFAge** (I) – this is the first age in the population model 4. **NXAge** (I) – this is the plus-group age in the population model 5. **NSims** (I) – this is the number of simulations to conduct for each bootstrap replicate of initial population size 6. **NFleet** (I) – this is the number of fleets in the harvest model 7. **NRecModel** (I) – this is the number of recruitment submodels in the population model 8. **DiscFlag** (I) – this is a logical flag to indicate whether discards are included in the harvest model (1=true, 0=false) 9. **ISeed** (I) – this is a positive integer seed to initialize the random number generator
`CASEID`	1. **Model** (S) – this is a string that describes the projection model run
`BOOTSTRAP`	1. **NBoot** (I)- this is the number of bootstrap replicates of initial population size 2. **BootFac** (F) – this is the multiplicative factor to convert the relative bootstrap population numbers at age to absolute numbers at age 3. **BootFile** (S) – this is the name of the bootstrap filename including the file path

Keyword	Input Variable
`HARVEST`	1. **HarvestSpec** [0:NYears-1] (F) – this is the harvest specification by year vector where an input of zero indicates an F-based harvest rate and any positive input indicates a quota-based harvest rate (that is, input=0 for F and input>0 for catch biomass) 2. **HarvestValue** [0:NYears-1][0:Nfleet-1] (F) – this is the harvest amount by year and fleet array where an input row is the set of annual F values or catches (in metric tons) depending on the harvest specification by year.
`RETROADJUST`	1. **RetroAdjust** [0:NAges-1] (F) – this is the vector of age-specific numbers at age multipliers for an initial population size at age vector if retrospective bias adjustment is applied
`NATMORT`	1. **NatMortFlag** (I) – this is the logical flag that indicates if the average natural mortality rate at age vector is to be read from an existing data file (input=1) or not (input) 2. **NatMortTimeFlag** (I) – this is the logical flag that indicates if the average natural mortality rate at age vector is a time-varying array (input =1) ordered by year (row) and age (column); otherwise the average natural mortality rate at age vector does not vary by year 3. • If (**NatMortFlag** = 1) then read **DataFiles**[*] (S) • Else if (**NatMortTimeFlag** = 1) then Read **AvgNatMort**[0:NAges-1][0:NYears-1] (F) • Else Read **AvgNatMort**[0:NAges-1][0] (F) - This is the logic for the average natural mortality rate at age vector inputs 4. **NatMortErr**[0:NAges-1] (F) This is the vector of age-specific CVs for sampling the natural mortality rate at age vector with lognormal process error

<table>
<tr><th>Keyword</th><th>Input Variable</th></tr>
<tr><td><code>BIOLOGICAL</code></td><td>
1. ZFracTimeFlag (I) – this is the logical flag that indicates if the within-year fractions of fishing (TF) and natural (TM) mortality that occur from January 1^{st} to the spawning season are a time-varying array (input =1) or constant values (input 1) where 0 TF 1 and 0 TM 1. For example, if the spawning season begins in July and input=0 then TF=TM=½

2. • If (ZFracTimeFlag = 1) then read TF[0:NYears-1] (F) and read TM[0:NYears-1] (F)
• Else read TF (F) and read TM (F)
</td></tr>
<tr><td><code>MATURITY</code></td><td>
1. MaturityFlag (I) – this is the logical flag that indicates if the average fraction mature at age vector is to be read from an existing data file (input =1) or not (input 1)

2. MaturityTimeFlag (I) – this is the logical flag that indicates if the average fraction mature at age vector is a time-varying array (input =1) ordered by year (row) and age (column); otherwise the average fraction mature at age vector does not vary by year.

3. • If (MaturityFlag = 1) then read DataFiles[*] (S)
• Else if (MaturityTimeFlag = 1) then read AvgMaturity [0:NAges-1][0:NYears-1] (F)
• Else read AvgMaturity[0:NAges-1][0] (F))

- this is the logic for the average fraction mature at age vector inputs

4. MaturityErr[0:NAges-1] (F) – this is the vector of age-specific CVs for sampling the fraction mature at age vector with lognormal process error
</td></tr>
</table>

Keyword	Input Variable
`STOCK_WEIGHT`	1. **StockWtFlag** (I) – this is the logical flag that indicates if the average stock weight at age vector is to be read from an existing data file (input =1) or not (input 1) 2. **StockWtTimeFlag** (I) – this is the logical flag that indicates if the average stock weight at age vector is a time-varying array (input =1) ordered by year (row) and age (column); otherwise the average stock weight at age vector does not vary by year 3. • If (**StockWtFlag** = 1) then read **DataFiles**[*] (S) • Else if (**StockWtTimeFlag** = 1) then read **AvgStockWeight** [0:NAges-1][0:NYears-1] (F) • Else read **AvgStockWeight** [0:NAges-1][0] (F)) - this is the logic for the average stock weight at age vector inputs| 4. **StockWtErr**[0:NAges-1] (F) – this is the vector of age-specific CVs for sampling the stock weight at age vector with lognormal process error

Keyword	Input Variable
SSB_WEIGHT	1. **SpawnWtFlag** (I) – this is the logical flag that indicates if the average spawning weight at age vector is to be read from an existing data file (input>0) or to be read from the input file (input=0) or to be set equal to the average stock weight at age vector (input=-1) 2. **SpawnWtTimeFlag** (I) – this is the logical flag that indicates if the average spawning weight at age vector is a time-varying array (input =1) ordered by year (row) and age (column); otherwise the average spawning weight at age vector does not vary by year 3. • If (**SpawnWtFlag** >0) then read **DataFiles**[*] (S) • Else if (**SpawnWtFlag** = -1) then set average spawning weight at age vector to equal the average stock weight at age vector • Else if (**SpawnWtTimeFlag** = 1) then read **AvgSpawnWeight** [0:NAges-1][0:NYears-1] (F) • Else read **AvgSpawnWeight** [0:NAges-1][0] (F) – this is the logic for the average spawning weight at age vector inputs 4. **SpawnWtErr**[0:NAges-1] (F) – this is the vector of age-specific CVs for sampling the spawning weight at age vector with lognormal process error

Keyword	Input Variable
MEAN_WEIGHT	1. **MeanStockWtFlag** (I) – this is the logical flag that indicates if the average mean weight at age vector is to be read from an existing data file (input>0) or not (input=0) 2. **MeanStockWtTimeFlag** (I) – this is the logical flag that indicates if the average mean weight at age vector is a time-varying array (input=1) ordered by year (row) and age (column); otherwise the average mean weight at age vector does not vary by year 3. • If (**MeanStockWtFlag** >0) then read **DataFiles**[*] (S) • Else if (**MeanStockWtTimeFlag** = 0) then read **AvgMeanStockWeight** [0:NAges-1][0:NYears-1] (F) • Else read **AvgMeanStockWeight** [0:NAges-1][0] (F) – this is the logic for the average mean weight at age vector inputs 4. **MeanStockWtErr**[0:NAges-1] (F) – this is the vector of age-specific CVs for sampling the mean weight at age vector with lognormal process error

Keyword	Input Variable
`FISHERY`	1. **FSelecFlag** (I) – this is the logical flag that indicates if the average fishery selectivity at age vectors by fleet are to be read from an existing data file (input=1) or not (input 1) 2. **FSelecTimeFlag** (I) – this is the logical flag that indicates if the average fishery selectivity at age vectors by fleet are a time-varying array (input=1) ordered by fleet (index 1), year (index 2), and age (index 3); otherwise the average fishery selectivity at age vectors by fleet do not vary by year 3. • If (**FSelecFlag** = 1) then read **DataFiles**[*] (S) • Else if (**FSelecTimeFlag** = 1) then read **AvgFSelec** [0:NAges-1][0:NYears-1][0:NFleets-1] (F) • Else read **AvgFSelec**[0:NAges-1][0][0:NFleets-1] (F) – this is the logic for the average fishery selectivity at age vectors by fleet inputs 4. **FSelecErr**[0:NAges-1][0:NFleets-1] (F) – this is the array of age-specific and fleet-specific CVs for sampling the fishery selectivity at age vectors by fleet with lognormal process error

Keyword	Input Variable
`DISCARD`	1. **DiscFracFlag** (I) – this is the logical flag that indicates if the average discard fraction at age vectors by fleet are to be read from an existing data file (input=1) or not (input 1) 2. **DiscFracTimeFlag** (I) – this is the logical flag that indicates if the average discard fraction at age vectors by fleet are a time-varying array (input =1) ordered by fleet (index 1), year (index 2), and age (index 3); otherwise the average discard fraction at age vectors by fleet do not vary by year 3. • If (**DiscFracFlag** = 1) then read **DataFiles**[*] (S) • Else if (**DiscFracTimeFlag** = 1) then read **AvgDiscFrac** [0:NAges-1][0:NYears-1][0:NFleets-1] (F) • Else read **AvgDiscFrac**[0:NAges-1][0][0:NFleets-1] (F) – this is the logic for the average discard fraction at age vectors by fleet inputs 4. **DiscFracErr**[0:NAges-1][0:NFleets-1] (F) – this is the array of age-specific and fleet-specific CVs for sampling the discard fraction at age vectors by fleet with lognormal process error

