

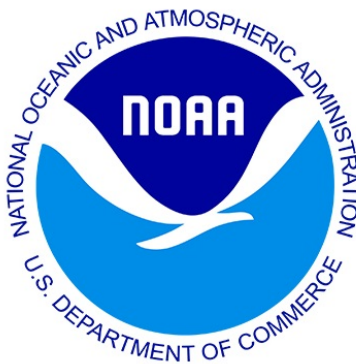
# **Stock Synthesis User Manual**

## **Version 3.30.13**

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# Introduction

Fish population (aka "stock") assessment models determine the impact of past fishing on the historical and current abundance of the population, evaluate sustainable rates of removals (catch), and project future levels of catch that will implement risk-averse catch rules. These catch rules are codified in regional Fishery Management Plans according to requirements of the Sustainable Fisheries Act. In the U.S., 500 federally managed fish and shellfish populations are under 50 Fishery Management Plans. About 200 of these populations are assessed according to a prioritized schedule for their current status each year, but many minor species have never been quantitatively assessed. Although the pace is slower than weather forecasting, fish stock assessments are operational models for fisheries management.

Assessment models typically assimilate several decades of annual catch, data on fish abundance from diverse surveys and fishery sources, and biological information regarding fish body size and the proportions at age. A suite of models is available depending on the degree of data availability and unique characteristics of the fish population or its fishery. Where feasible, environmental time series are used as indicators of changes in population or observation processes, especially to improve the accuracy of the projections of abundance and sustainable catch into the future. Such linkages are based principally on correlations given the challenge of conducting field observations on an appropriate scale. The frontier of model development is in the rapid estimation of parameters to include random temporal effects, in the simultaneous modeling of a suite of interacting species, and in the explicit treatment of the spatial distribution of the population.

Assessment models are loosely coupled to other models. For example, an ocean-temperature or circulation model or benthic-habitat map may be directly included in the pre-processing of the fish abundance survey. A time series of a derived ocean factor, like the North Atlantic Oscillation, can be included as an indicator of a change in a population process. Output of a multi-decadal time series of derived fish abundance can be an input to ecosystem and economic models to better understand cumulative impacts and benefits.

Stock Synthesis (SS) is an age- and size-structured assessment model in the class of models termed integrated analysis models. SS has a population sub-model that simulates a stock's growth, movement, and mortality processes; an observation sub-model estimates expected values for various types of data; a statistical sub-model characterizes the data's goodness of fit and obtains best-fitting parameters with associated variance; and a forecast sub-model projects needed management quantities. SS outputs the quantities, with confidence intervals, needed to implement risk-averse fishery control rules. The model is coded in C++ with parameter estimation enabled by automatic differentiation ([www.admb-project.org](http://www.admb-project.org)). Windows, Linux, and iOS versions are available. Output processing and associated tools are in R, and a graphical interface is in QT. SS is available from NOAA's VLAB. The rich feature set in SS allows it to be configured for a wide range of situations and it has become the basis for a large fraction of U.S. assessments and many other assessments around the world.

This manual provides a guide for using SS. The guide contains a description of the input and output files and usage instructions. A technical description of the model itself is in Methot and Wetzel (2013). The model and a graphical user interface are available from the NOAA VLAB at [vlab.ncep.noaa.gov/group/stock-synthesis/home](http://vlab.ncep.noaa.gov/group/stock-synthesis/home). The VLAB site also provides a user forum for posting questions and for accessing various additional materials. An output processor package, `r4ss`, in R is available for download from CRAN or GitHub. Additional information about the package can be located at [github.com/r4ss/r4ss](https://github.com/r4ss/r4ss).

Additional guidance for new users is available from the NOAA VLAB at [vlab.ncep.noaa.gov/group/stock-synthesis/document-library](http://vlab.ncep.noaa.gov/group/stock-synthesis/document-library). The "Begin Here - Introduction to Stock Synthesis" folder located in the Document Library contains step-by-step guidance for running Stock Synthesis.

## New Features Available in SS Version 3.30

Stock Synthesis version v.3.30 was designed specifically to provide more precise temporal control of growth, expected values for data, and for recruitment. In addition, a large number of new features that make substantial changes to the input formats have been introduced. Two executables of SS are provided. One, `ss_trans.exe`, will read SS v.3.24 input files and produce SS v.3.30 formatted versions of those input files. Nearly every feature in SS v.3.24 can be converted by this program. The other executable, `ss.exe`, will then be your primary new assessment tool. Additional information on each new feature available by clicking on the item.

Category	Item	Description
General	<a href="#">Generic Fleets</a>	Fleet specification section of data file is much changed and now includes fleet type, so fishery fleets, bycatch fleets, surveys, and someday predators are specified in any order
	<a href="#">List-oriented inputs</a>	Rather than specify the number of items to be read, now SS can figure it out on its own with lists terminated by -9999 in first field of the read vector
	<a href="#">Internal sub-seasons</a>	SS v.3.24 inherently has 2 subseasons each season (begin and middle) at which the age-length-key is calculated; now user specifies an even number of sub-seasons to use (2 to many)

Category	Item	Description
	<a href="#">Observation Timing</a>	Timing of observations now is input as year, month where month is real; e.g. April 15 is 4.5; age-length-key used for each observation is calculated to the nearest sub-season. Old "survey_timing" replaced by the month specific inputs. Season is calculated at runtime from the input month and the input season durations.
	<a href="#">Speed</a>	Smarter at when to re-calculate the age-length-key; trims tails of size-at-age so calculations avoid many inconsequential cells of the age-length matrix. Age-length-key tail compression is specified in the starter file.
	<a href="#">Converter</a>	Special version of SS, ss_trans.exe, will read files in SS v.3.24 format and write *.ss_new files in SS v.3.30 format. This is the advised method for converting previous version files, but always do a side-by-side comparison.
	<a href="#">Empirical Weight-at-Age</a>	Implementing empirical weight-at-age is now specified separately in the control file rather than under the maturity options.
	<a href="#">Prior Type</a>	Change in the prior numbering for parameters. Now, 0 indicates no prior, and 6 indicates a normal distribution prior.
Fishery and Catch	<a href="#">Catch multiplier</a>	Each fishing fleet's catch can now have a catchability (Q) that is a parameter in the mortality-growth parameter section.
	<a href="#">Catch input</a>	Catch input now as list: year, season, fleet, amount, standard error.
	<a href="#">Observations</a>	Fishery composition observations can be related to season long catch-at-age, or to a month-specific timing.
	<a href="#">Retention</a>	Option for dome-shaped retention function and for age-based retention.
Selectivity	<a href="#">Scaling Options</a>	A new non-parametric selectivity types that are scaled by the raw values at particular ages, rather than the max age.
	<a href="#">Two-Dimensional Autoregressive Selectivity</a>	Implementation of two-dimensional autoregressive selectivity implemented in SS v.3.30.10.



