AGEPRO Reference Manual

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Abstract

The AGEPRO reference manual describes the new version 4.2 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 new 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 standard projection analyses, projection analyses for stock rebuilding, and projection analyses to calculate annual catch limits with specific 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.

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, 1994; Brodziak et al. 1998). Subsequently, the model was applied to groundfish stocks at the 18th SARC (NEFSC 1994) to evaluate Amendment 5 harvest scenarios (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 projection: **recruitment**, **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 1^{st} 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 1st) 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 age $r \geq 0$. 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 1st) 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

(1) $$\underline{N}(t) = \begin{bmatrix} R(t) \\ N_{r+1}(t) \\ N_{r+2}(t) \\ \vdots \\ N_A(t) \end{bmatrix}$$

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 $a = r \ to \ A-1$ is given by

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

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** below).

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 $W_{S,a}(t)$ 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, $\underline{N}(t)$.

$$\underline{N}_S(t) = \begin{bmatrix} N_r(t) \cdot e^{-Z_{Frac}(t)[M_r(t) + F_r(t)]} \\ N_{r+1}(t) \cdot e^{-Z_{Frac}(t)[M_2(t) + F_2(t)]} \\ N_{r+2}(t) \cdot e^{-Z_{Frac}(t)[M_3(t) + F_3(t)]} \\ \vdots \\ N_A(t) \cdot e^{-Z_{Frac}(t)[M_A(t) + F_A(t)]} \end{bmatrix} \tag{4}$$

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

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

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 and Deriso 1999). The catch of age-*a* fish in year *t* by fleet *v* is $C_{v,a}(t)$

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

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 $W_{v,D,a}(t)$ 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

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

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

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

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. 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 (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. 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, quota-based harvest control is applied in year *t*; else if $I(t)$=0, effort-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

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

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 $Q_v(t)$, 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*

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

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

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

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*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 $\underline{N}^{(*)}(1) = \left\{\underline{N}^{(1)}(1), \underline{N}^{(2)}(1), ..., \underline{N}^{(B)}(1)\right\}$, 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 ($B>10^3$) 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

$$\underline{N}^{(b)}(1) = \left(N_r^{(b)}(1), ..., N_A^{(b)}(1)\right) = k_N \cdot \underline{n}^{(b)}(1) = \left(k_N \cdot n_r^{(b)}(1), ..., k_N \cdot n_A^{(b)}(1)\right)$$

Retrospective Adjustment

One can adjust the initial population numbers at age vector $\underline{\text{N}}(1)$ 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 $\underline{\text{C}}$, 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

(12) $$\underline{N}^*(1) = \left(C_r \cdot N_r(1), ..., C_a \cdot N_a(1), ..., C_A \cdot N_A(1)\right)^T$$

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

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

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 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 stochastic recruitment models are available for population projection in the AGEPRO software. Thirteen of the recruitment models are functionally dependent on B_S while seven do not depend on spawning biomass. Five of the recruitment models have time-dependent parameters, eleven 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-r 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

(14) $$I_1 = \left[0, B_{S,1}\right) \textit{ and for } j = 1,\ldots,J-2 \;\; I_j = \left[B_{S,j-1}, B_{S,j}\right) \textit{ and } I_J = \left[B_{S,J-1}, \infty\right)$$

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 $P_{j,k}$. Here $P_{j,k}$ is the element in the j^{th} row and k^{th} column of the Markov matrix $\underline{\underline{P}} = \left[P_{j,k}\right]$ of conditional recruitment probabilities with elements

(15) $$P_{j,k} = \Pr\left(R_k \mid B_{S,Observed} \in I_j\right)$$

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 $\left[O_{k-1}, O_k\right]$ 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

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

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 $\hat{R}(t) = \Pr\left(R = O_k \mid B_S(t) \in I_j\right)$ through time.

<u>Model 2. Empirical Recruits Per Spawning Biomass Distribution</u>
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. <u>The empirical recruits per spawning biomass distribution model depends on spawning biomass and is time-invariant.</u>

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

(17) $$S_t = \frac{R(t)}{B_S(t-1)}$$

and let R_S be the S^{th} 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

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

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 $\widehat{R_S}$ 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

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

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

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

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

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

The AGEPRO program can generate stochastic recruitments using model 2 with up to 100 stock-recruitment data points.

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 be independent 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

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

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 B_S values are near the bottom of the range, then this approach could be overly optimistic, for it assumes that all historically observed recruitment levels are possible, regardless of B_S. The AGEPRO program allows up to 100 observed recruitments for random sampling. Note that the empirical recruitment distribution model can be used to make deterministic projections by specifying a single observed recruitment.

Model 4. Two-Stage Empirical Recruits Per Spawning Biomass Distribution

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^* 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 using the two-stage model with up to 100 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

$$\hat{r}(t) = \frac{\alpha \cdot b_S(t-1)}{\beta + b_S(t-1)} \cdot e^w$$

(23)

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

The stock-recruitment parameters α, β, 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_B =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 $h \cdot R_0$ recruits when $B_S = 0.2B_0$ and has the form

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

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

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

and

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

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

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

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

(28)
$$\hat{r}(t) = \frac{\alpha \cdot b_S(t-1)}{1 + \left(\frac{b_S(t-1)}{k}\right)^{\beta}} \cdot e^{w}$$
$$where \;\; w \sim N(0, \sigma_w^2),\; \hat{R}(t) = c_R \cdot \hat{r}(t),\; and \;\; B_S(t) = c_B \cdot b_S(t)$$

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

$$\hat{r}(t) = e^w$$

(29)

$$\text{where } w \sim N\left(\mu_{\log(r)}, \sigma_{\log(r)}^2\right) \text{ and } \hat{R}(t) = c_R \cdot \hat{r}(t)$$

The lognormal distribution parameters $\mu_{\log(r)}$ and $\sigma_{\log(r)}^2$ 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. Time-Varying Empirical Recruitment Distribution

This model has been deprecated. The time-varying empirical recruitment 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

$$\hat{r}(t) = \frac{\alpha \cdot b_S(t-1)}{\beta + b_S(t-1)} \cdot e^{\varepsilon_t}$$

(30)

$$\text{where } \varepsilon_t = \phi\varepsilon_{t-1} + w_t \text{ with } w_t \sim N\left(0, \sigma_w^2\right),$$

$$\hat{R}(t) = c_R \cdot \hat{r}(t), \text{ and } B_S(t) = c_B \cdot b_S(t)$$

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 period prior to the projection. If this value is not known, the default is to set ε_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

(31)

$$\hat{r}(t) = \alpha \cdot b_S(t-1) \cdot e^{-\beta \cdot b_S(t-1)} \cdot e^{\varepsilon_t}$$

$$where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t\ \ with\ \ w_t \sim N\left(0,\sigma_w^2\right),$$
$$\hat{R}(t) = c_R \cdot \hat{r}(t),\ and\ \ B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters α, β, 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 period prior to the projection. If this value is not known, the default is to set ε_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

(32)

$$\hat{r}(t) = \frac{\alpha \cdot b_S(t-1)}{1 + \left(\frac{b_S(t-1)}{k}\right)^{\beta}} \cdot e^{\varepsilon_t}$$

$$where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t\ \ with\ \ w_t \sim N\left(0,\sigma_w^2\right),$$
$$\hat{R}(t) = c_R \cdot \hat{r}(t),\ and\ \ B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters α, β, k, 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 period prior to the projection. If this value is not known, the default is to set ε_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

(33)

$$n_r(t) = e^{\varepsilon_t}$$

$$\text{where } \varepsilon_t = \phi\varepsilon_{t-1} + w_t \text{ with } w_t \sim N\left(\mu_{\log(r)}, \sigma^2_{\log(r)}\right),$$
$$\text{and } R(t) = c_R \cdot n_r(t)$$

The lognormal distribution parameters $\mu_{\log(r)}$, $\sigma^2_{\log(r)}$, ϕ, and 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

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

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 $\widehat{R_S}$ 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

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

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

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

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 set to be

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

The AGEPRO program can generate stochastic recruitments using model 14 with up to 100 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 $\underline{R}_{Low}$ for the low spawning biomass state and an empirical recruitment distribution $\underline{R}_{High}$ 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 using model 15 with up to 100 stock-recruitment data points.