Keyword	Input Variable
`CATCH_WEIGHT`	1. • **CatchWtFlag** (I) – this is the logical flag that indicates if the average catch weight at age vectors by fleet are to be read from an existing data file (input>0) • or to be read from the input file (input=0) • or to be set equal to the average stock weight at age vector (input=-1) • or to be set equal to the average spawning weight at age vector (input=-2) • or to be set equal to the average mean weight at age vector (input=-3) 2. **CatchWtTimeFlag** (I) – this is the logical flag that indicates if the average catch weight at age vectors by fleet are a time-varying array (input =1) ordered by fleet (index 1), year (index 2), and age (index 3); otherwise the average catch weight at age vectors by fleet do not vary by year 3. • If (**CatchWtFlag** >0) then read **DataFiles**[*] (S) • Else if (**CatchWtFlag** = -1) then set average catch weight at age vector to equal the average stock weight at age vector • Else if (**CatchWtFlag** = -2) then set average catch weight at age vector to equal the average spawning weight at age vector • Else if (**CatchWtFlag** = -3) then set average catch weight at age vector to equal the average mean weight at age vector • Else if (**CatchWtTimeFlag** = 0) then read **AvgCatchWeight** [0:NAges-1][0:NYears-1][0:NFleets-1] (F) • Else read **AvgCatchWeight**[0:NAges-1][0][0:NFleets-1] (F) – this is the logic for the average catch weight at age vector inputs 4. **CatchWtErr**[0:NAges-1][0:NFleets-1] (F) – this is the array of age-specific and fleet-specific CVs for sampling the catch weight at age vectors by fleet with lognormal process error

Keyword	Input Variable
`DISC_WEIGHT`	1. • **DiscWtFlag** (I) – this is the logical flag that indicates if the average discard weight at age vectors by fleet are to be read from an existing data file (input>0) • or to be read from the input file (input =0) • or to be set equal to the average stock weight at age vector (input=-1) • or to be set equal to the average spawning weight at age vector (input=-2) • or to be set equal to the average mean weight at age vector (input=-3) • or to be set equal to the average catch weight at age vector (input=-4) 2. **DiscWtTimeFlag** (I)) – this is the logical flag that indicates if the average discard weight at age vectors by fleet are a time-varying array (input =1) ordered by fleet (index 1), year (index 2), and age (index 3); otherwise the average discard weight at age vectors by fleet do not vary by year 3. • If (**DiscWtFlag** = 1) then read **DataFiles**[*] (S) • Else if (**DiscWtFlag** = -1) then set average discard weight at age vector to equal the average stock weight at age vector • Else if (**DiscWtFlag** = -2) then set average discard weight at age vector to equal the average spawning weight at age vector • Else if (**DiscWtFlag** = -3) then set average discard weight at age vector to equal the average mean weight at age vector • Else if (**DiscWtFlag** = -4) then set average discard weight at age vector to equal the average catch weight at age vector • Else if (**DiscWtTimeFlag** = 1) then read **AvgDiscWeight** [0:NAges-1][0:NYears-1][0:NFleets-1] (F) • Else read **AvgDiscWeight**[0:NAges-1][0][0:NFleets-1] (F) – this is the logic for the average discard weight at age vector inputs 4. **DiscWtErr**[0:NAges-1][0:NFleets-1] (F) – this is the array of age-specific and fleet-specific CVs for sampling the discard weight at age vectors by fleet with lognormal process error

Keyword	Input Variable
`RECRUIT`	1. **RecFac** (F) – this is the multiplier to convert recruitment submodel units for recruitment to absolute numbers of fish 2. **SSBFac** (F) – this is the multiplier to convert recruitment submodel units for spawning biomass to absolute spawning weight of fish in kilograms 3. **MaxRecObs** (I) – this is the maximum number of recruitment observations for an empirical recruitment submodel (up to the maximum value of a long int, or about 2 billion array elements) 4. **RecruitType**[0:NRecModel-1] (I) – this is the vector of recruitment submodel types in the projection 5. **RecruitProb**[0:NYears-1][0:NRecModel-1] (F) – this is the array of recruitment submodel probabilities ordered by year (row) and submodel (column) with row sums equal to unity 6. For J=0 to (NRecModel – 1) Call **ReadRecruitModelInput**(J,[RecruitType[J]) – this is the set of function calls to read in the input data needed for each recruitment submodel in the order they are specified in RecruitType where the required input data for each submodel are listed in Table 4.
`BOUNDS`	1. **MaxWeight** (F) – this is the maximum value of an fish weight, noting that there is lognormal sampling variation for weight at age values 2. **MaxNatMort** (F) – this is the maximum natural mortality rate, noting that there is lognormal sampling variation for natural mortality at age values
`PERC`	1. **PercReportValue** (F) – this is the user-selected percentile for reporting the percentile of the projected distribution of the following by year: spawning stock biomass, stock biomass on January 1^{st}, mean biomass, combined catch biomass, landings, fishing mortality, and stock numbers at age
`REFPOINT`	1. **SSBThresh** (F) – this is the spawning biomass threshold expressed in biomass output units 2. **StockBioThresh** (F) – this is the stock biomass threshold expressed in biomass output units 3. **MeanBioThresh** (F) – this is the mean biomass threshold expressed in biomass output units 4. **FMortThresh** (F) – this is the fishing mortality threshold

Keyword	Input Variable
OPTIONS	1. **StockSummaryFlag** (I) – this is the logical flag to output stock summary information • I=0: No stock summary or auxiliary files • I=1. Stock summary in output file and no auxiliary files • I=2. Stock summary in output file and auxiliary files 2 through 10 are produced • I=3. Stock summary in output file and all auxiliary files are produced 2. **DataFlag** (I) – this is the logical flag to output population and fishery processes simulated with lognormal process error to auxiliary output files 3. **ExportRFlag** (I) – this is the logical flag to output projection results to an R dataframe
SCALE	1. **scalebio** (F) – the output units of biomass expressed in thousand metric tons 2. **scalerec** (F) – the output units of recruitment numbers 3. **scalestk** (F) – the output units of stock size numbers
REBUILD	1. **TargetYear** (I) – this is the user-selected target year for rebuilding to the target value 2. **TargetValue** (F) – this is the target biomass value in units of thousands of metric tons 3. **TargetType** (I) – this is the index for the type of population biomass as the target where index=0 is spawning stock biomass, index=1 is stock biomass on January 1st, else target is mean biomass 4. **TargetPercent** (F) – this is the percent frequency of achieving the target value by the target year where the percent frequency is a value between 0 (indicating zero chance of achieving target) and 100 (indicating 100 percent chance of achieving target).

Table 4: Input data structure for AGEPRO Recruitment Models

Table 4: Required input data for AGEPRO recruitment models, where spawning biomass and recruitment inputs are measured in units of `RECRUIT` the conversion factors **SSBFac** and **RecFac** respectively, which typically have units of **SSBFac**=**RecFac**=1000.

Model Number	Recruitment Model	Recruitment Model Input Description
1	Markov Matrix	• Input the number of Recruitment States: K • On the next line, input the recruitment values: $R_1, R_2, ..., R_K$ • On the next line, input number of spawning biomass states: J • On the next line, input $J-1$ cut points : $B_{S,1}, B_{S,2}, ..., B_{S,J-1}$ • On the next J lines, input the conditional recruitment probabilities for the spawning biomass states: – $\begin{matrix} P_{1,1}, & P_{1,2}, & \dots, & P_{1,K} \\ P_{2,1}, & P_{2,2}, & \dots, & P_{2,k} \\ \vdots & \vdots & \vdots & \vdots \\ P_{J,1}, & P_{J,2}, & \dots, & P_{J,K} \end{matrix}$

Model Number	Recruitment Model	Recruitment Model Input Description
2	Empirical Recruits Per Spawning Biomass Distribution	• Input the number of stock recruitment data points: T • On the next line, input the recruitments: $R_1, R_2, ..., R_T$ • On the next line, input the spawning biomasses: $B_{S,1}, B_{S,2}, ..., B_{S,T}$
3	Empirical Recruitment Distribution	• Input the number of recruitment data points: T • On the next line, input the recruitments: $R_1, R_2, ..., R_T$
4	Two-Stage Empirical Recruits Per Spawning Biomass Distribution	• Input the number of low and high recruits per spawning biomass data points: $T_{Low} \cdot T_{High}$ • On the next line, input the cutoff level of spawning biomass: B_S^* • On the next line, input the low state recruitments: $R_1, R_2, ..., R_{T_{Low}}$ • On the next line, input the low state spawning biomasses: $B_{S,1}, B_{S,2}, ..., B_{S,T_{Low}}$ • On the next line, input the high state recruitments: $R_1, R_2, ..., R_{T_{High}}$ • On the next line, input the high state spawning biomasses: $B_{S,1}, B_{S,2}, ..., B_{S,T_{High}}$
5	Beverton-Holt Curve with Lognormal Error	• Input the stock-recruitment parameters: $\alpha, \beta, \sigma_w^2$
6	Ricker Curve with Lognormal Error	• Input the stock-recruitment parameters: $\alpha, \beta, \sigma_w^2$
7	Shepherd Curve with Lognormal Error	• Input the stock-recruitment parameters: $\alpha, \beta, k, \sigma_w^2$
8	Lognormal Distribution	• Input the log-scale mean and standard deviation: $\mu_{\log(r)}, \sigma_{\log(r)}$
10	Beverton-Holt Curve with Autocorrected Lognornal Error	• Input the stock-recruitment parameters: $\alpha, \beta, \sigma_w^2$ • On the next line, input the autoregressive parameters: ϕ, ε_0