Category	Item	Description
Survey	<a href="#">Special Survey Types</a>	Special selectivity options (type 30 or >) are no longer specified within the control file. Specifying the use of one of these selectivity types is now done within the data file by selecting the survey "units".
	<a href="#">Link functions</a>	Q <sub>power</sub> is now one of several, and growing, set of link functions for catchability.
	<a href="#">Catchability setup reorganization</a>	Major reorganization of catchability (Q) setup, including the link specification.
	<a href="#">Q as a parameter</a>	Each survey now must have a Q parameter and its value still can float (as old option 5).
Recruitment	<a href="#">Shepherd SRR</a>	A 3-parameter Shepherd stock-recruitment curve is now an option.
	<a href="#">Shepherd SRR re-parameterization</a>	A 3-parameter Shepherd stock-recruitment curve is now an option in SS v.3.30.11 and higher.
	<a href="#">Ricker SRR re-parameterization</a>	A 3-parameter Ricker stock-recruitment curve is now an option in SS v.3.30.11 and higher.
	<a href="#">Recruitment timing</a>	Replace "birthseason" with "settlement event" that has explicit timing offset from spawning. Month of spawning and each settlement event must be specified and need not be at beginning of a season.
Benchmark	Global MSY	Global MSY based on knife edge age selection; also do calculation with single age selection. The global MSY value will automatically be included in the report file.
	Mean recruitment distribution	In multi-area model, can now specify range of years to use for the average recruitment distribution for forecasting. This feature is not yet implemented.
Forecast	Process error	Propagate random walk in mortality growth parameters, catchability, and selectivity into forecast. Specifying the end year for process error in the forecast period will implement this option. This option has only been partial implemented at this junction and will be completed in later versions.
Biology	<a href="#">Parameter order</a>	Mortality growth parameters now have maturity, fecundity, sex ratio, and weight-length by growth pattern.

Category	Item	Description
Statistical	<a href="#">Sex ratio</a>	Change sex ratio at birth from a constant to a morph-specific mortality growth parameter. This feature was not correctly implemented in SS v.3.30 earlier than v.3.30.12.
	<a href="#">Growth cessation</a>	New growth option which allows for growth cessation, implemented in SS v.3.30.13.
	<a href="#">Input variance adjuster</a>	Added variance adjustment factor for generalized size comp.
	Deviation vectors	Variance of deviation vectors is now specified with 2 parameters for standard error and auto-correlation (rho), so can be estimated.
Parameters	<a href="#">Dirichlet multinomial</a>	Dirichlet multinomial now a fleet-specific option; takes one parameter per fleet.
	<a href="#">Parameter order</a>	The prior standard deviation column for all parameter lines has been moved before the prior type column. This modification improves formatting output between integer and decimal inputs.
	Density dependence	Beginning of year summary biomass and the recruitment deviation parameters are mapped to the "environmental" matrix so that parameters can be density-dependent.
	<a href="#">Re-order</a>	Pay attention to the new order of the time-varying adjustments to parameters (block/trend, then environmental, then deviations).
Software version control	<a href="#">Time-varying parameters</a>	Long parameter lines for spawner-recruit relationship (SRR), catchability (Q), and tag parameters and complete re-vamp of the way that time-varying parameters are implemented for SRR and Q. Now shares same internal code as mortality-growth and selectivity parameters for time-varying capabilities.
	Version numbering	The implementation of as new version control has changed how executable versions will be specified. The executable releases are now named SS3.3x.xx.xx representing, in order; major features, minor features, and code fixes.

## SS v.3.24 Issues Detected

The process of updating and adding new features within SS v.3.30 expose several issues with the previous version that have been corrected:

1. Recruitment timing in multi-season models: When spawning occurred in a late season one year and recruits occurred at beginning of a season the next year, the recruits were starting at age-0, which was illogical. SS v.3.30 corrects this so that recruits are age-0 only if recruiting at or between the time of spawning and the end of the year, and recruits after January 1st start at age-0. A manual option in the control file allows users to attempt to replicate the SS v.3.24 protocol.
2. Lorenzen  $M$  and time-varying growth interaction: There needs to be a revision to SS v.3.30 so that growth can be updated each season prior to calculating Lorenzen  $M$ .
3. Length at maximum age: SS v.3.24 intended to decay this length over-time at  $M + F$  decreased the abundance of fish implicitly older than the maximum age (agemax). However, this decay was only implemented in years for which time-varying growth was updated.
4. SS v.3.24 had a lower bound of 1 when adjusting annual sample size (Nsamp) downward for composition data (length and age). The variance adjustment factors in the specified in the control file are multiplied across all annual sample size values for each data source (fleet and composition type). The issue with the lower bound of 1 resulted in sample size adjustment not being constant across small and large sample size years, possibly resulting in smaller samples have higher impact than may be desired. SS v.3.30 has reduced this lower bound to a value of 0.001 but has retained user control over this value within the data file ("minsamplesize" column in the Composition Data Structure matrix at the top of the length and age data sections) to allow comparison with older model versions.

## File Organization

### Input Files

1. starter.ss: required file containing filenames of the data file and the control file plus other run controls (required).
2. datafile: file containing model dimensions and the data (required)

3. control file: file containing set-up for the parameters (required)
4. forecast.ss: file containing specifications for reference points and forecasts (required)
5. ss.par: previously created parameter file that can be read to overwrite the initial parameter values in the control file (optional)
6. wtatage.ss: file containing empirical input of body weight by fleet and population and empirical fecundity-at-age (optional)
7. runnumber.ss: file containing a single number used as run number in output to CumReport.sso and in the processing of profilevalues.ss (optional)
8. profilevalues.ss: file contain special conditions for batch file processing (optional)

## Output Files

1. data.ss\_new: Contains a user-specified number of datafiles, generated through a parametric bootstrap procedure, and written sequentially to this file.
2. control.ss\_new: Updated version of the control file with final parameter values replacing the initial parameter values.
3. starter.ss\_new: New version of the starter file with annotations.
4. Forecast.ss\_new: New version of the forecast file with annotations.
5. warning.sso: This file contains a list of warnings generated during program execution.
6. echoinput.sso: This file is produced while reading the input files and includes an annotated echo of the input. The sole purpose of this output file is debugging input errors.
7. Report.sso: This file is the primary report file.
8. ss\_summary.sso: Output file that contains all the likelihood components, parameters, derived quantities, total biomass, summary biomass, and catch. This file offers an abridged version of the report file that is useful for quick model evaluation. This file is only available in SS v.3.30.08.03 and greater.
9. CompReport.sso: Observed and expected composition data in a list-based format.
10. Forecast-report.sso: Output of management quantities and for forecasts.

11. CumReport.sso: This file contains a brief version of the run output, output is appended to current content of file so results of several runs can be collected together. This is useful when a batch of runs is being processed.
12. Covar.sso: This file replaces the standard ADMB ss.cor with an output of the parameter and derived quantity correlations in database format.
13. ss.par: This file contains all estimated and fixed parameters from the model run.
14. ss.std, ss.rep, ss.cor etc.: Standard ADMB output files.
15. checkup.sso: Contains details of selectivity parameters and resulting vectors. This is written during the first call of the objective function.
16. Gradient.dat: New for SS v.3.30, this file shows parameter gradients at the end of the run.
17. rebuild.dat: Output formatted for direct input to Andre Punt's rebuilding analysis package. Cumulative output is output to REBUILD.SS (useful when doing MCMC or profiles).
18. SIS\_table.sso: Output formatted for reading into the NMFS Species Information System.
19. Parmtrace.sso: Parameter values at each iteration.
20. posteriors.sso, derived\_posteriors.sso, posterior\_vectors.sso: Files associated with MCMC.

## Auxiliary Files

These files are additional files (e.g. excel files) which allow for exploration or understanding of specific parameterization which can assist in selecting appropriate starting values. These files are available for download from the Vlab website.