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

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

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 $\frac{R}{B_S} \leq 0$ 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

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

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

(40)
$$n_r(t) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon$$
$$with\ R(t) = c_R \cdot n_r(t)$$

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

(41)
$$\log(n_r(t)) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon$$
$$with\ R(t) = c_R \cdot n_r(t)$$

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 $-0.5\sigma^2$, and the conversion coefficients for recruitment is c_R. 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 R under the assumption that the linear predictor of the *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

(42)
$$R(t) = c_R \cdot n_r(t)$$

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

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

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

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

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

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

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_t, is

(46)
$$\varepsilon_t \sim \exp(w)$$
$$where\ w \sim N\left(-0.5\sigma^2,\ \sigma^2\right)$$

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

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) $P_{v,D,a}(t)$
- Landed catch weight at age by fleet (CATCH_WEIGHT) $W_{v,L,a}(t)$
- 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 1st. The computational formula for B_T in year *t* is

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

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

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

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

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

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

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

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 $\left(B_{S,THRESHOLD}\right)$, mean biomass $\left(\overline{B}_{THRESHOLD}\right)$, and total stock biomass $\left(B_{T,THRESHOLD}\right)$ 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 $K_B\left(t\right)$ be the number of times that projected biomass $B\left(t\right)$ meets or exceeds a threshold biomass $B_{THRESHOLD}$ in year *t*. The counter $K_B\left(t\right)$ 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

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

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

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

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

(52) $$\Pr\left(\exists t \in \left[1,2,...,Y\right] \text{ such that } B\left(t\right) \geq B_{THRESHOLD}\right) = \frac{K_{THRESHOLD}}{K_{TOTAL}}$$

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

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

Note that the counter $K_B\left(t\right)$ 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 Equation 54 and the probability that $B_{THRESHOLD}$ would be met or exceeded at least once during the projection time horizon is given by Equation 55.

Fishing Mortality Thresholds

The user can specify the fishing mortality rate threshold for annual total fishing mortality $\left(F_{THRESHOLD}\right)$ 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 above). In particular, if $K_F\left(t\right)$ is the number of times that fishing mortality $F\left(t\right)$ exceeds the threshold fishing mortality $F_{THRESHOLD}$ in year *t*, then the annual probability that the fishing mortality threshold is exceeded is

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

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

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

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.

Age-Structured Projection Software

This section covers operational details for using the AGEPRO software and is organized into four 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 DOS command line, enter "agepro42.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:

```
>agepro42.exe inputfilename
> Bootstrap Iteration: 1
> Bootstrap Iteration: 2
...
> Bootstrap Iteration: NBootstrap
> Summary Reports …
```

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 1*st* 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 summaries of the distribution of population size at age by year. This is done by setting the StockSummaryFlag=1 under the keyword OPTIONS in the input file (Table 3). The summaries are 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 this option will typically produce a large file inputfilename.xx1 requiring on the order of 100Mb of storage.

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). 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 1^{st} 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 automatically create auxiliary raw output data files to record simulated trajectories of recruitment, spawning biomass, total stock biomass on January 1^{st}, mean biomass, combined catch biomass, landings, discards, and fishing mortality. This raw 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 raw output data file names are:

1. Stock numbers at age summary: inputfilename.xx1 (Note that this file is created only if StockSummaryFlag=1)
2. Recruitment: inputfilename.xx2
3. Spawning Stock Biomass: inputfilename.xx3
4. Total Stock Biomass on January 1^{st}: 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

The raw output data files have the same structure. In each output file, a single row represents a single simulated time trajectory with Y entries ordered from time t=1 to time t=Y. Within the file, trajectories are ordered by initial population vector (bootstrap) and then simulation for that initial 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 vectors and K simulations would have $B \cdot K$ rows that were ordered as

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

The output units of recruitment are numbers of fish. The output units of spawning biomass, total stock biomass, mean biomass, combined catch biomass, landings, and discards are kilograms. The units of F are the total annual fishing mortality rate calculated across all fleets.

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\Example1.INP

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_2017-12-29_13-58-58\Example1.BSN