Model Number	Recruitment Model	Recruitment Model Input Description
11	Ricker Curve with Autocorrected Lognormal Error	• Input the stock-recruitment parameters: $\alpha, \beta, \sigma_w^2$ • On the next line, input the autoregressive parameters: ϕ, ε_0
12	Shepherd Curve with Autocorrected Lognormal Error	• Input the stock-recruitment parameters: $\alpha, \beta, k, \sigma_w^2$ • On the next line, input the autoregressive parameters: ϕ, ε_0
13	Autocorrected Lognormal Distribution	• Input the log-scale mean and standard deviation: $\mu_{\log(r)}, \sigma_{\log(r)}$ • On the next line, input the autoregressive parameters: ϕ, ε_0
14	Empirical Cumulative Distribution Function of Recruitment	• Input the number of recruitment data points: T • On the next line, input the recruitments $R_1, R_2, ..., R_T$
15	Two-Stage Empirical Cumulative Distribution Function of Recruitment	• Input the number of low and high recruits per spawning biomass data points: $T_{Low} \cdot T_{High}$ • On the next line, input cutoff level of spawning biomass: B_S^* • On the next line, input the low state recruitments: $R_1, R_2, ..., R_{T_{Low}}$ • On the next line, input the high state recruitments: $R_1, R_2, ..., R_{T_{High}}$
16	Linear Recruits Per Spawning Biomass Predictor with Normal Error	• Input the predictors: N_P • On the next line, input the intercept coefficient: β_0 • On the next line, input the slope coefficient for each predictor: $\beta_1, \beta_2, ..., \beta_{N_p}$ • On the next line, input the error variance: σ^2 • On the next N_P lines, input the expected value of the predictor through projection time horizon: – $\begin{matrix} X_1(1), & ..., & X_1(Y) \\ X_2(1), & ..., & X_2(Y) \\ \vdots & \vdots & \vdots \\ X_P(1), & ..., & X_P(Y) \end{matrix}$

Model Number	Recruitment Model	Recruitment Model Input Description
17	Linear Recruits Per Spawning Biomass Predictor with Lognormal Error	• Input the number of predictors: N_P • On the next line, input the intercept: β_0 • On the next line, input the linear coefficient for each predictor: $\beta_1, \beta_2, ..., \beta_{N_P}$ • On the next line, input the log-scale error variance: σ^2 • And on the next N_P lines, input the expected predictor values over the forecast time horizon $1, ..., Y$ – $\begin{matrix} X_1(1) & X_1(2) & ... & X_1(Y) \\ X_2(1) & X_2(2) & ... & X_2(Y) \\ \vdots & \vdots & \vdots & \vdots \\ X_P(1) & X_P(2) & ... & X_P(Y) \end{matrix}$
18	Linear Recruitment Predictor with Normal Error	• Input the number of predictors: N_P • On the next line, input the intercept: β_0 • On the next line, input the linear coefficient for each predictor: $\beta_1, \beta_2, ..., \beta_{N_P}$ • On the next line, input the error variance: σ^2 • And on the next N_P lines, input the expected predictor values over the forecast time horizon $1, ..., Y$ – $\begin{matrix} X_1(1) & X_1(2) & ... & X_1(Y) \\ X_2(1) & X_2(2) & ... & X_2(Y) \\ \vdots & \vdots & \vdots & \vdots \\ X_P(1) & X_P(2) & ... & X_P(Y) \end{matrix}$
19	Loglinear Recruitment Predictor with Lognormal Error	• Input the number of predictors: N_P • On the next line, input the intercept: β_0 • On the next line, input the linear coefficient for each predictor: $\beta_1, \beta_2, ..., \beta_{N_P}$ • On the next line, input the log-scale error variance: σ^2 • And on the next N_P lines, input the expected predictor values over the forecast time horizon $1, ..., Y$ – $\begin{matrix} X_1(1) & X_1(2) & ... & X_1(Y) \\ X_2(1) & X_2(2) & ... & X_2(Y) \\ \vdots & \vdots & \vdots & \vdots \\ X_P(1) & X_P(2) & ... & X_P(Y) \end{matrix}$

Model Number	Recruitment Model	Recruitment Model Input Description
20	Fixed Recruitment	• Input the number of recruitment data points: T • On the next line, input the Recruitments: $R_1, R_2, ..., R_T$
21	Empirical Cumulative Distribution Function of Recruitment with Linear Decline to Zero	• Input the number of number of observed recruitment values: T • On the next line, input the recruitment values: $R_1, R_2, ..., R_T$ • And on the next line, input spawning biomass threshold: B_S^*

Model Outputs

An AGEPRO model run creates a standard output file that summarizes the projection analysis results (Figure 2). The model will also create a set of files containing the raw output results for key quantities of interest. The user also has the option of creating output files for the simulated process error data for documentation and the option of creating an R export file that stores the projections results in an R language dataframe.

There are nine categories of output in the standard output file. The first output describes the setup of the AGEPRO model and lists the input and bootstrap file names and the recruitment models and associated model probabilities. The second output shows the input harvest scenario in terms of quotas or fishing mortality rates by year and fleet. The third output shows the realized distribution of recruitment through time. The fourth output shows the realized distribution of spawning stock biomass through time. The fifth output shows the realized distribution of total stock biomass on January 1st through time. The sixth output shows the realized distribution of mean biomass through time. The seventh output shows the realized distribution of combined catch biomass across fleets through time. The eighth output shows the realized distribution of landings through time. The ninth output shows the realized distribution of total fishing mortality through time. In addition, if the user has setup REBUILD or PSTAR projection analyses, then the results of those analyses will also be listed in the standard output file.

The user may also select to produce output file summaries of auxiliary projection results and of the distribution of population size at age by year. This is done by setting the value of the StockSummaryFlag under the keyword OPTIONS in the input file (Table 3). There are four output options for StockSummaryFlag:

- StockSummaryFlag = 0. This is the terse output option which removes the auxiliary files and does not produce a population size at age file summary.
- StockSummaryFlag = 1. This option removes the auxiliary files, produces a population size at age summary in the output file, but does produce a population size at age file summary.
- StockSummaryFlag = 2. This option retains the auxiliary files, produces a population size at age summary in the output file, but does not produce

a population size at age file summary.
- StockSummaryFlag = 0. This is the verbose output option which retains the auxiliary files and produces a population size at age file summary.

The population size at age summary is output to a new file with the name inputfilename.xx1, where inputfilename is the name of the AGEPRO input file for the model. Note choosing to output the population size at age summary will typically produce a large file inputfilename.xx1 requiring on the order of 100Mb of storage. The auxiliary output files are needed for producing the summary of projection results in the projection output file. These files were automatically output in previous versions of AGEPRO but the user can now remove these files using the StockFlagSummary setting of "0" or "1" above.

The user may also select to produce a percentile summary of the key results in the outputfile. This is done by using the keyword PERC in the input file (Tables 2 and 3). The user may also select to store age-specific population and fisheries process error simulation results in auxiliary output files. This is done by setting the DataFlag=1 under the keyword OPTIONS in the input file (Table 3). Setting the DataFlag makes it possible to replicate a a projection run with the same random draws for setting population and fishery processes. The simulated process error data can include the following age-specific information, depending on the projection model setup: natural mortality at age, maturity fraction at age, stock weight on January 1st at age, spawning stock weight at age, mean population weight at age, fishery selectivity at age, discard fraction at age, catch weight at age and discard weight at age

The AGEPRO model will create auxiliary output data files to store simulated trajectories of recruitment, spawning biomass, total stock biomass on January 1st, mean biomass, combined catch biomass, landings, discards, and fishing mortality as well as catch by fleet if there is more than one fleet in the projection. This auxiliary output data can be used to characterize the distribution of these key outputs through time. One auxiliary file is created for each the outputs used in the projection model. The auxiliary output data files with names set to the projection inputfilename with an extension "xx#" are:

1. Stock numbers at age summary on January 1st: `inputfilename.xx1` see note 1
2. Recruitment: `inputfilename.xx2`
3. Spawning Stock Biomass: `inputfilename.xx3`
4. Total Stock Biomass on January 1st: `inputfilename.xx4`
5. Mean Biomass: `inputfilename.xx5`
6. Combined Catch Biomass: `inputfilename.xx6`
7. Landings: `inputfilename.xx7`
8. Discards: `inputfilename.xx8`
9. Fishing Mortality: `inputfilename.xx9`
10. Catch by Fleet: `inputfilename.xx10`

Note 1

Note that the stock numbers at age auxiliary file is created only if StockSummaryFlag=3.

The auxiliary output data files have similar file structures. In the stock numbers at age summary file each row represent the numbers at age (from age-1 to age-A) by year for each bootstrap-simulation block of Y rows. The auxiliary stock numbers at age output file will have a total number of rows equal to the number of bootstraps times the number of simulations per bootstrap.

For auxiliary output files 2 through 9, each row represents a single bootstrap-simulation combination and stores the simulated time trajectory of the output quantity with Y entries ordered from time $t = 1$ to time $t = Y$. Within each file, the projection trajectories are blocked by the bootstrap population vector and then the set of simulations for that bootstrap vector. For example, if $B_S^{[b,k]}(t)$ denotes the spawning biomass in year t simulated from the b^{th} initial population vector and the k^{th} simulation for that vector, then the output file for spawning biomass with B initial bootstrap vectors and K simulations would have $B \cdot K$ rows that were ordered as

$$\begin{bmatrix} B_S^{[1,1]}(1) & B_S^{[1,1]}(2) & ... & B_S^{[1,1]}(Y) \\ B_S^{[1,2]}(1) & B_S^{[1,2]}(2) & ... & B_S^{[1,2]}(Y) \\ \vdots & \vdots & \vdots & \vdots \\ B_S^{[B,K]}(1) & B_S^{[B,K]}(2) & ... & B_s^{[B,K]}(Y) \end{bmatrix} \tag{56}$$

For the catch by fleet summary file, each block of four consecutive tows represents the time series of fishing mortality, catch biomass, landed biomass and discard biomass by fleet. If there are N fleets, then there are $4N$ rows per bootstrap-simulation combination. These N blocks of four rows have the same ordering as the input fleet data, fleet 1, followed by fleet 2 and so on. Overall, the catch by fleet summary fleet has $4N \cdot B \cdot K$ rows.