1. SS3-OUTPUT.xls: Excel file with macros to read report.sso and display results.
2. Selex24\_dbl\_normal.xls:
  - (a) This excel file is used to show the shape of a double normal selectivity (option number 20 for age-based and 24 for length-based selectivity) given user-selected parameter values.
  - (b) Instructions are noted in the excel file but, to summarize
    - i. Users should only change entries in a yellow box.
    - ii. Parameter values are changed manually or using sliders, depending on the value of

cell I5.

- (c) It is recommend that users select plausible starting values for double-normal selectivity options, especially when estimating all 6 parameters
- (d) Please note that the excel file does NOT show the impact of setting parameters 5 or 6 to -999. In SS v.3.30, this allows the value of selectivity at the initial and final age or length to be determined by the shape of the double-normal arising from parameters 1-4, rather than forcing the selectivity at the initial and final age or length to be estimated separately using the value of parameters 5 and 6.

3. Selex17\_age\_randwalk.xls:

- (a) This excel file is used to show the shape of age-based selectivity arising from option 17 given user-selected parameter values
- (b) Users should only change entries in the yellow box.
- (c) The red box is the maximum cumulative value, which is subtracted from all cumulative values. This is then exponentiated to yield the estimated selectivity curve. Positive values yield increasing selectivity and negative values yield decreasing selectivity.

4. Prior\_Tester.xls:

- (a) The 'compare' tab of this spreadsheet shows how the various options for defining parameter priors work.

5. SS\_330\_Control\_Setup.xls:

- (a) Shows how to setup an example control file for SS.

6. SS\_330\_Data\_Input.xls:

- (a) Shows how to setup an example data input for SS.

7. SS\_330\_Starter&Forecast.xls:

- (a) Shows how to setup an example data input for SS.

8. Growth\_Comparison.xls:

- (a) Excel file to test parameterization between the growth curve options within SS.
- (b) Instructions are noted in the excel file but, to summarize
  - i. Users should only change entries in a yellow box.

- ii. Entries in a red box are used internally, and can be compared with other parameterizations, but should not be changed.
- (c) The SS-VB is identical to the standard von Bertenlaffy growth curve, but uses a parameterization where length is estimated at pre-defined ages, rather than  $A=0$  and  $A=Inf$ . The Schnute- Richards is identical to the Richards-Maunders, but similarly uses the parameterization with length at pre-defined ages. The Richards coefficient controls curvature, and if the curvature coefficient = 1, it reverts to the standard von Bertenlaffy growth curve.

#### 9. Movement.xls:

- (a) Excel file to explore SS movement parameterization.

## Starting SS

SS is typically run through the command line interface although it can also be called from another program such as R or the SS-GUI or a script file (such as a DOS batch file). SS is compiled for Windows, Mac, and Linux operating systems. The memory requirements depend on the complexity of the model you run, but in general, SS will run much slower on computers with inadequate memory. See the Running SS section on page 150 for additional notes on methods of running SS.

Communication with the program is through text files. When the program first starts, it reads the file `starter.ss`, which typically must be located in the same directory from which SS is being run. The file `starter.ss` contains required input information plus references to other required input files, as described in the File Organization section on page 6. The names of the control and data files must match the names specified in the `starter.ss` file. File names, including `starter.ss`, are case-sensitive on Linux and Mac systems but not on Windows. The `echoinput.sso` file outputs how the executable read each input file and can be used for troubleshooting when trying to get a model setup correctly. Output from SS is as text files containing specific keywords. Output processing programs, such as the SS GUI, Excel, or R can search for these keywords and parse the specific information located below that keyword in the text file.

## Converting Files from SS v.3.24

Converting files from SS v.3.24 to SS v.3.30 can be easily performed by using the program `ss_trans.exe`. The following file structure and steps are recommended for converting model files:

1. Create "transition" folder. Place four model files from version SS v.3.24 within the transition folder along with the SS transition executable (ss\_trans.exe). One tip is to use the control.ss\_new from the SS v.3.24 estimated model rather than the control.ss file which will set all parameter values at the previous estimated maximum likelihood estimated (MLE) parameters. Run the transition executable with phase = 0 within the starter file, with the read par file turned off (option 0).
2. Create "converted" folder. Place the ss\_new (data.ss\_new, control.ss\_new, starter.ss\_new, forecast.ss\_new) files created by the transition executable contained within the "transition" folder into this new folder. Rename the ss\_new files to the appropriate suffixes and change the names in the starter.ss file accordingly.
3. Review the control file to determine that all model functions converted correctly. The structural changes and assumptions for a couple of the advanced model features are too complicated to convert automatically. See below for some known features that may not convert.
4. Change the max phase to a value greater than the last phase in which the a parameter is set to estimated within the control file. Run the new SS v.3.30 executable (ss.exe) within the "converted" folder using the renamed ss\_new files created from the transition executable.
5. Compare likelihood and model estimates between the SS v.3.24 and SS v.3.30 model versions.

There are some options that have been substantially changed in SS v.3.30 which impedes the automatic converting of SS v.3.24 model files. Known examples of SS v.3.24 options that cannot be converted, but for which better alternatives are available in SS v.3.30 are:

1. The use of Q deviations,
2. Complex birth seasons,
3. Environmental effects on spawner-recruitment parameters,
4. Setup of time-varying quantities for models that used the no-longer-available (e.g logistic bound constraint).

## Starter File

SS begins by reading the file starter.ss. Its format and content is as follows. Note that the term COND in the Typical Value column means that the existence of input shown there is conditional on a value specified earlier in the file. Omit or comment out these entries if the appropriate condition has not been selected.



## STARTER.SS

Value	Options	Description
#C this is a starter comment	Must begin with #C then rest of the line is free form	All lines in this file beginning with #C will be retained and written to the top of several output files
data_file.dat		File name of the data file
control_file.ctl		File name of the control file
0	Initial Parameter Values: 0 = use values in control file; 1 = use ss.par after reading setup in the control file	Don't use this if there have been any changes to the control file that would alter the number or order of parameters stored in the ss.par file. Values in ss.par can be edited, carefully. Do not run ss_trans.exe from a ss.par from SS v.3.24.
1	Run display detail: 0 = none other than ADMB outputs; 1 = one brief line of display for each iteration; 2 = fuller display per iteration	With option 2, the display shows value of each -logL component for each iteration and it displays where crash penalties are created
1	Detailed age-structure report 0 = minimal (no Report file); 1 = include all output; 2 = brief output	Detailed age-structured report in Report.sso

Value	Options	Description
0	Write 1st iteration details 0 = omit 1 = write detailed intermediate calculations to echoinput.sso during first call	This output is largely unformatted and undocumented and is mostly used by the developer.
0	Parameter Trace 0 = omit 1 = write good iteration and active parameters 2 = write good iterations and all parameters 3 = write every iteration and all parameters 4 = write every iteration and active parameters	This controls the output to parmtrace.sso. The contents of this output can be used to determine which values are changing when a model approaches a crash condition. It also can be used to investigate patterns of parameter changes as model convergence slowly moves along a ridge.
1	Cumulative Report 0 = omit 1 = brief 2 = full	Controls reporting to the file Cumreport.sso. This cumulative report is most useful when accumulating summary information from likelihood profiles or when simply accumulating a record of all model runs within the current subdirectory
1	Full Priors 0 = only calculate priors for active parameters 1 = calculate priors for all parameters that have a defined prior	Turning on this option causes all prior values to be calculated. With this option off, the total log likelihood, which includes the log likelihood for priors, would change between model phases as more parameters became active.