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%      95%      99%
2004    1.6349   2.0914   2.5542   6.4615   29.3437   62.2498   77.8929   90.2558   286.7976
2005    1.6336   2.0901   2.5512   6.4411   29.2167   60.7815   77.8458   90.3986   287.6837
2006    1.6339   2.0818   2.5503   6.4087   29.2849   62.5382   78.0184   90.7273   288.0993
2007    1.6350   2.0884   2.5535   6.4762   29.2302   61.9145   77.9858   90.5247   286.4707
2008    1.6291   2.0739   2.5581   6.5566   29.2446   60.6213   77.7622   89.1439   285.0904
```

2009	1.6344	2.0814	2.5486	6.3915	29.2240	61.4137	77.9242	90.3276	286.2365

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%	95%	99%
2004	165.8676	168.7638	170.1585	172.7614	175.8218	178.5690	180.8508	182.8573	185.5046
2005	179.8766	183.7197	185.6327	188.7590	192.5027	195.8383	198.9160	201.2237	204.6554
2006	187.0135	191.4990	193.8062	197.3170	201.4796	205.3871	209.1779	211.8179	215.7972
2007	192.7856	197.3545	199.8073	203.5527	207.8812	212.1478	216.2523	218.9945	223.3188
2008	197.3263	201.9852	204.6063	208.5499	213.0613	217.5741	221.9399	224.8047	229.3702
2009	198.4668	203.2224	205.9017	210.1353	214.9276	219.7958	224.6939	227.6763	232.7305

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%	95%	99%
2004	187.3186	191.4205	193.6011	196.6419	200.3894	203.9891	207.4034	209.8751	213.3976
2005	197.4892	201.7822	204.0521	207.4953	211.5906	215.5423	219.3350	222.0173	226.0517
2006	203.4717	208.0624	210.6302	214.5143	218.9420	223.3492	227.6193	230.4027	234.8197
2007	208.3844	213.0947	215.5979	219.8570	224.5975	229.4958	234.4669	237.6307	242.8859
2008	212.2717	217.3223	220.0521	224.7293	230.0136	235.7004	241.6218	245.6423	254.4127
2009	212.1537	217.8630	220.8943	226.1200	232.1722	238.8682	246.3096	251.9540	265.1036

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%	95%	99%
2004	182.4411	186.3680	188.4693	191.4729	195.1343	198.6408	201.9259	204.3602	207.8469
2005	192.2976	196.4658	198.6699	202.0527	206.0414	209.8959	213.5926	216.1956	220.1596
2006	196.4374	200.8584	203.3081	207.0736	211.3400	215.5932	219.6988	222.4009	226.6468
2007	201.0939	205.6560	208.0465	212.1518	216.7343	221.4392	226.2450	229.2876	234.3949
2008	204.8011	209.7117	212.3378	216.8668	221.9600	227.4532	233.1969	237.0978	245.6776
2009	204.7867	210.2699	213.1971	218.2598	224.1077	230.5910	237.8015	243.2913	256.1328

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%	95%	99%
2004	0.6412	0.6528	0.6582	0.6686	0.6804	0.6910	0.6998	0.7076	0.7181
2005	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000
2006	4.1055	4.2163	4.2773	4.3641	4.4707	4.5678	4.6673	4.7226	4.8303
2007	4.2937	4.4271	4.4985	4.5986	4.7187	4.8331	4.9489	5.0200	5.1365
2008	4.4001	4.5202	4.5918	4.6971	4.8173	4.9389	5.0572	5.1349	5.2584
2009	4.3327	4.4380	4.5063	4.6087	4.7229	4.8433	4.9632	5.0356	5.1588

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%	95%	99%
2004	0.6412	0.6528	0.6582	0.6686	0.6804	0.6910	0.6998	0.7076	0.7181
2005	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000	0.7000
2006	4.1055	4.2163	4.2773	4.3641	4.4707	4.5678	4.6673	4.7226	4.8303
2007	4.2937	4.4271	4.4985	4.5986	4.7187	4.8331	4.9489	5.0200	5.1365
2008	4.4001	4.5202	4.5918	4.6971	4.8173	4.9389	5.0572	5.1349	5.2584
2009	4.3327	4.4380	4.5063	4.6087	4.7229	4.8433	4.9632	5.0356	5.1588

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%	95%	99%
2004	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048	0.0048
2005	0.0045	0.0046	0.0047	0.0047	0.0048	0.0049	0.0050	0.0051	0.0052
2006	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300
2007	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300
2008	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300
2009	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300	0.0300

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 of F=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 (see Appendix for input file) 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\Example2.INP

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_2017-12-29_14-19-44\Example2.BSN

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%	95%	99%
2014	150.1671	205.1791	227.5903	331.1452	1120.8200	2542.1990	6162.8810	6484.1110	11028.6100
2015	149.3512	204.6887	228.6934	334.4683	1120.1820	2541.2640	6152.7080	6487.6110	11048.1000
2016	154.2960	203.8387	225.7294	361.4124	1129.3905	2545.1890	6212.6520	6501.7350	10886.1000
2017	152.0371	210.7372	232.7332	359.0538	1129.9945	2544.1510	6190.1710	6506.0160	11309.1700
2018	153.6666	204.7484	227.5898	349.5553	1122.8935	2544.3130	6203.1390	6499.2570	11243.7600
2019	152.0957	209.2503	231.1399	342.5836	1125.1445	2543.9000	6212.2790	6536.6520	11337.6800
2020	150.5870	206.1237	230.0479	360.4650	1132.4435	2544.9890	6226.1050	6535.5360	11422.0900

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%	95%	99%
2014	3.5200	4.3275	4.7137	5.4851	6.4722	7.5894	8.7222	9.4729	10.9446
2015	5.4666	6.9514	7.6632	8.9364	10.7412	12.9279	14.9858	16.4572	19.3031
2016	6.4490	8.0138	8.8712	10.3627	12.4238	15.0340	17.4631	19.0611	22.6196
2017	6.5380	7.9215	8.7276	10.2139	12.2223	14.6496	17.0540	18.4992	21.5570
2018	5.6092	6.9035	7.6665	9.1293	11.0387	13.3430	15.5845	16.9557	19.8974
2019	4.0236	5.3269	6.0556	7.5435	9.4281	11.6586	13.8259	15.2291	17.8403
2020	3.8158	4.9913	5.6425	6.9951	8.7759	10.8012	12.7350	14.0313	16.5065

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%	95%	99%
2014	5.8387	7.3015	8.0296	9.3083	11.0600	13.2142	15.2749	16.6707	19.5190
2015	7.1894	8.8204	9.7234	11.2971	13.5244	16.2526	18.8028	20.6046	24.1617
2016	7.7881	9.4605	10.4082	12.1233	14.4212	17.2943	20.0188	21.8708	25.6910
2017	7.7478	9.3316	10.2328	11.9419	14.2320	16.9148	19.6778	21.2949	24.6684
2018	7.2064	8.7307	9.5603	11.2420	13.3875	15.8500	18.2481	19.8581	22.8287
2019	4.9782	6.5211	7.4069	9.0983	11.3092	13.8388	16.3219	17.7958	20.9340
2020	4.7593	6.1337	6.9781	8.5232	10.5738	12.9143	15.2091	16.6590	19.4733

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%	95%	99%
2014	6.7743	8.5594	9.4054	10.9301	13.1275	15.7951	18.3751	20.0235	23.4287
2015	7.5738	9.4465	10.3652	12.1587	14.5926	17.5658	20.4590	22.3897	26.2371
2016	7.9903	9.7496	10.6488	12.4953	14.9115	17.8132	20.7241	22.5648	26.2661
2017	7.6799	9.2810	10.1779	11.9493	14.2831	17.0375	19.6923	21.2855	24.9087
2018	6.1034	7.6719	8.5812	10.3214	12.6155	15.2101	17.6818	19.3861	22.5858