The units of the entries of the auxiliary output files are similar. The output units of the stock numbers at age and the recruitment files are numbers of fish. The output units of the spawning biomass, total stock biomass, mean biomass, combined catch biomass, landings, and discards files are metric tons. The units of the F summary file are the total annual instantaneous fishing mortality rate calculated across all fleets. The output units of the catch by fleet file are the annual instantaneous fishing mortality rates by fleet, and the catch, landings and discard biomasses by fleet in metric tons.

AGEPRO Projection Examples

The following set of examples is provided to illustrate projection options and features of the software. These projections use actual fishery data but are for the purposes of illustration only.

Example 1

The first example is a fishing mortality and landings quota projection for Acadian redfish. The time horizon is 2004-2009. The fishery is comprised of two fleets that have identical fishing mortality rates in 2004, identical quotas in 2005, and fishing mortality rates that differ by 2-fold during 2006-2009. This is standard projection analysis with 1000 bootstraps and 100 simulations per bootstrap based on an ADAPT-VPA stock assessment analysis. The model also outputs an R dataframe.

Running example 1 (see Appendix for input file) produces the following output:

```
AGEPRO VERSION 4.2

REDFISH - RECRUITMENT MODEL 14

Date & Time of Run: 29 Dec 2017  13:59

Input File Name:    C:\Users\Jon.Brodziak\Documents\AGEPRO\Example1_2017-12-29_13-58-58\E

First Age Class:                        1
Number of Age Classes:                 26
Number of Years in Projection:          6
Number of Fleets:                       2
Number of Recruitment Models:           1
Number of Bootstraps:                1000
```

```
Number of Simulations:                100

Bootstrap File Name:           C:\Users\Jon.Brodziak\Documents\AGEPRO\Example1_2017-12-2

Number of Feasible Solutions:     100000  of     100000 Realizations

Input Harvest Scenario

Year  Type        Fleet-1    Fleet-2

2004  F-Mult       0.0024     0.0024
2005  Landings        350        350
2006  F-Mult       0.0100     0.0200
2007  F-Mult       0.0100     0.0200
2008  F-Mult       0.0100     0.0200
2009  F-Mult       0.0100     0.0200

Recruits     1000000  Fish

Year Class   Average       StdDev
2004         40.1044      48.2427
2005         39.9399      48.4981
2006         40.2597      48.6950
2007         39.9988      48.2832
2008         39.7856      47.8594
2009         39.9688      48.3182

Recruits Distribution

Year Class 1%         5%         10%        25%        50%        75%        90%        9
2004      1.6349     2.0914     2.5542     6.4615    29.3437    62.2498    77.8929    90.2
2005      1.6336     2.0901     2.5512     6.4411    29.2167    60.7815    77.8458    90.3
2006      1.6339     2.0818     2.5503     6.4087    29.2849    62.5382    78.0184    90.7
2007      1.6350     2.0884     2.5535     6.4762    29.2302    61.9145    77.9858    90.5
2008      1.6291     2.0739     2.5581     6.5566    29.2446    60.6213    77.7622    89.1
2009      1.6344     2.0814     2.5486     6.3915    29.2240    61.4137    77.9242    90.3

Spawning Stock Biomass  x       1000 MT

Year       Average        StdDev
2004      175.6964        4.2235
2005      192.3968        5.2539
2006      201.4634        6.0700
2007      207.9323        6.4531
```

2008	213.1455	6.8011
2009	215.0860	7.3413

Spawning Stock Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	
2004	165.8676	168.7638	170.1585	172.7614	175.8218	178.5690	180.8508	182.8
2005	179.8766	183.7197	185.6327	188.7590	192.5027	195.8383	198.9160	201.2
2006	187.0135	191.4990	193.8062	197.3170	201.4796	205.3871	209.1779	211.8
2007	192.7856	197.3545	199.8073	203.5527	207.8812	212.1478	216.2523	218.9
2008	197.3263	201.9852	204.6063	208.5499	213.0613	217.5741	221.9399	224.8
2009	198.4668	203.2224	205.9017	210.1353	214.9276	219.7958	224.6939	227.6

JAN-1 Stock Biomass x 1000 MT

Year	Average	StdDev
2004	200.4105	5.4728
2005	211.6190	6.0268
2006	219.0101	6.6628
2007	224.8245	7.3809
2008	230.5534	8.6653
2009	233.1329	10.5266

JAN-1 Stock Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2004	187.3186	191.4205	193.6011	196.6419	200.3894	203.9891	207.4034	209.8
2005	197.4892	201.7822	204.0521	207.4953	211.5906	215.5423	219.3350	222.0
2006	203.4717	208.0624	210.6302	214.5143	218.9420	223.3492	227.6193	230.4
2007	208.3844	213.0947	215.5979	219.8570	224.5975	229.4958	234.4669	237.6
2008	212.2717	217.3223	220.0521	224.7293	230.0136	235.7004	241.6218	245.6
2009	212.1537	217.8630	220.8943	226.1200	232.1722	238.8682	246.3096	251.9

Mean Biomass x 1000 MT

Year	Average	StdDev
2004	195.1458	5.3333
2005	206.0696	5.8806
2006	211.4024	6.4287
2007	216.9493	7.1218
2008	222.4861	8.3790
2009	225.0471	10.1991

Mean Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2004	182.4411	186.3680	188.4693	191.4729	195.1343	198.6408	201.9259	204.3
2005	192.2976	196.4658	198.6699	202.0527	206.0414	209.8959	213.5926	216.1
2006	196.4374	200.8584	203.3081	207.0736	211.3400	215.5932	219.6988	222.4
2007	201.0939	205.6560	208.0465	212.1518	216.7343	221.4392	226.2450	229.2
2008	204.8011	209.7117	212.3378	216.8668	221.9600	227.4532	233.1969	237.0
2009	204.7867	210.2699	213.1971	218.2598	224.1077	230.5910	237.8015	243.2

Combined Catch Biomass x 1000 MT

Year	Average	StdDev
2004	0.6798	0.0165
2005	0.7000	0.0000
2006	4.4690	0.1527
2007	4.7193	0.1773
2008	4.8199	0.1837
2009	4.7281	0.1781

Combined Catch Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2004	0.6412	0.6528	0.6582	0.6686	0.6804	0.6910	0.6998	0.7
2005	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7
2006	4.1055	4.2163	4.2773	4.3641	4.4707	4.5678	4.6673	4.7
2007	4.2937	4.4271	4.4985	4.5986	4.7187	4.8331	4.9489	5.0
2008	4.4001	4.5202	4.5918	4.6971	4.8173	4.9389	5.0572	5.1
2009	4.3327	4.4380	4.5063	4.6087	4.7229	4.8433	4.9632	5.0

Landings x 1000 MT

Year	Average	StdDev
2004	0.6798	0.0165
2005	0.7000	0.0000
2006	4.4690	0.1527
2007	4.7193	0.1773
2008	4.8199	0.1837
2009	4.7281	0.1781

Landings Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2004	0.6412	0.6528	0.6582	0.6686	0.6804	0.6910	0.6998	0.7
2005	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7
2006	4.1055	4.2163	4.2773	4.3641	4.4707	4.5678	4.6673	4.7

2007	4.2937	4.4271	4.4985	4.5986	4.7187	4.8331	4.9489	5.0
2008	4.4001	4.5202	4.5918	4.6971	4.8173	4.9389	5.0572	5.1
2009	4.3327	4.4380	4.5063	4.6087	4.7229	4.8433	4.9632	5.0

Total Fishing Mortality

Year	Average	StdDev
2004	0.0048	0.0000
2005	0.0048	0.0001
2006	0.0300	0.0000
2007	0.0300	0.0000
2008	0.0300	0.0000
2009	0.0300	0.0000

Total Fishing Mortality Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2004	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0
2005	0.0045	0.0046	0.0047	0.0047	0.0048	0.0049	0.0050	0.0
2006	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0
2007	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0
2008	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0
2009	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0

Probability Spawning Stock Biomass Exceeds Threshold 236.700 (1000 MT)

Year	Probability
2004	0.000000
2005	0.000000
2006	0.000000
2007	0.000000
2008	0.000010
2009	0.001950

Probability Threshold Exceeded at Least Once = 0.0019

Probability Total Fishing Mortality Exceeds Threshold 0.0400

Year	Probability
2004	0.000000
2005	0.000000
2006	0.000000

```
2007    0.000000
2008    0.000000
2009    0.000000

Probability Threshold Exceeded at Least Once =     0.0000
```

Example 2

The second example is a fishing mortality and landings quota projection for Gulf of Maine haddock with a PStar analysis in 2018. The time horizon is 2014-2020. The fishery is comprised of one fleet. This is PStar projection analysis with 1000 bootstraps and 10 simulations per bootstrap based on an ASAP stock assessment analysis. The model output shows that total allowable catch amounts in 2018 to produce probabilities of overfishing of 10%, 20%, 30%, 40% and 50% at the overfishing level ofF=0.35. The total allowable catches to produce overfishing probabilities of 10%, 20%, 30%, 40% and 50% are calculated to be 1780, 1998, 2176, 2332, and 2497 mt, respectively. The model output includes a stock summary of numbers at age and also outputs a percentile analysis for key outputs at the 90th percentile.