Value	Options	Description
1	Soft Bounds 0 = omit 1 = use	This option creates a weak symmetric beta penalty for the selectivity parameters. This becomes important when estimating selectivity functions in which the values of some parameters cause other parameters to have negligible gradients, or when bounds have been set too widely such that a parameter drifts into a region in which it has negligible gradient. The soft bound creates a weak penalty to move parameters away from the bounds.
1	Data File Output 0 = none 1 = output an annotated replicate of the input data file 2 = add a second data file containing the model's expected values with no added error 3+ = add N-2 parametric bootstrap data files	All output files are sequentially output to data.ss_new and will need to be parsed by the user into separate data files. The output of the input data file makes no changes, so retains the order of the original file. Output files 2-N contain only observations that have not been excluded through use of the negative year denotation, and the order of these output observations is as processed by the model. The N obs values are adjusted accordingly. At this time, the tag recapture data is not output to data.ss_new.
8	Turn off estimation -1 = exit after reading input files 0 = exit after one call to the calculation routines and production of sso and ss_new files <positive value> = exit after completing this phase	The 0 option is useful for (1) quickly reading in a messy set of input files and producing the annotated control.ss_new and data.ss_new files, or (2) examining model output based solely on input parameter values. Similarly, the value option allows examination of model output after completing a specified phase. Also see usage note for restarting from a specified phase.
10	MCMC burn interval	Need to document this and set good default
2	MCMC thin interval	Need to document this and set good default

Value	Options	Description
0.0	<b>Jitter</b> A positive value here will add a small random jitter to the initial parameter values. When using the jitter option, care should be given when defining the low and high bounds for parameter values and particularly -999 or 999 should not be used to define bounds for estimated parameters.	The jitter function has been revised with SS v.3.30. Starting values are now jittered based on a normal distribution based on the $\text{pr}(P_{\text{MIN}}) = 0.1\%$ and the $\text{pr}(P_{\text{MAX}}) = 99.9\%$ .
-1	SD Report Start -1 = begin annual SD report in start year <year> = begin SD report this year	
-1	SD Report End -1 = end annual SD report in end year -2 = end annual SD report in last forecast year <value> = end SD report in this year	
2	Extra SD Report Years 0 = none <value> = number of years to read	In a long time series application, the model variance calculations will be smaller and faster if not all years are included in the SD reporting. For example, the annual SD reporting could start in 1960 and the extra option could select reporting in each decade before then.
COND: If Extra SD report years > 0		
1940 1950	Vector of years for additional SD reporting	

Value	Options	Description
0.0001	Final convergence	This is a reasonable default value for the change in log likelihood denoting convergence. For applications with much data and thus a large total log likelihood value, a larger convergence criterion may still provide acceptable convergence
0	Retrospective year 0 = none -x = retrospective year relative to end year	Adjusts the model end year and disregards data after this year. May not handle time varying parameters completely.
0	Summary biomass min age	Minimum integer age for inclusion in the summary biomass used for reporting and for calculation of total exploitation rate
1	Depletion basis 0 = skip 1 = $X \cdot SB_0$ 2 = $X \cdot SB_{MSY}$ 3 = $X \cdot SB_{styr}$ 4 = $X \cdot SB_{endyr}$	Selects the basis for the denominator when calculating degree of depletion in SSB. The calculated values are reported to the SD report.
0.40	Fraction (X) for depletion denominator	So would calculate the ratio of $SSB_y / (0.40 \cdot SSB_0)$
1	SPR report basis 0 = skip 1 = use $1 - SPR_{target}$ 2 = use $1 - SPR$ at MSY 3 = use $1 - SPR$ at $B_{target}$	SPR is the equilibrium SSB per recruit that would result from the current year's pattern and intensity of F's. The SPR approach to measuring fishing intensity was implemented because the concept of a single annual F does not exist in SS. The quantities identified by 1, 2, and 3 here are all calculated in the benchmarks section. Then the one specified here is used as the selected denominator in a ratio with the

Value	Options	Description
	4 = no denominator, so report actual 1-SPR values	annual value of $(1 - \text{SPR})$ . This ratio (and its variance) is reported to the SD report output for the years selected above in the SD report year selection.
4	F std report value 0 = skip 1 = exploitation rate in biomass 2 = exploitation rate in numbers 3 = sum(full F's by fleet) 4 = population F for range of ages 5 = unweighted average F for range of ages	In addition to SPR, an additional proxy for annual F can be specified here. As with SPR, the selected quantity will be calculated annually and in the benchmarks section. The ratio of the annual value to the selected (see F report basis below) benchmark value is reported to the SD report vector. Options 1 and 2 use total catch for the year and summary abundance at the beginning of the year, so combines seasons and areas. But if most catch occurs in one area and there is little movement between areas, this ratio is not informative about the F in the area where the catch is occurring. Option 3 is a simple sum of the full F's by fleet, so may provide non-intuitive results when there are multi areas or seasons or when the selectivities by fleet do not have good overlap in age. Option 4 is a real annual F calculated as a numbers weighted F for a specified range of ages (read below). The F is calculated as $Z - M$ where Z and M are each calculated an $\ln(N_{t+1}/N_t)$ with and without F active, respectively. The numbers are summed over all biology morphs and all areas for the beginning of the year, so subsumes any seasonal pattern.
COND: If F std reporting > 4		Specify range of ages. Upper age must be less than max age because of incomplete handling of the accumulator age for this calculation.
13 17	Age range if F std reporting = 4	
1	F report basis 0 = not relative, report raw values 1 = use F std value corresponding to $\text{SPR}_{\text{target}}$ 2 = use F std value corresponding to $F_{\text{MSY}}$ 3 = use F std value corresponding to $F_{\text{Btarget}}$	Selects the denominator to use when reporting the F std report values. Note that order of these options differs from the biomass report basis options.

Value	Options	Description
0.01	MCMC output detail 0 = default 1 = output likelihood components and associated lambda values 2 = expanded output 3 = make output subdirectory for each MCMC vector.	Specify format of MCMC output. This input requires the specification of two items; the output detail and a bump value to be added to the $\ln(R0)$ in the first call to MCMC. A bias adjustment of 1.0 is applied to recruitment deviations in the MCMC phase, which could result in reduced recruitment estimates relative to the MLE when a lower bias adjustment value is applied. A small value, called the "bump", is added to the $\ln(R0)$ for the first call to MCMC in order to prevent the stock from hitting the lower bounds when switching from MLE to MCMC. If you wanted to select the default output option and apply a bump value of 0.01 this is specified by 0.01 where the integer value represents the output detail and the decimal is the bump value.
0	Age-length-key (ALK) tolerance level, 0 >= values required	Value of 0 will not apply any compression. Values > 0 (e.g. 0.0001) will apply compression to the ALK which will increase the speed of calculations. The size of this value will impact the run time of your model, but one should be careful to ensure that the value used does not appreciably impact the estimated quantities relative to no compression of the ALK. The suggested value if applied is 0.0001.
3.30	3.30: Indicates that the control and data files are currently in SS v3.30 format. 999: Indicates that the control and data file are in a previous SS v.3.24 version. The ss_trans.exe executable should be used which will convert the files to the new format in the control.ss_new and data.ss_new files.	The transition executable for SS v.3.30 will create converted files in the new format from previous versions (must be SS v.3.24) when 999 is given. All ss_new files are in the SS v.3.30 format, so starter.ss_new has SS v.3.30 on the last line. The mortality-growth parameter section has a new sequence, so SS v.3.30 cannot read a ss.par file produced by SS v.3.24 and earlier, so please ensure that read par file option at the top of the starter file is set to 0. The Converting Files from SS v.3.24 section has additional information on model features that may impede file conversion.
<b>End of Starter File</b>		

## Jitter

The jitter function has been updated with SS v.3.30. The following steps are now performed to determine the jittered starting parameter values:

1. A normal distribution is calculated such that the  $\text{pr}(P_{\text{MIN}}) = 0.1\%$  and the  $\text{pr}(P_{\text{MAX}}) = 99.9\%$ .
2. A jitter shift value, termed " $K$ ", is calculated from the distribution based on the  $\text{pr}(P_{\text{CURRENT}})$ .
3. A random value is drawn, " $J$ ", from the range of  $K$ -jitter to  $K$ +jitter with the constraint that it cannot be  $<0.1\%$  or  $> 99.9\%$  of the distribution.
4.  $J$  is a new cumulative normal probability value.
5. Calculate a new parameter value,  $P_{\text{JITTERED}}$ , such that  $\text{pr}(P_{\text{JITTERED}}) = J$ .