2019	4.9062	6.3754	7.2373	8.9247	11.0836	13.6122	15.9977	17.5320	20.7117
2020	4.6255	5.9719	6.7819	8.3407	10.4020	12.7506	15.0877	16.4991	19.5794

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%	95%	99%
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
2015	0.4340	0.5427	0.6046	0.7113	0.8555	1.0264	1.1884	1.3045	1.5357
2016	0.5651	0.7098	0.7834	0.9215	1.1052	1.3265	1.5480	1.6929	1.9909
2017	0.7298	0.9039	0.9911	1.1700	1.4071	1.6944	1.9823	2.1726	2.6016
2018	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966
2019	0.5368	0.7012	0.8076	0.9984	1.2549	1.5584	1.8669	2.0601	2.4484
2020	0.5392	0.7114	0.8088	1.0025	1.2569	1.5518	1.8438	2.0309	2.3896

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%	95%	99%
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
2015	0.4340	0.5427	0.6046	0.7113	0.8555	1.0264	1.1884	1.3045	1.5357
2016	0.5651	0.7098	0.7834	0.9215	1.1052	1.3265	1.5480	1.6929	1.9909
2017	0.7298	0.9039	0.9911	1.1700	1.4071	1.6944	1.9823	2.1726	2.6016
2018	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966	2.4966
2019	0.5368	0.7012	0.8076	0.9984	1.2549	1.5584	1.8669	2.0601	2.4484
2020	0.5392	0.7114	0.8088	1.0025	1.2569	1.5518	1.8438	2.0309	2.3896

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%	95%	99%
2014	0.1148	0.1340	0.1461	0.1696	0.2014	0.2412	0.2857	0.3139	0.3952

2015	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
2016	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
2017	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
2018	0.1825	0.2189	0.2408	0.2860	0.3500	0.4296	0.5190	0.5799	0.7405
2019	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
2020	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000

JAN-1 Stock Numbers at Age - 1000 Fish

2014

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	1095.7400	1126.8200	1157.6700	1199.9000	1247.3900	1293.2100	1339.0500	1360.0600	1404.8700
2	5815.7300	7232.0700	8377.4700	10215.8000	12906.8500	16274.7000	19489.5000	22076.3000	26764.3000
3	605.2860	742.5500	868.7790	1068.1800	1346.6300	1645.2400	2021.1100	2259.3700	2788.3600
4	1901.0200	2180.2500	2400.8400	2791.0000	3321.5800	3853.1700	4463.8300	4836.6200	5563.4700
5	176.1790	213.9540	241.0530	284.5670	342.7900	418.2160	477.3430	529.6300	634.5340
6	32.9855	41.5396	46.7232	56.6142	69.9137	88.1928	104.1120	118.6870	136.1660
7	12.9987	16.9683	19.9008	24.6551	31.1685	38.9058	47.6952	55.4722	66.0063
8	50.5496	64.3146	72.2744	89.3943	110.0280	133.9590	157.0870	170.5340	207.6260
9+	103.9710	159.1740	182.0530	225.6940	284.1005	356.5180	433.8950	482.1760	567.9220

2015

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	150.1671	205.1791	227.5903	331.1452	1120.8200	2542.1990	6162.8810	6484.1110	11028.6100
2	887.8562	922.5597	942.9964	979.3431	1019.9400	1061.2890	1100.2170	1123.0770	1160.5660
3	4724.3670	5884.9600	6798.6190	8276.9970	10469.3300	13189.7300	15985.8800	18030.0100	21786.0300
4	458.6349	579.8621	677.1247	832.9786	1056.4355	1303.7760	1602.3610	1814.0020	2236.2140
5	1388.8850	1636.0870	1812.6300	2132.5230	2555.2555	2996.3000	3495.6230	3824.3460	4417.0360
6	120.7904	150.2547	172.1194	206.6085	252.4803	312.3292	361.4383	400.4779	498.4812
7	21.3308	27.8132	31.8572	39.5234	50.0190	63.7509	76.3860	88.3243	102.9572
8	8.1611	11.0643	12.9375	16.8231	21.5830	27.4805	34.0739	39.6238	48.4185
9+	99.1900	142.4742	166.3174	212.3172	272.2853	345.9320	425.8746	468.2724	564.1196

2016

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	149.3512	204.6887	228.6934	334.4683	1120.1820	2541.2640	6152.7080	6487.6110	11048.1000
2	122.6079	167.5320	186.7238	270.6380	932.5010	2086.0260	5051.1580	5326.5060	9020.4290
3	710.6238	743.4937	762.5140	792.6984	826.6821	862.4630	895.3975	913.9427	949.1091
4	3699.5560	4632.8560	5342.0500	6523.0780	8265.4655	10393.9500	12573.6900	14252.8300	17146.8600
5	353.6407	447.9320	522.2761	642.1836	814.4617	1004.5240	1234.6130	1397.6710	1723.4520
6	1022.0040	1210.2630	1332.3580	1574.6600	1884.6520	2212.1540	2583.8580	2825.5160	3269.6370
7	85.6311	107.2060	122.3344	147.0802	180.6755	222.8392	258.5840	286.6373	358.1803
8	14.7620	19.2894	22.1592	27.4605	34.8072	44.3394	53.2656	61.4762	71.9711
9+	76.3752	107.4038	125.3629	160.6426	205.1725	259.9684	318.5978	352.4900	422.2210

2017

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	154.2960	203.8387	225.7294	361.4124	1129.3905	2545.1890	6212.6520	6501.7350	10886.1000
2	122.4453	166.9060	186.5583	273.5268	924.9599	2074.8450	5058.8330	5326.8450	9059.0880
3	98.6721	135.7598	151.5422	218.5243	758.2042	1695.3800	4090.3880	4320.9590	7276.3590
4	555.9447	583.0513	598.1129	623.8630	651.9622	681.2245	708.2104	724.4374	754.6333
5	2851.8990	3580.1050	4117.6850	5024.5930	6371.6070	8004.3590	9689.6580	10972.1000	13239.3800
6	261.0618	330.7912	384.8489	473.6005	600.6945	742.7213	913.8329	1037.5410	1277.2900
7	726.6373	861.8317	950.5333	1123.4050	1341.5895	1577.9470	1845.7470	2020.5990	2342.8860
8	59.3449	74.6039	85.0226	102.4041	125.6241	155.1049	180.6077	200.1796	252.7425
9+	65.8990	89.2369	103.3606	131.8739	167.2694	209.3213	257.1538	283.2395	341.7310

2018

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	152.0371	210.7372	232.7332	359.0538	1129.9945	2544.1510	6190.1710	6506.0160	11309.1700
2	125.9985	167.1557	185.6035	295.5600	935.4454	2097.9120	5084.9840	5334.7680	8852.2650
3	99.7584	134.7766	152.1943	222.3991	751.9013	1685.2500	4105.3300	4336.8570	7370.9580
4	78.4004	106.8737	119.8788	172.1859	597.7342	1338.5740	3226.9110	3417.3480	5798.7450
5	424.1483	447.3210	459.3271	479.6160	502.7516	526.7769	548.9252	561.7752	586.3748
6	2089.6800	2644.4020	3036.4550	3710.9630	4707.0140	5923.2100	7170.1380	8083.2790	9706.0750

7	187.2364	235.6444	273.3657	337.6416	428.3732	530.8136	653.5985	742.1140	910.3953
8	502.6856	601.8133	660.8785	780.8261	935.3516	1100.4240	1284.5000	1409.9500	1644.4540
9+	88.7375	117.2458	132.9764	162.7726	203.1062	248.8700	296.8760	328.0390	390.5430

2019

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	153.6666	204.7484	227.5898	349.5553	1122.8935	2544.3130	6203.1390	6499.2570	11243.7600
2	125.6385	171.2869	191.4572	293.4845	936.8988	2101.1120	5065.3120	5337.1690	9282.9010
3	100.6454	133.9611	149.4112	239.4418	755.7065	1695.1120	4083.9320	4302.3260	7124.3410
4	75.9471	101.6247	116.3168	169.1645	576.0969	1288.6220	3151.6090	3347.2970	5651.9420
5	56.9325	77.0244	87.8735	126.1823	438.8362	990.5278	2389.8910	2567.0220	4265.1580