Running example 2 produces the following output:

```
AGEPRO VERSION 4.2

GoM haddock ASAP_final (1977-2011 recruitment)

Date & Time of Run: 29 Dec 2017  14:19

Input File Name:    C:\Users\Jon.Brodziak\Documents\AGEPRO\Example2_2017-12-29_14-19-44\E

First Age Class:                        1
Number of Age Classes:                  9
Number of Years in Projection:          7
Number of Fleets:                       1
Number of Recruitment Models:           1
Number of Bootstraps:                1000
Number of Simulations:                 10

Bootstrap File Name:            C:\Users\Jon.Brodziak\Documents\AGEPRO\Example2_2017-12-2

Number of Feasible Solutions:      10000  of      10000 Realizations

Input Harvest Scenario
```

```
Year  Type         Value

2014  Landings       500
2015  F-Mult      0.2000
2016  F-Mult      0.2000
2017  F-Mult      0.2000
2018  Removals      2497
2019  F-Mult      0.2000
2020  F-Mult      0.2000

Recruits        1000  Fish

Year Class   Average       StdDev
2014       2113.8225    2387.2409
2015       2095.2435    2388.6322
2016       2161.9981    2415.4853
2017       2154.6634    2430.4964
2018       2141.7581    2406.3266
2019       2156.4185    2450.1039
2020       2183.0481    2465.0965

Recruits Distribution

Year Class 1%         5%        10%        25%        50%        75%        90%        9
2014    150.1671   205.1791   227.5903   331.1452  1120.8200  2542.1990  6162.8810  6484.1
2015    149.3512   204.6887   228.6934   334.4683  1120.1820  2541.2640  6152.7080  6487.6
2016    154.2960   203.8387   225.7294   361.4124  1129.3905  2545.1890  6212.6520  6501.7
2017    152.0371   210.7372   232.7332   359.0538  1129.9945  2544.1510  6190.1710  6506.0
2018    153.6666   204.7484   227.5898   349.5553  1122.8935  2544.3130  6203.1390  6499.2
2019    152.0957   209.2503   231.1399   342.5836  1125.1445  2543.9000  6212.2790  6536.6
2020    150.5870   206.1237   230.0479   360.4650  1132.4435  2544.9890  6226.1050  6535.5

Spawning Stock Biomass  x       1000 MT

Year       Average       StdDev
2014        6.6153       1.5860
2015       11.0899       2.9220
2016       12.8636       3.4163
2017       12.6038       3.2662
2018       11.3916       3.0953
2019        9.7421       3.0356
2020        9.0292       2.7831

Spawning Stock Biomass Distribution
```

Year	1%	5%	10%	25%	50%	75%	90%	
2014	3.5200	4.3275	4.7137	5.4851	6.4722	7.5894	8.7222	9.4
2015	5.4666	6.9514	7.6632	8.9364	10.7412	12.9279	14.9858	16.4
2016	6.4490	8.0138	8.8712	10.3627	12.4238	15.0340	17.4631	19.0
2017	6.5380	7.9215	8.7276	10.2139	12.2223	14.6496	17.0540	18.4
2018	5.6092	6.9035	7.6665	9.1293	11.0387	13.3430	15.5845	16.9
2019	4.0236	5.3269	6.0556	7.5435	9.4281	11.6586	13.8259	15.2
2020	3.8158	4.9913	5.6425	6.9951	8.7759	10.8012	12.7350	14.0

JAN-1 Stock Biomass x 1000 MT

Year	Average	StdDev
2014	11.4167	2.9021
2015	13.9657	3.6246
2016	14.8968	3.8103
2017	14.6414	3.6817
2018	13.7025	3.4096
2019	11.6265	3.4733
2020	10.8758	3.2285

JAN-1 Stock Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	5.8387	7.3015	8.0296	9.3083	11.0600	13.2142	15.2749	16.6
2015	7.1894	8.8204	9.7234	11.2971	13.5244	16.2526	18.8028	20.6
2016	7.7881	9.4605	10.4082	12.1233	14.4212	17.2943	20.0188	21.8
2017	7.7478	9.3316	10.2328	11.9419	14.2320	16.9148	19.6778	21.2
2018	7.2064	8.7307	9.5603	11.2420	13.3875	15.8500	18.2481	19.8
2019	4.9782	6.5211	7.4069	9.0983	11.3092	13.8388	16.3219	17.7
2020	4.7593	6.1337	6.9781	8.5232	10.5738	12.9143	15.2091	16.6

Mean Biomass x 1000 MT

Year	Average	StdDev
2014	13.5594	3.5654
2015	15.0921	4.0054
2016	15.3716	3.9588
2017	14.6866	3.7276
2018	12.9499	3.5927
2019	11.4205	3.4391
2020	10.7213	3.2607

Mean Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	6.7743	8.5594	9.4054	10.9301	13.1275	15.7951	18.3751	20.0
2015	7.5738	9.4465	10.3652	12.1587	14.5926	17.5658	20.4590	22.3
2016	7.9903	9.7496	10.6488	12.4953	14.9115	17.8132	20.7241	22.5
2017	7.6799	9.2810	10.1779	11.9493	14.2831	17.0375	19.6923	21.2
2018	6.1034	7.6719	8.5812	10.3214	12.6155	15.2101	17.6818	19.3
2019	4.9062	6.3754	7.2373	8.9247	11.0836	13.6122	15.9977	17.5
2020	4.6255	5.9719	6.7819	8.3407	10.4020	12.7506	15.0877	16.4

Combined Catch Biomass x 1000 MT

Year	Average	StdDev
2014	0.5000	0.0000
2015	0.8803	0.2338
2016	1.1420	0.3043
2017	1.4560	0.3947
2018	2.4966	0.0000
2019	1.3033	0.4176
2020	1.2978	0.4060

Combined Catch Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5
2015	0.4340	0.5427	0.6046	0.7113	0.8555	1.0264	1.1884	1.3
2016	0.5651	0.7098	0.7834	0.9215	1.1052	1.3265	1.5480	1.6
2017	0.7298	0.9039	0.9911	1.1700	1.4071	1.6944	1.9823	2.1
2018	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4
2019	0.5368	0.7012	0.8076	0.9984	1.2549	1.5584	1.8669	2.0
2020	0.5392	0.7114	0.8088	1.0025	1.2569	1.5518	1.8438	2.0

Landings x 1000 MT

Year	Average	StdDev
2014	0.5000	0.0000
2015	0.8803	0.2338
2016	1.1420	0.3043
2017	1.4560	0.3947
2018	2.4966	0.0000
2019	1.3033	0.4176
2020	1.2978	0.4060

Landings Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5
2015	0.4340	0.5427	0.6046	0.7113	0.8555	1.0264	1.1884	1.3
2016	0.5651	0.7098	0.7834	0.9215	1.1052	1.3265	1.5480	1.6
2017	0.7298	0.9039	0.9911	1.1700	1.4071	1.6944	1.9823	2.1
2018	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4
2019	0.5368	0.7012	0.8076	0.9984	1.2549	1.5584	1.8669	2.0
2020	0.5392	0.7114	0.8088	1.0025	1.2569	1.5518	1.8438	2.0

Total Fishing Mortality

Year	Average	StdDev
2014	0.2105	0.0583
2015	0.2000	0.0000
2016	0.2000	0.0000
2017	0.2000	0.0000
2018	0.3687	0.1159
2019	0.2000	0.0000
2020	0.2000	0.0000

Total Fishing Mortality Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	0.1148	0.1340	0.1461	0.1696	0.2014	0.2412	0.2857	0.3
2015	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2
2016	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2
2017	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2
2018	0.1825	0.2189	0.2408	0.2860	0.3500	0.4296	0.5190	0.5
2019	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2
2020	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2

JAN-1 Stock Numbers at Age - 1000 Fish

2014

Age	1%	5%	10%	25%	50%	75%	90%	9
1	1095.7400	1126.8200	1157.6700	1199.9000	1247.3900	1293.2100	1339.0500	1360.0
2	5815.7300	7232.0700	8377.4700	10215.8000	12906.8500	16274.7000	19489.5000	22076.3
3	605.2860	742.5500	868.7790	1068.1800	1346.6300	1645.2400	2021.1100	2259.3
4	1901.0200	2180.2500	2400.8400	2791.0000	3321.5800	3853.1700	4463.8300	4836.6
5	176.1790	213.9540	241.0530	284.5670	342.7900	418.2160	477.3430	529.6
6	32.9855	41.5396	46.7232	56.6142	69.9137	88.1928	104.1120	118.6
7	12.9987	16.9683	19.9008	24.6551	31.1685	38.9058	47.6952	55.4
8	50.5496	64.3146	72.2744	89.3943	110.0280	133.9590	157.0870	170.5

9+	103.9710	159.1740	182.0530	225.6940	284.1005	356.5180	433.8950	482.1

2015

Age	1%	5%	10%	25%	50%	75%	90%	9
1	150.1671	205.1791	227.5903	331.1452	1120.8200	2542.1990	6162.8810	6484.1
2	887.8562	922.5597	942.9964	979.3431	1019.9400	1061.2890	1100.2170	1123.0
3	4724.3670	5884.9600	6798.6190	8276.9970	10469.3300	13189.7300	15985.8800	18030.0
4	458.6349	579.8621	677.1247	832.9786	1056.4355	1303.7760	1602.3610	1814.0
5	1388.8850	1636.0870	1812.6300	2132.5230	2555.2555	2996.3000	3495.6230	3824.3
6	120.7904	150.2547	172.1194	206.6085	252.4803	312.3292	361.4383	400.4
7	21.3308	27.8132	31.8572	39.5234	50.0190	63.7509	76.3860	88.3
8	8.1611	11.0643	12.9375	16.8231	21.5830	27.4805	34.0739	39.6
9+	99.1900	142.4742	166.3174	212.3172	272.2853	345.9320	425.8746	468.2