## Forecast File

The specification of options for forecasts is contained in the mandatory input file named forecast.ss. For additional detail on the forecast file see Appendix C on page [198](#).

## Terminology

The term COND appears in the value column of this documentation (it does not actually appear in the forecast file), it indicates that the following section is omitted except under certain conditions, or that the factors included in the following section depend upon certain conditions. In most cases, the description in the definition column is the same as the label output to the forecast.ss\_new file.



## FORECAST.SS

Value	Options	Description
1	<a href="#">Benchmarks/Reference Points</a> 0 = omit 1 = calculate $F_{SPR}$ , $F_{Btarget}$ , and $F_{MSY}$ 2 = calculate $F_{SPR}$ , $F_{Btarget}$ , $F_{MSY}$ , $F_{0.10}$	SS checks for consistency of the Forecast specification and the benchmark specification. It will turn benchmarks on if necessary and report a warning.
1	MSY Method 1 = $F_{SPR}$ as proxy 2 = calculate $F_{MSY}$ 3 = $F_{Btarget}$ as proxy or $F_{0.10}$ 4 = $F_{end\ year}$ as proxy	Specifies basis for $F_{MSY}$ .
0.45	$SPR_{target}$	SS searches for F multiplier that will produce this level of spawning biomass per recruit (reproductive output) relative to unfished value.
0.40	Relative Biomass Target	SS searches for F multiplier that will produce this level of spawning biomass relative to unfished value. This is not “per recruit” and takes into account the spawner-recruitment relationship.
0 0 0 0 0 0 0 0 0 0	Benchmark Years -999: start year >0: absolute year <= 0: year relative to end year	Requires 10 values, (1,2) beginning and ending years for biology (growth, natmort, maturity, fecundity), (3,4) selectivity, (5,6) relative Fs, (7,8) movement and recruitment distribution; (9,10) SRparms for averaging years in calculating benchmark quantities

Value	Options	Description
1	Benchmark Relative F Basis 1 = use year range 2 = set range for relF same as forecast below	Does not affect year range for selectivity and biology.
2	Forecast 0 = none (no forecast years) 1 = use $F_{SPR}$ 2 = use $F_{MSY}$ 3 = use $F_{Btarget}$ or $F_{0.10}$ 4 = set to average F scalar for the forecast relative F years below 5 = input annual F scalar	This input is required but is ignored if benchmarks are turned off. If $F_{MSY}$ is selected, it uses whatever proxy, e.g. $F_{SPR}$ or $F_{BTGT}$ is selected in the benchmark section.
10	N forecast years (must be $\geq 1$ )	At least one forecast year now required which differs from version SS v.3.24 that allowed zero forecast years.
1	F scalar	Only used if Forecast option = 5 (input annual F scalar).
0 0 0 0 0 0	Forecast Years >0 = absolute year <= 0 = year relative to end year	Requires 6 values: beginning and ending years for selectivity, relative Fs, and recruitment distribution that will be used to create averages to use in forecasts. In future, hope to allow random effects to propagate into forecast. NOTE: Relative F for bycatch only fleets is scaled just like other fleets. More options for this in future.

Value	Options	Description
0	Forecast Selectivity Option 0 = forecast selectivity is mean from year range 1 = forecast selectivity from annual time-varying parameters	Determines the selectivity used in the forecast years.
1	Control Rule 1 = catch as function of SSB, buffer on F 2 = F as function of SSB, buffer on F 3 = catch as function of SSB, buffer on catch 4 = F is a function of SSB, buffer on catch	
0.40	Control Rule Upper Limit	Biomass level (as a fraction of $SSB_0$ ) above which F is constant at control rule $F_{target}$ .
0.10	Control Rule Lower Limit	Biomass level (as a fraction of $SSB_0$ ) below which F is set to 0.
0.75	Control Rule Buffer (multiplier or -1)	Control rule $F_{target}$ as a fraction of selected $F_{MSY}$ proxy. A value of -1 will allow the user to input a forecast year specific control rule fraction (added in v. 3.30.13). Note, if using Pope's F, then this value will be applied to the catch rather than the F. Model's that use either continuous F or the hybrid F will apply this value directly to the F. Future versions will allow a user to specify whether the adjustment should be applied to either the catch or F independent of the fishing mortality method selected.

Value	Options	Description
COND -1: Conditional input for annual control rule buffer	2019 0.8 2020 0.6 2021 0.5 -9999 0	Year and control rule buffer value. Can enter a value for each year, or starting sequence of years. The final control rule buffer value will apply to all sequent forecast years.
3	Number of forecast loops (1,2,3)	SS sequentially goes through the forecast up to three times. Maximum number of forecast loops: 1=OFL only, 2=ABC control rule, 3=set catches equal to control rule or input catch and redo forecast implementation error.
3	First forecast loop with stochastic recruitment	If this is set to 1 or 2, then OFL and ABC will be as if there was perfect knowledge about recruitment deviations in the future.
0	Forecast recruitment 0 = spawner recruit curve 1 = value*(spawner recruit curve) 2 = value*(virgin recruitment) 3 = recent mean from year range above	Option 0, ignore input and do forecast recruitment as before SS v.3.30.10, if 1, then use next value as a multiplier applied after env/block/regime is applied, if 2, then use value as multiplier times adjusted virgin recruitment (after time-varying adjustments to R0), and if 3, then use value as the number of years from end of main recruitment deviations to average (mean is the recruitments, not the deviations).
1	Scaler or N years recent main recruitments to average	This input depends upon option selected directly above. If option 1 or 2 selected this value should be a scalar value to be applied to recruitment. If option 3 is selected above this should be input as the number of years to average recruitment.