6	241.0660	274.4351	290.0872	315.9705	342.6452	368.9478	392.5774	405.1795	430.8668
7	1088.2510	1459.0940	1752.8150	2264.1170	3022.4015	3969.4200	4952.0780	5644.7680	6985.5020
8	92.5160	126.7009	153.4395	200.6431	262.7260	334.9452	427.0272	493.7872	614.5672
9+	249.7404	360.1757	416.3782	521.9749	661.7476	821.6150	987.4303	1108.2670	1319.1460

2020

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	152.0957	209.2503	231.1399	342.5836	1125.1445	2543.9000	6212.2790	6536.6520	11337.6800
2	125.4417	168.1045	186.3815	286.0352	934.1904	2103.3390	5072.6260	5335.4040	9113.0580
3	101.2067	138.5952	155.5509	238.0804	764.2864	1702.1790	4113.1280	4342.2010	7582.7920
4	79.8333	105.2166	118.2490	189.0875	597.1814	1343.2180	3222.5690	3401.1950	5652.6620
5	58.6316	78.3392	90.1692	130.4061	445.5383	997.0890	2427.3970	2591.6970	4376.1830
6	41.8457	56.4963	64.9800	93.3839	324.2153	733.5625	1763.0560	1905.3330	3168.3210
7	171.4524	195.2795	206.3613	224.8976	244.1048	263.1188	280.4399	289.7867	308.1276
8	749.8229	1020.1310	1215.3620	1577.0540	2104.9460	2770.4520	3463.9650	3924.7230	4854.7490
9+	244.0270	346.8155	405.7743	507.1333	642.8957	794.1324	959.9258	1070.2010	1260.2230

Requested Percentile Report

Percentile = 90.00 %

	2014	2015	2016	2017	2018	2019	2020
Recruits	6162.8810	6152.7080	6212.6520	6190.1710	6203.1390	6212.2790	6226.1050
Spawning Stock Biomass	8.7222	14.9858	17.4631	17.0540	15.5845	13.8259	12.7350
Jan-1 Stock Biomass	15.2749	18.8028	20.0188	19.6778	18.2481	16.3219	15.2091
Mean Biomass	18.3751	20.4590	20.7241	19.6923	17.6818	15.9977	15.0877
Combined Catch Biomass	0.5000	1.1884	1.5480	1.9823	2.4966	1.8669	1.8438
Landings	0.5000	1.1884	1.5480	1.9823	2.4966	1.8669	1.8438
FMort	0.2857	0.2000	0.2000	0.2000	0.5190	0.2000	0.2000

Stock Numbers at Age							
Age 1	1339.0500	6162.8810	6152.7080	6212.6520	6190.1710	6203.1390	6212.2790
Age 2	19489.5000	1100.2170	5051.1580	5058.8330	5084.9840	5065.3120	5072.6260
Age 3	2021.1100	15985.8800	895.3975	4090.3880	4105.3300	4083.9320	4113.1280
Age 4	4463.8300	1602.3610	12573.6900	708.2104	3226.9110	3151.6090	3222.5690
Age 5	477.3430	3495.6230	1234.6130	9689.6580	548.9252	2389.8910	2427.3970
Age 6	104.1120	361.4383	2583.8580	913.8329	7170.1380	392.5774	1763.0560
Age 7	47.6952	76.3860	258.5840	1845.7470	653.5985	4952.0780	280.4399
Age 8	157.0870	34.0739	53.2656	180.6077	1284.5000	427.0272	3463.9650
Age 9	433.8950	425.8746	318.5978	257.1538	296.8760	987.4303	959.9258

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 90th percentile.

Running example 3 (see Appendix for input file) 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\Example3.INP

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_2017-12-29_14-49-07\Example3.BSN

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%	95%	99%
2014	153.7521	208.0085	229.3621	347.0616	1132.0955	2545.3470	6225.6320	6522.2980	11133.4100
2015	152.8537	207.5118	228.9794	352.4027	1126.1215	2542.6540	6181.5870	6500.1300	11200.0900
2016	152.0864	205.9702	227.0639	334.5421	1120.9140	2544.0470	6196.3710	6505.2510	10864.6400
2017	153.9306	204.6065	223.9934	335.6253	1120.2075	2541.6660	6154.7360	6491.9800	10947.3800
2018	151.7663	206.4086	227.8564	353.3611	1136.3925	2544.5000	6227.9310	6534.0640	11412.9500
2019	150.6260	205.4969	229.0507	342.5477	1120.8380	2543.5260	6205.1600	6521.0480	11515.9200
2020	152.6280	209.8481	230.9342	348.8617	1120.4415	2541.6850	6179.7760	6495.6550	11322.8800

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%	95%	99%
2014	3.5078	4.3130	4.7139	5.4741	6.4677	7.5996	8.7246	9.5079	10.8959
2015	5.5792	7.0419	7.7295	9.0558	10.8637	13.1038	15.2164	16.6561	19.6792
2016	6.8389	8.5537	9.4430	11.0420	13.2202	15.9565	18.5612	20.2245	23.9665
2017	7.3671	8.9936	9.9199	11.6008	13.8159	16.5604	19.2488	20.9204	24.5266
2018	7.4340	9.0080	9.8747	11.5974	13.8368	16.4445	18.9478	20.6655	24.1175
2019	7.2135	8.7442	9.6034	11.3116	13.5319	16.0556	18.4609	20.0106	23.2609
2020	7.1247	8.5118	9.3369	11.0000	13.2158	15.6735	18.0730	19.5799	22.4662

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%	95%	99%
2014	5.9561	7.3305	8.0160	9.3127	11.0570	13.2145	15.2783	16.6890	19.4895
2015	7.0768	8.8151	9.7325	11.3215	13.5287	16.2558	18.8747	20.6014	24.4138
2016	8.1564	9.8810	10.8909	12.7070	15.0950	18.1127	20.8555	22.7520	26.5054
2017	8.5564	10.2829	11.2717	13.1921	15.6896	18.6290	21.5091	23.3583	27.0562
2018	8.5860	10.3039	11.2642	13.1568	15.7288	18.5593	21.3129	23.1065	26.8372
2019	8.3366	10.0510	10.9747	12.8914	15.3734	18.1349	20.8302	22.5606	26.1722
2020	8.1237	9.7586	10.7283	12.5950	15.0481	17.7564	20.3938	22.0870	25.1322

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%	95%	99%
2014	6.8296	8.5113	9.3948	10.9509	13.0968	15.7592	18.2887	20.0230	23.4237
2015	7.8519	9.6342	10.6250	12.5018	14.9013	17.9378	20.8969	22.8972	27.2031
2016	8.6093	10.4184	11.4735	13.4336	16.0525	19.1332	22.1543	24.0733	28.1761
2017	8.7683	10.6194	11.6720	13.6335	16.2788	19.3000	22.2328	24.2065	28.2042
2018	8.6469	10.3838	11.3612	13.3676	15.9913	18.8559	21.6646	23.4338	27.1640
2019	8.3179	9.9544	10.9414	12.8538	15.4182	18.2748	20.9306	22.6906	26.1512
2020	7.9700	9.6937	10.6649	12.5609	15.0972	17.9037	20.6399	22.3327	25.8592

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%	95%	99%
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
2015	0.1003	0.1249	0.1392	0.1633	0.1963	0.2339	0.2728	0.2977	0.3469
2016	0.1394	0.1741	0.1925	0.2250	0.2708	0.3237	0.3775	0.4135	0.4824
2017	0.1914	0.2364	0.2608	0.3046	0.3669	0.4417	0.5168	0.5646	0.6686
2018	0.2283	0.2769	0.3047	0.3575	0.4290	0.5124	0.5971	0.6567	0.7565
2019	0.2287	0.2767	0.3051	0.3569	0.4295	0.5137	0.5978	0.6517	0.7612
2020	0.2444	0.2973	0.3263	0.3852	0.4629	0.5511	0.6407	0.6968	0.8046

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%	95%	99%
2014	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
2015	0.1003	0.1249	0.1392	0.1633	0.1963	0.2339	0.2728	0.2977	0.3469
2016	0.1394	0.1741	0.1925	0.2250	0.2708	0.3237	0.3775	0.4135	0.4824
2017	0.1914	0.2364	0.2608	0.3046	0.3669	0.4417	0.5168	0.5646	0.6686
2018	0.2283	0.2769	0.3047	0.3575	0.4290	0.5124	0.5971	0.6567	0.7565
2019	0.2287	0.2767	0.3051	0.3569	0.4295	0.5137	0.5978	0.6517	0.7612
2020	0.2444	0.2973	0.3263	0.3852	0.4629	0.5511	0.6407	0.6968	0.8046

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%	95%	99%
2014	0.1162	0.1334	0.1462	0.1696	0.2015	0.2408	0.2839	0.3145	0.3851
2015	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445