2016

Age	1%	5%	10%	25%	50%	75%	90%	9
1	149.3512	204.6887	228.6934	334.4683	1120.1820	2541.2640	6152.7080	6487.6
2	122.6079	167.5320	186.7238	270.6380	932.5010	2086.0260	5051.1580	5326.5
3	710.6238	743.4937	762.5140	792.6984	826.6821	862.4630	895.3975	913.9
4	3699.5560	4632.8560	5342.0500	6523.0780	8265.4655	10393.9500	12573.6900	14252.8
5	353.6407	447.9320	522.2761	642.1836	814.4617	1004.5240	1234.6130	1397.6
6	1022.0040	1210.2630	1332.3580	1574.6600	1884.6520	2212.1540	2583.8580	2825.5
7	85.6311	107.2060	122.3344	147.0802	180.6755	222.8392	258.5840	286.6
8	14.7620	19.2894	22.1592	27.4605	34.8072	44.3394	53.2656	61.4
9+	76.3752	107.4038	125.3629	160.6426	205.1725	259.9684	318.5978	352.4

2017

Age	1%	5%	10%	25%	50%	75%	90%	9
1	154.2960	203.8387	225.7294	361.4124	1129.3905	2545.1890	6212.6520	6501.7
2	122.4453	166.9060	186.5583	273.5268	924.9599	2074.8450	5058.8330	5326.8
3	98.6721	135.7598	151.5422	218.5243	758.2042	1695.3800	4090.3880	4320.9
4	555.9447	583.0513	598.1129	623.8630	651.9622	681.2245	708.2104	724.4
5	2851.8990	3580.1050	4117.6850	5024.5930	6371.6070	8004.3590	9689.6580	10972.1
6	261.0618	330.7912	384.8489	473.6005	600.6945	742.7213	913.8329	1037.5
7	726.6373	861.8317	950.5333	1123.4050	1341.5895	1577.9470	1845.7470	2020.5
8	59.3449	74.6039	85.0226	102.4041	125.6241	155.1049	180.6077	200.1
9+	65.8990	89.2369	103.3606	131.8739	167.2694	209.3213	257.1538	283.2

2018

Age	1%	5%	10%	25%	50%	75%	90%	9

1	152.0371	210.7372	232.7332	359.0538	1129.9945	2544.1510	6190.1710	6506.0
2	125.9985	167.1557	185.6035	295.5600	935.4454	2097.9120	5084.9840	5334.7
3	99.7584	134.7766	152.1943	222.3991	751.9013	1685.2500	4105.3300	4336.8
4	78.4004	106.8737	119.8788	172.1859	597.7342	1338.5740	3226.9110	3417.3
5	424.1483	447.3210	459.3271	479.6160	502.7516	526.7769	548.9252	561.7
6	2089.6800	2644.4020	3036.4550	3710.9630	4707.0140	5923.2100	7170.1380	8083.2
7	187.2364	235.6444	273.3657	337.6416	428.3732	530.8136	653.5985	742.1
8	502.6856	601.8133	660.8785	780.8261	935.3516	1100.4240	1284.5000	1409.9
9+	88.7375	117.2458	132.9764	162.7726	203.1062	248.8700	296.8760	328.0

2019

Age	1%	5%	10%	25%	50%	75%	90%	9
1	153.6666	204.7484	227.5898	349.5553	1122.8935	2544.3130	6203.1390	6499.2
2	125.6385	171.2869	191.4572	293.4845	936.8988	2101.1120	5065.3120	5337.1
3	100.6454	133.9611	149.4112	239.4418	755.7065	1695.1120	4083.9320	4302.3
4	75.9471	101.6247	116.3168	169.1645	576.0969	1288.6220	3151.6090	3347.2
5	56.9325	77.0244	87.8735	126.1823	438.8362	990.5278	2389.8910	2567.0
6	241.0660	274.4351	290.0872	315.9705	342.6452	368.9478	392.5774	405.1
7	1088.2510	1459.0940	1752.8150	2264.1170	3022.4015	3969.4200	4952.0780	5644.7
8	92.5160	126.7009	153.4395	200.6431	262.7260	334.9452	427.0272	493.7
9+	249.7404	360.1757	416.3782	521.9749	661.7476	821.6150	987.4303	1108.2

2020

Age	1%	5%	10%	25%	50%	75%	90%	9
1	152.0957	209.2503	231.1399	342.5836	1125.1445	2543.9000	6212.2790	6536.6
2	125.4417	168.1045	186.3815	286.0352	934.1904	2103.3390	5072.6260	5335.4
3	101.2067	138.5952	155.5509	238.0804	764.2864	1702.1790	4113.1280	4342.2
4	79.8333	105.2166	118.2490	189.0875	597.1814	1343.2180	3222.5690	3401.1
5	58.6316	78.3392	90.1692	130.4061	445.5383	997.0890	2427.3970	2591.6
6	41.8457	56.4963	64.9800	93.3839	324.2153	733.5625	1763.0560	1905.3
7	171.4524	195.2795	206.3613	224.8976	244.1048	263.1188	280.4399	289.7
8	749.8229	1020.1310	1215.3620	1577.0540	2104.9460	2770.4520	3463.9650	3924.7
9+	244.0270	346.8155	405.7743	507.1333	642.8957	794.1324	959.9258	1070.2

Requested Percentile Report

Percentile = 90.00 %

	2014	2015	2016	2017	2018	2
Recruits	6162.8810	6152.7080	6212.6520	6190.1710	6203.1390	6212.2

```
Spawning Stock Biomass          8.7222     14.9858     17.4631     17.0540     15.5845     13.8
Jan-1 Stock Biomass            15.2749     18.8028     20.0188     19.6778     18.2481     16.3
Mean Biomass                   18.3751     20.4590     20.7241     19.6923     17.6818     15.9
Combined Catch Biomass          0.5000      1.1884      1.5480      1.9823      2.4966      1.8
Landings                        0.5000      1.1884      1.5480      1.9823      2.4966      1.8
FMort                           0.2857      0.2000      0.2000      0.2000      0.5190      0.2

Stock Numbers at Age
Age 1                        1339.0500   6162.8810   6152.7080   6212.6520   6190.1710   6203.1
Age 2                       19489.5000   1100.2170   5051.1580   5058.8330   5084.9840   5065.3
Age 3                        2021.1100  15985.8800    895.3975   4090.3880   4105.3300   4083.9
Age 4                        4463.8300   1602.3610  12573.6900    708.2104   3226.9110   3151.6
Age 5                         477.3430   3495.6230   1234.6130   9689.6580    548.9252   2389.8
Age 6                         104.1120    361.4383   2583.8580    913.8329   7170.1380    392.5
Age 7                          47.6952     76.3860    258.5840   1845.7470    653.5985   4952.0
Age 8                         157.0870     34.0739     53.2656    180.6077   1284.5000    427.0
Age 9                         433.8950    425.8746    318.5978    257.1538    296.8760    987.4

PStar Summary Report

Overfishing F =     0.3500   Target Year = 2018

  PStar          TAC

  0.1000         1780
  0.2000         1998
  0.3000         2176
  0.4000         2332
  0.5000         2497
```

Example 3

The third example is a fishing mortality and landings quota projection for Gulf of Maine haddock with a rebuilding analysis for 2014-2020. The fishery is comprised of one fleet with process error in fishery selectivity. This is rebuilding projection with 1000 bootstraps and 10 simulations per bootstrap based on an ASAP stock assessment analysis. The model output shows the constant fishing mortality to rebuild the stock is $F_{REBUILD} = 0.045$. The model output includes a stock summary of numbers at age and also outputs a percentile analysis for key outputs at the 90^{th} percentile.

Running example 3 produces the following output:

```
AGEPRO VERSION 4.2

GoM haddock ASAP_final FREBUILD Projection

Date & Time of Run: 29 Dec 2017  14:49

Input File Name:    C:\Users\Jon.Brodziak\Documents\AGEPRO\Example3_2017-12-29_14-49-07\E

First Age Class:                        1
Number of Age Classes:                  9
Number of Years in Projection:          7
Number of Fleets:                       1
Number of Recruitment Models:           1
Number of Bootstraps:                1000
Number of Simulations:                 10

Bootstrap File Name:            C:\Users\Jon.Brodziak\Documents\AGEPRO\Example3_2017-12-2

Number of Feasible Solutions:      10000  of      10000 Realizations

Input Harvest Scenario

Year  Type         Value

2014  Landings        500
2015  F-Mult       0.3000
2016  F-Mult       0.3000
2017  F-Mult       0.3000
2018  F-Mult       0.3000
2019  F-Mult       0.3000
2020  F-Mult       0.3000

Recruits        1000  Fish

Year Class   Average        StdDev
2014       2170.8200     2441.8617
2015       2144.2492     2416.6899
2016       2150.4373     2418.5021
2017       2077.7020     2359.7104
2018       2169.2781     2458.9123
2019       2146.2591     2453.9399
2020       2109.8574     2409.5591

Recruits Distribution
```

Year Class	1%	5%	10%	25%	50%	75%	90%	9
2014	153.7521	208.0085	229.3621	347.0616	1132.0955	2545.3470	6225.6320	6522.2
2015	152.8537	207.5118	228.9794	352.4027	1126.1215	2542.6540	6181.5870	6500.1
2016	152.0864	205.9702	227.0639	334.5421	1120.9140	2544.0470	6196.3710	6505.2
2017	153.9306	204.6065	223.9934	335.6253	1120.2075	2541.6660	6154.7360	6491.9
2018	151.7663	206.4086	227.8564	353.3611	1136.3925	2544.5000	6227.9310	6534.0
2019	150.6260	205.4969	229.0507	342.5477	1120.8380	2543.5260	6205.1600	6521.0
2020	152.6280	209.8481	230.9342	348.8617	1120.4415	2541.6850	6179.7760	6495.6