Value	Options	Description
0	Forecast loop control #5	Reserved for future model features.
2015	First year for caps and allocations	Should be after years with fixed inputs.
0	Implementation Error	The standard deviation of the log of the ratio between the realized catch and the target catch in the forecast. (set value >0.0 to cause implementation error deviations to be an estimated parameter that will add variance to forecast).
0	Rebuilder 0 = omit West Coast rebuilder output 1 = do West Coast rebuilder output	Creates a rebuild.dat file to be used for West Coast groundfish rebuilder program.
2004	Rebuilder catch (Year Declared) >0 = year first catch should be set to zero -1 = set to 1999	
2004	Rebuilder start year (Year Initial) >0 = year for current age structure -1 = set to end year +1	
1	Fleet Relative F 1 = use first-last allocation year 2 = read season(row) x fleet (column) set below	
2	Basis for maximum forecast catch 2 = total catch biomass	

Value	Options	Description
	3 = retained catch biomass 5 = total catch numbers 6 = retained total numbers	
COND 2: Conditional input for fleet relative F		
0.1 0.8 0.1	Fleet allocation by relative F fraction	The fraction of the forecast F value. For a multiple area model user must define a fraction for each fleet and each area. The total fractions must sum to one over all fleets and areas. Starting in version 3.30 this now also includes surveys which are treated similar to fleets. Ex: # Fleet 1 Fleet 2 Survey X (rows are seasons)
1 50 -9999 -1	Maximum total catch by fleet	Enter fleet number and its max. Last line of the entry must have fleet number = -9999.
-9999 -1	Maximum total catch by area -1 = no maximum	Enter area number and its max. Last line of the entry must have area number = -9999.
1 1 -9999 -1	Fleet assignment to allocation group	Enter list of fleet number and its allocation group number if it is in a group. Last line of the entry must have fleet number = -9999.
COND: if N allocation groups is >0		
2002 1	Allocation to each group for each year of the forecast	Enter a year and the allocation fraction to each group for that year. SS will fill those values to the end of the forecast, then read another year from this list. Terminate with -9999 in year field. Annual values are rescaled to sum to 1.0.
-9999 1		

Value	Options	Description
-1	Basis for forecast catch -1 = Read basis with each observation, allows for a mixture of dead, retained, or F basis by different fleets for the fixed catches below. 2 = Dead catch 3 = Retained catch 99 = Input harvest rate (F)	
COND: == -1	Forecasted catches - enter one line per number of fixed forecast year catch	
2012 1 1 1200 2	Year & Season & Fleet & Catch or F value & Basis	
2013 1 1 1400 3	Year & Season & Fleet & Catch or F value & Basis	
-9999 1 1 0000 2	Indicates end of inputted catches to read	
COND: > 0	Forecasted catches - enter one line per number of fixed forecast year catch	
2012 1 1 1200	Year & Season & Fleet & Catch or F value	
2013 1 1 1200	Year & Season & Fleet & Catch or F value	
-9999 1 1 0000	Indicates end of inputted catches to read	
999	End of Input	
<b>End of Forecast File</b>		

## Benchmark Calculations

This feature of SS is designed to calculate an equilibrium fishing rate intended to serve as a proxy for the fishing rate that would provide maximum sustainable yield (MSY). Then in the forecast module these fishing rates can be used in the projections.

Four reference points can be calculated by SS:

- $F_{MSY}$ : Search for the  $F$  that produces maximum equilibrium (e.g. dead catch), or set  $F_{MSY}$  equal to one of the other three options
- $F_{SPR}$ : Search for the  $F$  that produces spawning biomass per recruit this is a specific fraction, termed  $SPR_{target}$ , of spawning biomass per recruit under unfished conditions. Note that this is in relative terms so it does not take into account the spawner-recruit relationship.
- $F_{Btarget}$ : Search for the  $F$  that produces an absolute spawning biomass that is a specified fraction, termed relative biomass target, of the unfished spawning biomass. Note that this is in absolute terms so takes into account the spawner-recruit relationship.
- $F_{0.10}$ : Search for the  $F$  that produces a slope in yield per recruit,  $dY/dF$ , that is 10% of the slope at the origin. Note that this option is mutually exclusive with  $F_{Btarget}$ . Only one will be calculated and the one that is calculated can serve as the proxy for  $F_{MSY}$  and forecasting.

### Estimation

Each of the potential reference points is calculated by searching across a range of  $F$  multiplier levels, calculating equilibrium biomass and catch at that  $F$ , using Newton-Raphson method to calculate a better  $F$  multiplier value, and iterating a fixed number of times to achieve convergence on the desired level.

### Calculations

The calculation of equilibrium biomass and catch uses the same code that is used to calculate the virgin conditions and the initial equilibrium conditions. This equilibrium calculation code takes into account all morph, timing, biology, selectivity, and movement conditions as they apply while doing the time series calculations. You can verify this by running SS to calculate  $F_{MSY}$  then hardwire initial  $F$  to equal this value, use the  $F_{method}$  approach 2 so each annual  $F$  is equal to  $F_{MSY}$  and then set forecast  $F$  to be the same  $F_{MSY}$ . Then run SS without estimation and no recruitment deviations. You should see that the population has an initial equilibrium abundance equal to  $B_{MSY}$  and stays at this level during the time series and forecast.

### Catch Units



For each fleet, SS always calculates catch in terms of biomass (mt) and numbers (1000s) for encountered (selected) catch, dead catch, and retained catch. These three categories differ only when some fleets have discarding or are designated as a bycatch fleet. SS uses total dead catch biomass as the quantity that is principally reported and the quantity that is optimized when searching for  $F_{MSY}$ . The quantity "dead catch" may occasionally be referred to as "yield".

## Biomass Units

The principle measure of fish abundance, for the purpose of reference point calculation, is female reproductive output. This is referred to as SSB (spawning stock biomass) and sometimes just "B" because the typical user settings have one unit of reproductive output (fecundity) per kg of mature female biomass. So when the output label says  $B_{MSY}$ , this is actually the female reproductive output at the proxy for  $F_{MSY}$ .

## Fleet Allocation

An important concept for the reference point calculation is the allocation of fishing rate among fleets. Internally, this is  $Bmark\_relF(f, s)$  and it is the fraction of the F multiplier assigned to each fleet,  $f$  and season,  $s$ . The value,  $F\_multiplier * Bmark\_relF(f, s)$ , is the F level for a particular fleet in a particular season and for the age that has a selectivity of 1.0. Other ages will have different F values according to their selectivity.

- The  $Bmark\_relF$  values can be calculated by SS from a range of years specified in the input for Benchmark Years or it can be set to be the same as the  $Forecast\_RelF$ , which in turn can be based on a range of years or can be input as a set of fixed values.
- Note that for Bycatch Fleets, the F's calculated by application of  $Bmark\_relF$  for a bycatch fleet can be overridden by a F value calculated from a range of years or a fixed F value that is input by the user. If such an override is selected for a bycatch fleet, that F value is not adjusted by changes to the F multiplier. This allows the user to treat a bycatch fleet as a constant background F while the optimal F for other fleets is sought. Also for bycatch fleets, there is user control for whether or not the dead catch from the bycatch fleet is included in the total dead catch that is optimized when searching for  $F_{MSY}$ .

## Virgin vs. Unfished

The concept of unfished spawning biomass,  $SSB_{unf}$ , is important to the reference points calculations. Unfished spawning biomass can be potentially different than virgin spawning biomass,  $SSB_{virgin}$ .

- Virgin spawning biomass is calculated from the parameter values associated with the start year of the model configuration and it serves as the basis from which the population model starts and the basis for calculation of stock depletion.

- Unfished spawning biomass can be calculated for any year or range of years, so can change over time as  $R_0$ , steepness, or biological parameters change.
- In the reference points calculation, the Benchmark Years input specifies the range of time over which various quantities are averaged to calculate the reference points. For biology, selectivity,  $F$ 's, and movement the values being averaged are the year-specific derived quantities. But for the stock-recruitment parameters ( $R_0$  and steepness), the parameter values themselves are averaged over time.
- During the time series or forecast, the current year's unfished spawning output ( $SSB_{unf}$ ) is used as the basis for the spawner-recruitment curve against which deviations from the spawner-recruitment curve are applied. So, if  $R_0$  is made time-varying, then the spawner-recruit curve itself is changed. However, if the regime shift parameter is time-varying, then this is an offset from the spawner-recruitment curve and not a change in the curve itself. Changes in  $R_0$  will change year-specific reference points and change the expected value for annual recruitments, but changes in regime shift parameter only change the expected value for annual recruitments.
- In reporting the time series of depletion level, the denominator can be based on virgin spawning output ( $SSB_{virgin}$ ) or  $B_{MSY}$ . Note that  $B_{MSY}$  is based on unfished spawning output ( $SSB_{unf}$ ) for the specified range of Benchmark years, not on  $SSB_{virgin}$ .