2016	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445
2017	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445
2018	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445
2019	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445
2020	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445

JAN-1 Stock Numbers at Age - 1000 Fish

2014

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	1095.7400	1126.8200	1157.6700	1199.9000	1247.3900	1293.2100	1339.0500	1360.0600	1404.8700
2	5815.7300	7232.0700	8377.4700	10215.8000	12906.8500	16274.7000	19489.5000	22076.3000	26764.3000

3	605.2860	742.5500	868.7790	1068.1800	1346.6300	1645.2400	2021.1100	2259.3700	2788.3600
4	1901.0200	2180.2500	2400.8400	2791.0000	3321.5800	3853.1700	4463.8300	4836.6200	5563.4700
5	176.1790	213.9540	241.0530	284.5670	342.7900	418.2160	477.3430	529.6300	634.5340
6	32.9855	41.5396	46.7232	56.6142	69.9137	88.1928	104.1120	118.6870	136.1660
7	12.9987	16.9683	19.9008	24.6551	31.1685	38.9058	47.6952	55.4722	66.0063
8	50.5496	64.3146	72.2744	89.3943	110.0280	133.9590	157.0870	170.5340	207.6260
9+	103.9710	159.1740	182.0530	225.6940	284.1005	356.5180	433.8950	482.1760	567.9220

2015

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	153.7521	208.0085	229.3621	347.0616	1132.0955	2545.3470	6225.6320	6522.2980	11133.4100
2	886.9999	920.9055	944.3435	979.9522	1020.1620	1060.7430	1100.8560	1122.0680	1162.0630
3	4740.6350	5881.5180	6788.0890	8280.2530	10437.9000	13190.6000	15924.2900	17940.1300	21772.2100
4	462.1501	579.5480	678.5247	836.1118	1057.6295	1300.8420	1601.9910	1805.4510	2228.2810
5	1402.6870	1632.0730	1811.3860	2130.7570	2557.1140	3001.1490	3490.7850	3797.3750	4431.1560
6	121.0333	150.3102	172.2205	206.2701	252.2545	312.3252	361.8990	399.4688	500.4583
7	21.2549	27.8869	31.7288	39.5810	50.0350	63.4947	76.4838	88.1371	102.7191
8	8.1178	11.0340	12.9066	16.8518	21.5642	27.4360	34.0090	39.6686	48.5591
9+	99.6480	143.0746	165.8811	212.3056	272.7287	345.4891	426.8521	469.6036	565.7290

2016

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	152.8537	207.5118	228.9794	352.4027	1126.1215	2542.6540	6181.5870	6500.1300	11200.0900
2	125.6120	169.9832	187.3362	285.8009	935.7087	2106.8640	5088.4640	5358.8910	9065.7230
3	717.8408	749.2020	767.2159	798.8983	833.9748	868.6385	901.6998	920.6849	957.7862
4	3849.5580	4772.2030	5517.5350	6713.5670	8486.4350	10724.0600	12954.9300	14583.3900	17684.0800
5	368.8452	470.1688	546.3981	674.9982	854.9253	1053.6940	1296.1080	1465.7940	1812.3090
6	1112.4340	1304.3160	1447.6410	1703.7200	2044.2600	2402.5000	2796.6280	3037.7140	3551.5220
7	95.8425	119.3594	136.5312	163.6895	200.5233	247.8007	287.8207	317.0682	397.7311
8	16.6931	22.0278	25.0771	31.2594	39.5369	50.2574	60.4657	69.4576	81.1850
9+	87.9257	122.3541	142.6734	181.7372	232.7070	294.7329	361.5172	399.8996	479.7186

2017

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	152.0864	205.9702	227.0639	334.5421	1120.9140	2544.0470	6196.3710	6505.2510	10864.6400
2	124.9328	169.5370	187.5875	289.2126	936.7591	2082.4200	5059.7310	5330.1260	9139.4520
3	102.7604	138.0878	153.3027	233.9465	767.8980	1732.9510	4159.4080	4386.5270	7358.2990
4	578.2827	604.7967	621.0119	646.7345	676.8689	707.3514	734.5654	751.9041	781.6806
5	3091.6750	3845.1700	4440.2080	5421.1320	6866.7700	8644.6120	10492.0100	11781.0100	14283.2900
6	296.0683	374.3265	437.9340	540.8164	682.1429	842.5300	1037.5380	1173.8450	1454.1730
7	879.9575	1036.5260	1146.0000	1352.4100	1621.8885	1915.9780	2223.3420	2419.6970	2822.7990
8	75.7144	94.2965	107.6556	129.2856	158.5479	195.8338	227.5058	250.5553	316.8310
9+	86.1764	115.7229	134.3767	170.3536	216.4243	270.1949	329.6626	363.0636	442.1880

2018

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	153.9306	204.6065	223.9934	335.6253	1120.2075	2541.6660	6154.7360	6491.9800	10947.3800
2	124.3599	168.1019	186.5384	274.1155	933.7431	2097.5150	5068.9150	5351.9300	8980.8960
3	102.6584	138.0619	153.2109	234.4648	768.2888	1705.2570	4137.6920	4376.4240	7491.3740
4	83.0630	111.7923	125.1747	190.0386	624.9189	1406.8860	3375.8670	3580.8130	5996.0150
5	463.1497	486.4656	499.5535	521.4975	546.8899	572.8059	596.2554	610.6294	636.2804
6	2458.2110	3074.0040	3543.9720	4341.7510	5493.7480	6912.7910	8409.3140	9431.2870	11449.5100
7	232.8949	297.6859	348.1032	429.2734	541.3385	669.5108	824.7090	932.7457	1149.7860
8	693.9673	815.9270	903.8471	1069.8840	1279.5850	1510.4820	1752.6630	1913.4760	2242.3930
9+	131.7504	172.7009	195.3063	239.6761	298.3704	363.7684	430.1583	479.6413	576.7128

2019

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	151.7663	206.4086	227.8564	353.3611	1136.3925	2544.5000	6227.9310	6534.0640	11412.9500
2	126.1664	166.8946	184.0337	273.6497	926.2880	2074.8740	5060.7700	5321.2440	9009.6770
3	101.1790	137.3052	152.7485	223.9679	764.1367	1718.8710	4145.2170	4387.6230	7300.6000
4	83.1064	111.7158	124.8275	190.8343	624.4940	1389.5640	3365.4510	3567.1850	6061.0810
5	67.4937	90.0772	101.2675	154.1486	505.3076	1142.8570	2726.6630	2894.6220	4833.3090
6	367.9427	387.4575	398.0623	416.4294	437.2194	459.0043	478.4960	491.2420	512.2461
7	1965.4640	2431.6780	2821.0370	3445.3130	4364.2560	5494.9360	6693.2650	7529.1950	9091.8490

8	183.2299	234.7869	274.1439	339.3622	427.2745	529.8703	651.1502	737.6687	912.8956
9+	645.5298	785.3057	869.6136	1034.7050	1242.1625	1464.2670	1703.0170	1862.6330	2167.4780

2020

Age	1%	5%	10%	25%	50%	75%	90%	95%	99%
1	150.6260	205.4969	229.0507	342.5477	1120.8380	2543.5260	6205.1600	6521.0480	11515.9200
2	123.8571	167.9808	187.1525	289.8989	937.2894	2106.1880	5097.7430	5374.9480	9313.5090
3	102.3573	135.9500	150.7452	222.9596	759.5409	1692.0840	4135.9360	4364.2630	7376.7490
4	81.7678	111.0348	123.6390	182.1238	620.7917	1400.0710	3356.1290	3576.1200	5956.0300
5	67.0329	89.8906	100.9146	154.5096	504.2604	1124.6640	2720.8110	2890.6500	4865.1570
6	54.1054	71.9035	81.1756	123.2250	405.4597	915.6747	2177.4730	2329.5830	3886.8050
7	290.4778	305.5871	315.3789	330.0894	347.1659	365.1161	381.6304	391.7124	410.2046
8	1534.5130	1921.6320	2227.5890	2721.7010	3447.9955	4331.5540	5284.6800	5929.2270	7222.0580
9+	695.9149	838.0460	934.9111	1101.1280	1328.9345	1555.9650	1818.6410	1978.0690	2310.0400

Requested Percentile Report

Percentile = 90.00 %

	2014	2015	2016	2017	2018	2019	2020
Recruits	6225.6320	6181.5870	6196.3710	6154.7360	6227.9310	6205.1600	6179.7760