Spawning Stock Biomass x 1000 MT

Year	Average	StdDev
2014	6.6170	1.5864
2015	11.2472	2.9734
2016	13.6893	3.6225
2017	14.2545	3.6743
2018	14.2000	3.5843
2019	13.8474	3.4929
2020	13.5056	3.3958

Spawning Stock Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	
2014	3.5078	4.3130	4.7139	5.4741	6.4677	7.5996	8.7246	9.5
2015	5.5792	7.0419	7.7295	9.0558	10.8637	13.1038	15.2164	16.6
2016	6.8389	8.5537	9.4430	11.0420	13.2202	15.9565	18.5612	20.2
2017	7.3671	8.9936	9.9199	11.6008	13.8159	16.5604	19.2488	20.9
2018	7.4340	9.0080	9.8747	11.5974	13.8368	16.4445	18.9478	20.6
2019	7.2135	8.7442	9.6034	11.3116	13.5319	16.0556	18.4609	20.0
2020	7.1247	8.5118	9.3369	11.0000	13.2158	15.6735	18.0730	19.5

JAN-1 Stock Biomass x 1000 MT

Year	Average	StdDev
2014	11.4174	2.8996
2015	13.9853	3.6385
2016	15.5776	3.9671
2017	16.1162	4.0252
2018	16.0743	3.9486
2019	15.7028	3.8651
2020	15.3638	3.7809

JAN-1 Stock Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	5.9561	7.3305	8.0160	9.3127	11.0570	13.2145	15.2783	16.6
2015	7.0768	8.8151	9.7325	11.3215	13.5287	16.2558	18.8747	20.6
2016	8.1564	9.8810	10.8909	12.7070	15.0950	18.1127	20.8555	22.7
2017	8.5564	10.2829	11.2717	13.1921	15.6896	18.6290	21.5091	23.3
2018	8.5860	10.3039	11.2642	13.1568	15.7288	18.5593	21.3129	23.1
2019	8.3366	10.0510	10.9747	12.8914	15.3734	18.1349	20.8302	22.5
2020	8.1237	9.7586	10.7283	12.5950	15.0481	17.7564	20.3938	22.0

Mean Biomass x 1000 MT

Year	Average	StdDev
2014	13.5499	3.5542
2015	15.4331	4.0737
2016	16.4904	4.2029
2017	16.6939	4.1849
2018	16.3128	4.0289
2019	15.7412	3.9122
2020	15.4252	3.8993

Mean Biomass Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	6.8296	8.5113	9.3948	10.9509	13.0968	15.7592	18.2887	20.0
2015	7.8519	9.6342	10.6250	12.5018	14.9013	17.9378	20.8969	22.8
2016	8.6093	10.4184	11.4735	13.4336	16.0525	19.1332	22.1543	24.0
2017	8.7683	10.6194	11.6720	13.6335	16.2788	19.3000	22.2328	24.2
2018	8.6469	10.3838	11.3612	13.3676	15.9913	18.8559	21.6646	23.4
2019	8.3179	9.9544	10.9414	12.8538	15.4182	18.2748	20.9306	22.6
2020	7.9700	9.6937	10.6649	12.5609	15.0972	17.9037	20.6399	22.3

Combined Catch Biomass x 1000 MT

Year	Average	StdDev
2014	0.5000	0.0000
2015	0.2016	0.0530
2016	0.2789	0.0737
2017	0.3796	0.1018
2018	0.4419	0.1161
2019	0.4422	0.1156
2020	0.4748	0.1232

Combined Catch Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5
2015	0.1003	0.1249	0.1392	0.1633	0.1963	0.2339	0.2728	0.2
2016	0.1394	0.1741	0.1925	0.2250	0.2708	0.3237	0.3775	0.4
2017	0.1914	0.2364	0.2608	0.3046	0.3669	0.4417	0.5168	0.5
2018	0.2283	0.2769	0.3047	0.3575	0.4290	0.5124	0.5971	0.6
2019	0.2287	0.2767	0.3051	0.3569	0.4295	0.5137	0.5978	0.6
2020	0.2444	0.2973	0.3263	0.3852	0.4629	0.5511	0.6407	0.6

Landings x 1000 MT

Year	Average	StdDev
2014	0.5000	0.0000
2015	0.2016	0.0530
2016	0.2789	0.0737
2017	0.3796	0.1018
2018	0.4419	0.1161
2019	0.4422	0.1156
2020	0.4748	0.1232

Landings Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5
2015	0.1003	0.1249	0.1392	0.1633	0.1963	0.2339	0.2728	0.2
2016	0.1394	0.1741	0.1925	0.2250	0.2708	0.3237	0.3775	0.4
2017	0.1914	0.2364	0.2608	0.3046	0.3669	0.4417	0.5168	0.5
2018	0.2283	0.2769	0.3047	0.3575	0.4290	0.5124	0.5971	0.6
2019	0.2287	0.2767	0.3051	0.3569	0.4295	0.5137	0.5978	0.6
2020	0.2444	0.2973	0.3263	0.3852	0.4629	0.5511	0.6407	0.6

Total Fishing Mortality

Year	Average	StdDev
2014	0.2102	0.0578
2015	0.0445	0.0000
2016	0.0445	0.0000
2017	0.0445	0.0000
2018	0.0445	0.0000
2019	0.0445	0.0000
2020	0.0445	0.0000

Total Fishing Mortality Distribution

Year	1%	5%	10%	25%	50%	75%	90%	9
2014	0.1162	0.1334	0.1462	0.1696	0.2015	0.2408	0.2839	0.3
2015	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0
2016	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0
2017	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0
2018	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0
2019	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0
2020	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0

JAN-1 Stock Numbers at Age - 1000 Fish

2014

Age	1%	5%	10%	25%	50%	75%	90%	9
1	1095.7400	1126.8200	1157.6700	1199.9000	1247.3900	1293.2100	1339.0500	1360.0
2	5815.7300	7232.0700	8377.4700	10215.8000	12906.8500	16274.7000	19489.5000	22076.3
3	605.2860	742.5500	868.7790	1068.1800	1346.6300	1645.2400	2021.1100	2259.3
4	1901.0200	2180.2500	2400.8400	2791.0000	3321.5800	3853.1700	4463.8300	4836.6
5	176.1790	213.9540	241.0530	284.5670	342.7900	418.2160	477.3430	529.6
6	32.9855	41.5396	46.7232	56.6142	69.9137	88.1928	104.1120	118.6
7	12.9987	16.9683	19.9008	24.6551	31.1685	38.9058	47.6952	55.4
8	50.5496	64.3146	72.2744	89.3943	110.0280	133.9590	157.0870	170.5
9+	103.9710	159.1740	182.0530	225.6940	284.1005	356.5180	433.8950	482.1

2015

Age	1%	5%	10%	25%	50%	75%	90%	9
1	153.7521	208.0085	229.3621	347.0616	1132.0955	2545.3470	6225.6320	6522.2
2	886.9999	920.9055	944.3435	979.9522	1020.1620	1060.7430	1100.8560	1122.0
3	4740.6350	5881.5180	6788.0890	8280.2530	10437.9000	13190.6000	15924.2900	17940.1
4	462.1501	579.5480	678.5247	836.1118	1057.6295	1300.8420	1601.9910	1805.4
5	1402.6870	1632.0730	1811.3860	2130.7570	2557.1140	3001.1490	3490.7850	3797.3
6	121.0333	150.3102	172.2205	206.2701	252.2545	312.3252	361.8990	399.4
7	21.2549	27.8869	31.7288	39.5810	50.0350	63.4947	76.4838	88.1
8	8.1178	11.0340	12.9066	16.8518	21.5642	27.4360	34.0090	39.6
9+	99.6480	143.0746	165.8811	212.3056	272.7287	345.4891	426.8521	469.6

2016

Age	1%	5%	10%	25%	50%	75%	90%	9
1	152.8537	207.5118	228.9794	352.4027	1126.1215	2542.6540	6181.5870	6500.1
2	125.6120	169.9832	187.3362	285.8009	935.7087	2106.8640	5088.4640	5358.8
3	717.8408	749.2020	767.2159	798.8983	833.9748	868.6385	901.6998	920.6
4	3849.5580	4772.2030	5517.5350	6713.5670	8486.4350	10724.0600	12954.9300	14583.3

5	368.8452	470.1688	546.3981	674.9982	854.9253	1053.6940	1296.1080	1465.7
6	1112.4340	1304.3160	1447.6410	1703.7200	2044.2600	2402.5000	2796.6280	3037.7
7	95.8425	119.3594	136.5312	163.6895	200.5233	247.8007	287.8207	317.0
8	16.6931	22.0278	25.0771	31.2594	39.5369	50.2574	60.4657	69.4
9+	87.9257	122.3541	142.6734	181.7372	232.7070	294.7329	361.5172	399.8

2017

Age	1%	5%	10%	25%	50%	75%	90%	9
1	152.0864	205.9702	227.0639	334.5421	1120.9140	2544.0470	6196.3710	6505.2
2	124.9328	169.5370	187.5875	289.2126	936.7591	2082.4200	5059.7310	5330.1
3	102.7604	138.0878	153.3027	233.9465	767.8980	1732.9510	4159.4080	4386.5
4	578.2827	604.7967	621.0119	646.7345	676.8689	707.3514	734.5654	751.9
5	3091.6750	3845.1700	4440.2080	5421.1320	6866.7700	8644.6120	10492.0100	11781.0
6	296.0683	374.3265	437.9340	540.8164	682.1429	842.5300	1037.5380	1173.8
7	879.9575	1036.5260	1146.0000	1352.4100	1621.8885	1915.9780	2223.3420	2419.6
8	75.7144	94.2965	107.6556	129.2856	158.5479	195.8338	227.5058	250.5
9+	86.1764	115.7229	134.3767	170.3536	216.4243	270.1949	329.6626	363.0