## Forecast Recruitment Adjustment

Recruitment during the forecast years sometimes needs to be set at a level other than that determined by the spawner-recruitment curve. One way to do this is by an environmental or block effect on the regime shift parameter. A more straightforward approach is now provided by the special forecast recruitment feature described here. There are 4 options provided for this feature. These are:

- 0 = Do nothing: This is the default and will invoke no special treatment for the forecast recruitments.
- 1 = Multiplier on spawner-recruitment: The expected recruitment from the SRR is multiplied by this factor.
  - This is a multiplier, so null effect comes from a value of 1.0.
  - The order of operations is to apply the SRR, then the regime effect, then this special forecast effect, then bias adjustment, then the deviations.
  - In the spawner recruit output of the report.sso there are 4 recruitment values stored.

- 2 = Multiplier on virgin recruitment: The virgin recruitment is multiplied by this factor.
  - This is a multiplier, so null effect comes from a value of 1.0.
  - The order of operations is to apply any environmental or block effects to  $R_0$ , then apply the special forecast effect, then bias adjustment, then the deviations.
  - Note that environmental or block effects on  $R_0$  are rare and are different than environment or block effects on the regime parameter.
- 3 = Mean recent recruitment: calculate the mean recruitment and use it.
  - Note that bias adjustment is not applied to this mean because the values going into the mean have already been bias adjusted.

This feature affects the expected recruitment in all years after the last year of the main recruitment deviations. This means that if the last year of main recruitment deviations is before end year, then the last few recruitments, termed "late", are also affected by this forecast option. For example, option 3 would allow you to set the last 2 years of the time series and all forecast years to have recruitment equal to the mean recruitment for the last 10 years of the main recruitment era.

## Data File

### Overview of Data File

1. Dimensions (years, ages, number of fleets, number of surveys, etc.)
2. Fleet and survey names, timing, etc.
3. Catch amount (biomass or numbers)
4. Discard
5. Mean body weight or mean body length
6. Length composition set-up
7. Length composition
8. Age composition set-up
9. Age imprecision definitions

10. Age composition
11. Mean length-at-age or mean bodyweight-at-age
12. Generalized size composition (e.g., weight frequency)
13. Tag-recapture
14. Stock composition (e.g. morphs identified by otolith microchemistry)
15. Environmental data
16. Selectivity observations (new placeholder, not yet implemented)

## Units of Measure

The normal units of measure are as follows:

- Catch biomass - metric tons
- Body weight - kilograms
- Body length - usually in centimeters, weight-at-length parameters must correspond to the units of body length and body weight
- Survey abundance - any units if catchability (Q) is freely scaled; metric tons or thousands of fish if Q has a quantitative interpretation
- Output biomass - metric tons
- Numbers - thousands of fish, because catch is in metric tons and body weight is in kilograms
- Spawning biomass - metric tons of mature females if  $\text{eggs/kg} = 1$  for all weights; otherwise has units that are based on the user-specified fecundity

## Time Units

- Spawning is restricted to happening once per year at a specified date (in real months).
- Recruitment happens at specified recruitment events that occur at user-specified dates (in real months).

- There can be one to many recruitment events; each producing a platoon as a portion of the total recruitment.
- A settlement platoon enters the model at age 0 if settlement is between the time of spawning and the end of the year; it enters at age 1 if settlement is after the first of the year; these ages at settlement can be overridden in the settlement setup.
- All fish advance to the next older integer age on January 1, no matter when they were born during the year. Consult with your ageing lab to assure consistent interpretation.
- Time-varying parameters are allowed to change annually, not seasonally.
- Rates like growth and mortality are per year.

## Seasons

- Seasons are the time step during which constant rates apply.
- Catch and discard amounts are per season and F is calculated per season.
- The year can have just one annual season, or be subdivided into seasons of unequal length.
- Season duration is input in real months and is converted into fractions of an annum. Annual rate values are multiplied by the per annum season duration.
- If the sum of the input season durations is not close to 12.0, then the input durations is divided by 12. This allows for a special situation in which the year could be only 0.25 in duration (e.g. seasons as years) so that spawning and time-varying parameters can occur more frequently.

## Subseasons and Timing of events in SS v.3.30

SS v.3.24 and all earlier versions effectively had two subseasons per season because the age-length-key (ALK) for each observation used the mid-season mean length-at-age and spawning occurred at the beginning of a specified season. Subseasons in SS v.3.30 provide more precision in the timing of events.

- Even number (min = 2) of subseasons per season (regardless of season duration):
  - 2 subseasons will mimic SS v.3.24
  - Specifying more sub seasons will give finer temporal resolution, but will slow the model

down, the effect of which is mitigated by only calculating growth as needed.

- Survey timing is now cruise-specific and specified in units of months (e.g. April 15 = 4.5).
  - sstrans.exe will convert year, season in SS v.3.24 format to year, real month in SS v.3.30 format.
- Survey integer season and spawn integer season assigned at runtime based on real month and season duration(s).
- The closest subseason is calculated for each observation.
- Growth and the age-length-key (ALK) is only calculated at beginning and mid-season or when there is an observation in that subseason.
- Fishery body weight uses mid-subseason growth.
- Survey body weight and size composition is calculated using the nearest subseason.
- Reproductive output now has specified spawn timing (in months fraction) and interpolates growth to that timing.
- Survey numbers calculated at cruise survey timing using  $e^{-Z}$ .
- Continuous Z for entire season. Same as applied in version SS v.3.24.

## Terminology

Where the term COND appears in the value column of this documentation (it does not actually appear in the data file), it indicates that the following section is omitted except under certain conditions, or that the factors included in the following section depend upon certain conditions. In most cases, the description in the definition column is the same as the label output to the data.ss\_new file.

## Model Dimensions

Value	Description
#V3.30.XX.XX	Model version number. This is written by SS in the new files and a good idea to keep updated in the input files.

#C data using new survey	Data file comment. Must start with #C to be retained then written to top of various output files. These comments can occur anywhere in the data file, but must have #C in columns 1-2.
1971	Start year
2001	End year
1	Number of seasons per year
12	Vector with N months in each season. These do not need to be integers. Note: If the sum of this vector is close to 12.0, then it is rescaled to sum to 1.0 so that season duration is a fraction of a year. But if the sum is not close to 12.0, then the entered values are simply divided by 12. So with one season per year and 3 months per season, the calculated season duration will be 0.25, which allows a quarterly model to be run as if quarters are years. All rates in SS are calculated by season (growth, mortality, etc.) using annual rates * season duration.
2	The number of subseasons. Entry must be even and the minimum value is 2. This is for the purpose of finer temporal granularity in calculating growth and the associated age-length key.
1.5	Spawning month; spawning biomass is calculated at this time of year (1.5 means January 15) and used as basis for the total recruitment of all settlement events resulting from this spawning.
2	Number of sexes (1/2/-1): 1 = current one gender, ignore fraction female input in the control file, 2 = current two gender, use fraction female in the control file, and -1 = one gender and multiply the spawning biomass by the fraction female in the control file.
20	Number of ages. The value here will be the plus-group age. SS starts at age 0.
1	Number of areas
2	Total number of fishing and survey fleets (which now can be in any order).