Spawning Stock Biomass	8.7246	15.2164	18.5612	19.2488	18.9478	18.4609	18.0730
Jan-1 Stock Biomass	15.2783	18.8747	20.8555	21.5091	21.3129	20.8302	20.3938
Mean Biomass	18.2887	20.8969	22.1543	22.2328	21.6646	20.9306	20.6399
Combined Catch Biomass	0.5000	0.2728	0.3775	0.5168	0.5971	0.5978	0.6407
Landings	0.5000	0.2728	0.3775	0.5168	0.5971	0.5978	0.6407
FMort	0.2839	0.0445	0.0445	0.0445	0.0445	0.0445	0.0445

Stock Numbers at Age							
Age 1	1339.0500	6225.6320	6181.5870	6196.3710	6154.7360	6227.9310	6205.1600
Age 2	19489.5000	1100.8560	5088.4640	5059.7310	5068.9150	5060.7700	5097.7430
Age 3	2021.1100	15924.2900	901.6998	4159.4080	4137.6920	4145.2170	4135.9360
Age 4	4463.8300	1601.9910	12954.9300	734.5654	3375.8670	3365.4510	3356.1290
Age 5	477.3430	3490.7850	1296.1080	10492.0100	596.2554	2726.6630	2720.8110
Age 6	104.1120	361.8990	2796.6280	1037.5380	8409.3140	478.4960	2177.4730
Age 7	47.6952	76.4838	287.8207	2223.3420	824.7090	6693.2650	381.6304
Age 8	157.0870	34.0090	60.4657	227.5058	1752.6630	651.1502	5284.6800
Age 9	433.8950	426.8521	361.5172	329.6626	430.1583	1703.0170	1818.6410

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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
$B_T(t)$	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
$F_B(t)$	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 $Q(t)$
	Else if $I(t)$ = 0, then fishery harvest is based on a fishing mortality rate $F(t)$
$L(t)$	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 1^{st} 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
$P_{R,i}(t)$	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 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

Table 1. Glossary, continued.

Variable	Description
$W_{v,L,a}(t)$	Average landed (catch) weight 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 $t = 1, 2, ..., Y$

Table 2. Table of AGEPRO input 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

Table 2. Table of AGEPRO input keywords, continued.

KEYWORD	PURPOSE
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
PSTAR	Input information for calculating TAC to produce P* which is the probability of overfishing in the target projection year

Table 3. Structure of an AGEPRO version 4.2 input file by keyword. Inputs are space delimited.

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
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.

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

KEYWORD	INPUT VARIABLE
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 !=1) 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
BIOLOGICAL	1. **ZFracTimeFlag** (I) – this is the logical flag that indicates if the fractions of fishing and natural mortality that occur before spawning are a time-varying array (input =1) or constant values 2. If (**ZFracTimeFlag** = 1) then read **TF**[0:NYears-1] (F) and read **TM**[0:NYears-1] (F) Else read **TF**[0] (F) and read **TM**[0] (F) – this is the logic for the fractions of fishing and natural mortality that occur before spawning

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

KEYWORD	INPUT VARIABLE
MATURITY	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
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

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

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
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

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

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
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

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

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

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

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

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

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 4. **RecruitType**[0:NRecModel-1] (I) – this is the vector of recruitment submodel types included 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
OPTIONS	1. **StockSummaryFlag** (I) – this is the logical flag to output stock summary information 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

Table 3. Structure of an AGEPRO version 4.2 input file by keyword, continued.

KEYWORD	INPUT VARIABLE
PERC	1. **PercReportValue** (F) **–** this is the user-selected percentile for reporting the percentile of the projected distribution of the following quantities of interest 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
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 0=spawning stock biomass, 1= stock biomass on January 1st, else = 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).
PSTAR	1. **KPStar** (I) **–** this is the user-selected number of PStar values to be evaluated in the target year 2. **PStar**[0:KPStar-1] (F) – these are the PStar values to evaluate where PStar is the probability of exceeding the overfishing level 3. **PStarF** (F) – this is the fishing mortality rate that defines the overfishing level 4. **TargetYear** (I) **–** this is the user-selected target year for which the total annual catch to produce the user-selected PStar values is calculated

Table 4. Required input data for AGEPRO recruitment models, where spawning biomass and recruitment inputs are measured in units of 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: $p_{1,1}, p_{1,2}, ..., p_{1,K}$ $p_{2,1}, p_{2,2}, ..., p_{2,K}$ $\vdots$ $p_{J,1}, p_{J,2}, ..., p_{J,K}$
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}, 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: $B_{S,1}, B_{S,2}, ..., B_{S,T_{High}}$

Table 4. Required input data for AGEPRO recruitment models, continued.

Model Number	**Recruitment Model**	**Recruitment Model Input Description**
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 Autocorrelated Lognormal Error	Input the stock-recruitment parameters: $\alpha, \beta, \sigma_w^2$ On the next line input the autoregressive parameters: ϕ, ε_0
11	Ricker Curve with Autocorrelated 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 Autocorrelated Lognormal Error	Input the stock-recruitment parameters: $\alpha, \beta, k, \sigma_w^2$ On the next line input the autoregressive parameters: ϕ, ε_0

Table 4. Required input data for AGEPRO recruitment models, continued.

Model Number	**Recruitment Model**	**Recruitment Model Input Description**