2018

Age	1%	5%	10%	25%	50%	75%	90%	9
1	153.9306	204.6065	223.9934	335.6253	1120.2075	2541.6660	6154.7360	6491.9
2	124.3599	168.1019	186.5384	274.1155	933.7431	2097.5150	5068.9150	5351.9
3	102.6584	138.0619	153.2109	234.4648	768.2888	1705.2570	4137.6920	4376.4
4	83.0630	111.7923	125.1747	190.0386	624.9189	1406.8860	3375.8670	3580.8
5	463.1497	486.4656	499.5535	521.4975	546.8899	572.8059	596.2554	610.6
6	2458.2110	3074.0040	3543.9720	4341.7510	5493.7480	6912.7910	8409.3140	9431.2
7	232.8949	297.6859	348.1032	429.2734	541.3385	669.5108	824.7090	932.7
8	693.9673	815.9270	903.8471	1069.8840	1279.5850	1510.4820	1752.6630	1913.4
9+	131.7504	172.7009	195.3063	239.6761	298.3704	363.7684	430.1583	479.6

2019

Age	1%	5%	10%	25%	50%	75%	90%	9
1	151.7663	206.4086	227.8564	353.3611	1136.3925	2544.5000	6227.9310	6534.0
2	126.1664	166.8946	184.0337	273.6497	926.2880	2074.8740	5060.7700	5321.2
3	101.1790	137.3052	152.7485	223.9679	764.1367	1718.8710	4145.2170	4387.6
4	83.1064	111.7158	124.8275	190.8343	624.4940	1389.5640	3365.4510	3567.1
5	67.4937	90.0772	101.2675	154.1486	505.3076	1142.8570	2726.6630	2894.6
6	367.9427	387.4575	398.0623	416.4294	437.2194	459.0043	478.4960	491.2
7	1965.4640	2431.6780	2821.0370	3445.3130	4364.2560	5494.9360	6693.2650	7529.1
8	183.2299	234.7869	274.1439	339.3622	427.2745	529.8703	651.1502	737.6
9+	645.5298	785.3057	869.6136	1034.7050	1242.1625	1464.2670	1703.0170	1862.6

2020

Age	1%	5%	10%	25%	50%	75%	90%	9
1	150.6260	205.4969	229.0507	342.5477	1120.8380	2543.5260	6205.1600	6521.0
2	123.8571	167.9808	187.1525	289.8989	937.2894	2106.1880	5097.7430	5374.9
3	102.3573	135.9500	150.7452	222.9596	759.5409	1692.0840	4135.9360	4364.2
4	81.7678	111.0348	123.6390	182.1238	620.7917	1400.0710	3356.1290	3576.1
5	67.0329	89.8906	100.9146	154.5096	504.2604	1124.6640	2720.8110	2890.6
6	54.1054	71.9035	81.1756	123.2250	405.4597	915.6747	2177.4730	2329.5
7	290.4778	305.5871	315.3789	330.0894	347.1659	365.1161	381.6304	391.7
8	1534.5130	1921.6320	2227.5890	2721.7010	3447.9955	4331.5540	5284.6800	5929.2
9+	695.9149	838.0460	934.9111	1101.1280	1328.9345	1555.9650	1818.6410	1978.0

Requested Percentile Report

Percentile = 90.00 %

	2014	2015	2016	2017	2018	2
Recruits	6225.6320	6181.5870	6196.3710	6154.7360	6227.9310	6205.1
Spawning Stock Biomass	8.7246	15.2164	18.5612	19.2488	18.9478	18.4
Jan-1 Stock Biomass	15.2783	18.8747	20.8555	21.5091	21.3129	20.8
Mean Biomass	18.2887	20.8969	22.1543	22.2328	21.6646	20.9
Combined Catch Biomass	0.5000	0.2728	0.3775	0.5168	0.5971	0.5
Landings	0.5000	0.2728	0.3775	0.5168	0.5971	0.5
FMort	0.2839	0.0445	0.0445	0.0445	0.0445	0.0
Stock Numbers at Age						
Age 1	1339.0500	6225.6320	6181.5870	6196.3710	6154.7360	6227.9
Age 2	19489.5000	1100.8560	5088.4640	5059.7310	5068.9150	5060.7
Age 3	2021.1100	15924.2900	901.6998	4159.4080	4137.6920	4145.2
Age 4	4463.8300	1601.9910	12954.9300	734.5654	3375.8670	3365.4
Age 5	477.3430	3490.7850	1296.1080	10492.0100	596.2554	2726.6
Age 6	104.1120	361.8990	2796.6280	1037.5380	8409.3140	478.4
Age 7	47.6952	76.4838	287.8207	2223.3420	824.7090	6693.2
Age 8	157.0870	34.0090	60.4657	227.5058	1752.6630	651.1
Age 9	433.8950	426.8521	361.5172	329.6626	430.1583	1703.0

Acknowledgments

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Example 1 Input File

```
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[CASEID]
REDFISH - RECRUITMENT MODEL 14
[GENERAL]
2004 2009 1 26 100 2 1 0 49667890
[BOOTSTRAP]
1000 1000
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[STOCK_WEIGHT]
0 1
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
0.565 0.581 0.595 0.583 0.582 0.637
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
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[MEAN_WEIGHT]
0 1
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
0.565 0.581 0.595 0.583 0.582 0.637
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
0.565 0.581 0.595 0.583 0.582 0.637
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
0.565 0.581 0.595 0.583 0.582 0.637
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
0.565 0.581 0.595 0.583 0.582 0.637
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
0.565 0.581 0.595 0.583 0.582 0.637
0.01 0.02 0.059 0.099 0.145 0.178 0.201 0.25 0.272 0.31 0.348 0.391 0.423 0.429 0.463 0.495 0.503 0.508 0.
0.565 0.581 0.595 0.583 0.582 0.637
0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.00
0.001 0.001 0.001 0.001 0.001 0.001
```

Example 2 Input File

```
AGEPRO VERSION 4.0
[CASEID]
GoM haddock ASAP_final (1977-2011 recruitment)
[GENERAL]
2014  2020  1  9  10  1  1  0  854236
[BOOTSTRAP]
1000  1000
C:\Users\Jon.Brodziak\Documents\AGEPRO\Example2_2017-12-29_14-19-44\Example2.BSN
[STOCK_WEIGHT]
0  0
0.15  0.4  0.71  1  1.24  1.43  1.59  1.82  2.04
0.14  0.13  0.07  0.05  0.03  0.03  0.08  0.03  0.04
[SSB_WEIGHT]
-1  0
[MEAN_WEIGHT]
0  0
0.3  0.6  0.89  1.17  1.4  1.55  1.7  1.96  2.04
0.14  0.11  0.11  0.06  0.05  0.05  0.05  0.07  0.04
[CATCH_WEIGHT]
-3  0
[NATMORT]
0  0
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
[BIOLOGICAL]
0
0.25
0.25
[MATURITY]
0  0
0.04  0.28  0.81  0.98  1  1  1  1  1
0.23  0.08  0.02  0.001  0.001  0.001  0.001  0.001  0.001
[FISHERY]
0  0
0  0.05  0.19  0.3  0.52  0.69  0.82  1  0.83
0.36  0.19  0.14  0.15  0.13  0.13  0.12  0.001  0.16
[RECRUIT]
1000  1000  50
14
1
1
1
1
1
1
1
35
5997  1476  6048  6435  4612  774  2445  1043  282  265  134  443  187  244  267  711  1318  2903  2540  1
[HARVEST]
1  0  0  0  2  0  0
500  0.2  0.2  0.2  500  0.2  0.2
[PSTAR]
5
0.1  0.2  0.3  0.4  0.5
0.35
2018
```

Example 3 Input File

```
AGEPRO VERSION 4.0
[CASEID]
GoM haddock ASAP_final FREBUILD Projection
[GENERAL]
2014  2020  1  9  10  1  1  0  30076
[BOOTSTRAP]
1000  1000
C:\Users\Jon.Brodziak\Documents\AGEPRO\Example3_2017-12-29_14-49-07\Example3.BSN
[STOCK_WEIGHT]
0  0
0.15  0.4  0.71  1  1.24  1.43  1.59  1.82  2.04
0.14  0.13  0.07  0.05  0.03  0.03  0.08  0.03  0.04
[SSB_WEIGHT]
-1  0
[MEAN_WEIGHT]
0  0
0.3  0.6  0.89  1.17  1.4  1.55  1.7  1.96  2.04
0.14  0.11  0.11  0.06  0.05  0.05  0.05  0.07  0.04
[CATCH_WEIGHT]
-3  0
[NATMORT]
0  0
0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2  0.2
0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
[BIOLOGICAL]
0
0.25
0.25
[MATURITY]
0  0
0.04  0.28  0.81  0.98  1  1  1  1  1
0.23  0.08  0.02  0.001  0.001  0.001  0.001  0.001  0.001
[FISHERY]
0  0
0  0.05  0.19  0.3  0.52  0.69  0.82  1  0.83
0.36  0.19  0.14  0.15  0.13  0.13  0.12  0.001  0.16
[RECRUIT]
1000  1000  50
14
1
1
1
1
1
1
1
35
5997  1476  6048  6435  4612  774  2445  1043  282  265  134  443  187  244  267  711  1318  2903  2540  1
[HARVEST]
1  0  0  0  0  0  0
500  0.3  0.3  0.3  0.3  0.3  0.3
[REBUILD]
2020  11000  0  75
[BOUNDS]
10  0.6
[OPTIONS]
```