13	Autocorrelated 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}, 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 high state recruitments: $R_1, R_2, ..., R_{T_{High}}$
16	Linear Recruits Per Spawning Biomass Predictor with Normal Error	Input the number of 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 the projection time horizon: $X_1(1), ..., X_1(Y)$ $X_2(1), ..., X_2(Y)$ $\vdots$ $X_p(1), ..., X_p(Y)$

Table 4. Required input data for AGEPRO recruitment models, continued.

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*: $X_1(1) \quad X_1(2) \quad \dots \quad X_1(Y)$ $X_2(1) \quad X_2(2) \quad \dots \quad X_2(Y)$ $\vdots \quad \vdots \quad \vdots \quad \vdots$ $X_p(1) \quad X_p(2) \quad \dots \quad X_p(Y)$
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*: $X_1(1) \quad X_1(2) \quad \dots \quad X_1(Y)$ $X_2(1) \quad X_2(2) \quad \dots \quad X_2(Y)$ $\vdots \quad \vdots \quad \vdots \quad \vdots$ $X_p(1) \quad X_p(2) \quad \dots \quad X_p(Y)$

Table 4. Required input data for AGEPRO recruitment models, continued.

Model Number	Recruitment Model	Recruitment Model Input Description
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*: $X_1(1) \quad X_1(2) \quad \dots \quad X_1(Y)$ $X_2(1) \quad X_2(2) \quad \dots \quad X_2(Y)$ $\vdots \quad \vdots \quad \vdots \quad \vdots$ $X_p(1) \quad X_p(2) \quad \dots \quad X_p(Y)$
20	Fixed Recruitment	Input the number of recruitment data points: Y On the next line input the recruitments: $R_1, R_2, ..., R_Y$
21	Empirical Cumulative Distribution Function of Recruitment with Linear Decline to Zero	Input the 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^*

Figure 1. Flowchart for AGEPRO

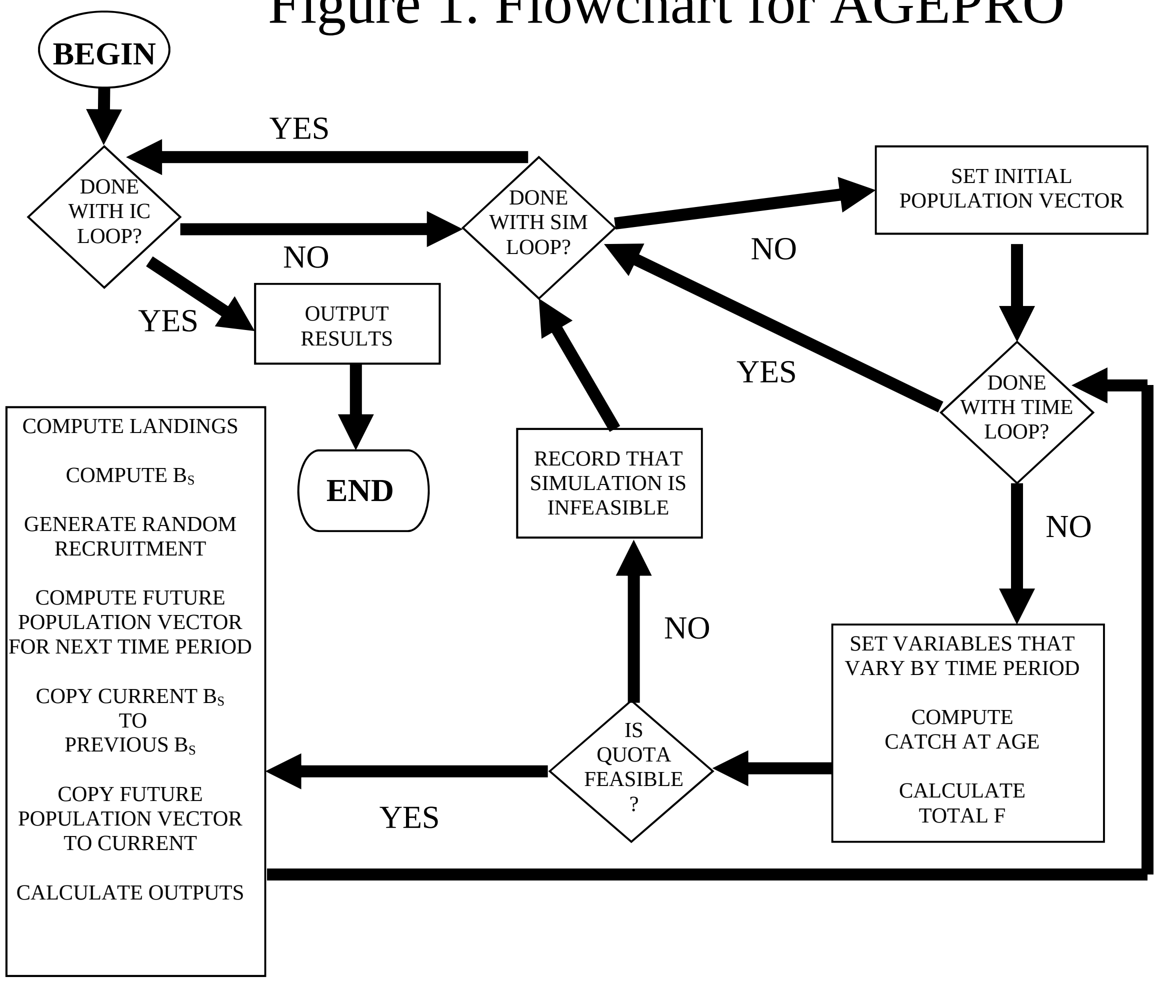
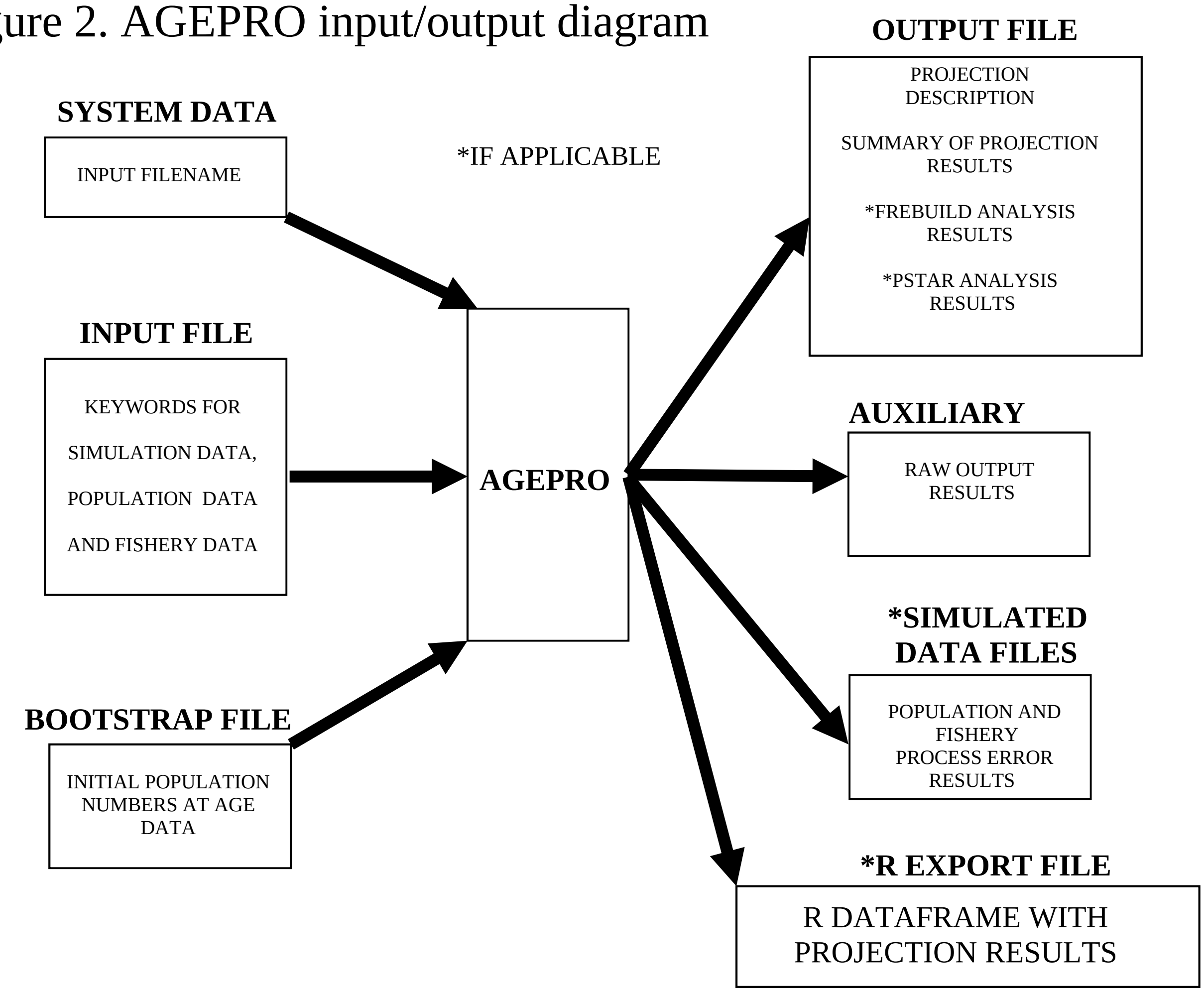


Figure 2. AGEPRO input/output diagram



Appendix

Example 1 Input File

AGEPRO VERSION 4.0
[CASEID]
REDFISH - RECRUITMENT MODEL 14
[GENERAL]
2004 2009 1 26 100 2 1 0 49667890
[BOOTSTRAP]
1000 1000
C:\Users\Jon.Brodziak\Documents\AGEPRO\Example1_2017-12-29_13-58-58\Example1.BSN
[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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
0.565 0.581 0.595 0.583 0.582 0.637
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0.001 0.001 0.001 0.001 0.001 0.001
[SSB_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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
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 0.001 0.001 0.001 0.001
0.001 0.001 0.001 0.001 0.001 0.001
[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 0.548 0.558
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 0.548 0.558
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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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
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 0.548 0.558
0.565 0.581 0.595 0.583 0.582 0.637
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0.001 0.001 0.001 0.001 0.001 0.001
[CATCH_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 0.548 0.558
0.565 0.581 0.595 0.583 0.582 0.637
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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 0.548 0.558
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0.565 0.581 0.595 0.583 0.582 0.637
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0.565 0.581 0.595 0.583 0.582 0.637
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0.565 0.581 0.595 0.583 0.582 0.637
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0.001 0.001 0.001 0.001 0.001 0.001
[NATMORT]
0 1
0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
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0.05 0.05
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
[BIOLOGICAL]
0
0.4
0.4
[MATURITY]
0 1
0.01 0.02 0.05 0.15 0.36 0.64 0.85 0.95 0.98 0.99 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0.01 0.02 0.05 0.15 0.36 0.64 0.85 0.95 0.98 0.99 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0.01 0.02 0.05 0.15 0.36 0.64 0.85 0.95 0.98 0.99 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0.01 0.02 0.05 0.15 0.36 0.64 0.85 0.95 0.98 0.99 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0.01 0.02 0.05 0.15 0.36 0.64 0.85 0.95 0.98 0.99 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0.01 0.02 0.05 0.15 0.36 0.64 0.85 0.95 0.98 0.99 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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 0.001 0.001
0.001 0.001 0.001 0.001 0.001 0.001 0.001
[FISHERY]
0 1
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 0.783 0.656 0.522 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 0.783 0.656 0.522 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 0.783 0.656 0.522 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 0.783 0.656 0.522 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 0.783 0.656 0.522 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
0 0.002 0.011 0.054 0.223 0.522 0.656 0.783 1 1 0.783 0.656 0.522 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
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 0.001 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 0.001 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 0.001
[RECRUIT]

1000000 1 75
14
1
1
1
1
1
1
53
73.5939 78.1845 70.6004 62.1267 66.0886 69.9814 49.9445 70.4022 42.6731 85.2977 48.2887 98.1364 76.867 33.8211
7.8195 4.3288 2.6275 2.7917 4.2174 249.227 6.5051 2.5329 1.9038 1.7011 1.5596 2.2002 52.7585 2.4754 2.8037 10.179
21.2349 8.6637 20.0313 11.1925 5.0913 4.3675 28.9894 51.3917 8.7334 35.7165 327.489 73.3318 35.0047 22.4337 24.9481
32.1726 34.4703 29.245 81.7098 30.5807 25.3895 26.28 30.1793
[HARVEST]
0 1 0 0 0 0
0.00239 350 0.01 0.01 0.01 0.01
0.00239 350 0.02 0.02 0.02 0.02
[REFPOINT]
236700 0 0 0.04
[OPTIONS]
0 0 1

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  1080  2179  2276  13429
2547  1121  1216  219  6281  386  1118  1218  215  301  966  6659
[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
[BOUNDS]
10  0.6
[OPTIONS]
1  0  0
[SCALE]
1000  1000  1000
[PERC]
90
```

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  1080  2179  2276  13429
2547  1121  1216  219  6281  386  1118  1218  215  301  966  6659
[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]
1  0  0
[SCALE]
1000  1000  1000
[PERC]
90
```