## Season Length and Time Steps

Time steps in SS v.3.30 can have finer granularity compared to previous versions where season can be broken into subseason and the age-length key (ALK) can be calculated multiple times over the course of a year:

ALK	ALK*	ALK*	ALK	ALK*	ALK
Subseason 1	Subseason 2	Subseason 3	Subseason 4	Subseason 5	Subseason 6

ALK\* only re-calculated when there is a survey that subseason

Quantities are calculated at the following times:

- Continuous Z for entire season;
- Even number (min = 2) of subseasons per season (regardless of season duration);
- Fishery body weight uses mid subseason ALK;
- Spawning biomass has specified spawn\_timing (in months.fraction); uses closest ALK to that timing;
- Survey timing is now observation-specific and specified in units of months.fraction (Apr 15 = 4.5);
- Survey season and spawn season assigned at runtime based on month and on season duration(s);
- Survey body weight and length composition uses closest ALK to survey timing;
- Survey numbers calculated at survey timing using  $e^{-Z}$ .

## Fleet Definitions

The catch data input has been modified to improve the user flexibility to add/subtract fishing and survey fleets to a model set-up. The fleet setup input is transposed so each fleet is now a row. Previous versions (SS v.3.24 and earlier) required that fishing fleets be listed first followed by survey only fleets. In version SS v.3.30 all fleets now have the same status within the model structure and each has a specified fleet type (except for models that use tag recapture data, this will be corrected in future versions). Available types are: catch fleet, bycatch only, or survey.



Inputs that define the fishing and survey fleets:

2                      Number of fleets which includes survey in any order					
Fleet Type	Timing	Area	Catch Units	Catch Mult.	Fleet Name
1	-1	1	1	0	FISHERY1
3	1	1	2	0	SURVEY1

## Fleet Type

Define the fleet type (e.g., fishery fleet, survey fleet):

- 1 = fleet with input catches,
- 2 = bycatch fleet (all catch discarded),
- 3 = survey: assumes no catch removals even if associated catches are specified below. If you would like to remove survey catch set fleet type to option = 1 with specific month timing for removals (defined below in Timing),
- 4 = ignored (not yet implemented).

## Timing

Timing for data observations has been revised in SS v.3.30:

- Fishery = -1 treat as catch occurred over the whole season or a user can override this assumption by using the code 10XX (e.g 1007 would indicate that catch was removed mid-year in July). Fishery fleets can either have a -1 which means that CPUE and composition observations default to using the total seasonal catch-at-age and midseason length-at-age, or they can have a timing value of 1 (actually any positive value) in which case the expected value for CPUE and composition observations will be sampled at the time indicated by the month value associated with the observation. If the -1 code is entered here, then individual observations (e.g., compositional data) can override the midseason default by entering the month as 1000+month. For example, 1004.5 would be entered for a mid-April observation.
- Survey = 1 The fleet timing here for surveys is not used and only the month value with the observation is relevant (e.g., month specification in the indices of abundance or the month for composition data).

## Area

An integer value indicating the area in which a fleet operates.

## Catch Units

Ignored for survey fleets, their units are read later:

- 1 = biomass (in metric tons),
- 2 = numbers (thousands of fish).

See [Units of Measure](#) for more information.

## Catch Multiplier

Invokes use of a catch multiplier, which is then entered as a parameter in the MG parameter section. The estimated value or fixed value of the catch multiplier is multiplied by the estimated catch before being compared to the observed catch:

- 0 = No catch multiplier used,
- 1 = Apply a catch multiplier which is defined as an estimable parameter in the control file after the cohort growth deviation in the biology parameter section. The model's estimated retained catch will be multiplied by this factor before being compared to the observed retained catch.

# Optional Bycatch Fleets

The option to include bycatch fleets was introduced in SS v.3.30.10. This is an optional input and if no bycatch is to be included in the catches this section can be ignored.

If a fleet above was set as a bycatch fleet (fleet type = 2), the following line is required:

Optional inputs that define bycatch fleet:

Fleet Index	Include in MSY	Fmult	F or First Year	F or Last Year	Not used
1	1	1	1982	2010	999

## Fleet Index

Fleet to include bycatch catch for (fleet number). Fleet number is assigned within the model based on the order of listed fleets in the Fleet Definition section. If there are multiple bycatch fleets, then a line for each fleet is required in the bycatch section.

## Include in MSY

The options are:

- 1 = deadfish in MSY, ABC, and other benchmark and forecast output,
- 2 = omit from MSY and ABC (but still include the mortality).

## Fmult

The options are:

- 1 = F multiplier scales with other fleets,
- 2 = bycatch F constant at input value,
- 3 = bycatch F from range of years.

## F or First Year

F or first year of range.

## F or Last Year

F or last year of range.

## Not Used

This column is not yet used and is reserved for future features.

# Catch

After reading the fleet-specific indicators, a list of catch values by fleet and season are read in by the model. The format for the catches is year, season that the catch will be attributed to, fleet, a catch value, and a year specific catch standard error. Only positive catches need to be entered, so there is no need for records for the survey fleets. To include an equilibrium catch value the year should be noted as -999 and this is now season specific. There is no longer a need to specify the number of records to be read; instead the list is terminated by entering a record with the value of -9999 in the year field. The updated list based approach extends throughout the data file (e.g. catch, length- and age-composition data), the control file (e.g. lambdas), and the forecast file (e.g. total catch by fleet, total catch by area, allocation groups, forecasted catch).

In addition, it is possible to collapse the number of seasons. So if a season value is greater than the N

seasons for a particular model, that catch is added to the catch for N seasons. This is generally to collapse a seasonal model into an annual model. In a seasonal model, use of season = 0 will cause SS to distribute the input value of catch equally among the N seasons. SS assumes that catch occurs continuously over seasons and hence is not specified as month in the catch data section. However, all other data types will need to be specified by month.

The new format for version SS v.3.30 for a 2 season model with 2 fisheries looks like the table below. The example is sorted by fleet, but the sort order does not matter. In data.ss\_new, the sort order is fleet, year, season.

Catches by year, season for every fleet:

Year	Season	Fleet	Catch	Catch SE
-999	1	1	56	0.05
-999	2	1	62	0.05
1975	1	1	876	0.05
1975	2	1	343	0.05
...	...	...	...	...
-999	1	2	55	0.05
-999	2	2	22	0.05
1975	1	2	555	0.05
1975	2	2	873	0.05
...	...	...	...	...
-9999	0	0	0	0

- Catch can be in terms of biomass or numbers for each fleet.
- Catch is retained catch. If there is discard also, then it is handled in the discard section below. This is the recommended setup which results in a model estimated retention curve based upon the discard data (specifically discard composition data). However, there may be instances where the data do not support estimation of retention curves. In these instances catches can be specified as all dead (retained + discard estimates).
- If there is reason to believe that the retained catch values underestimate the true catch, then it is possible in the retention parameter set up to create the ability for the model to estimate the degree of unrecorded catch. However, this is better handled with the new catch multiplier option.

## Bycatch

Bycatch fleets have an F so impose mortality and catch fish. All this catch is discarded. There must be a value entered for retained catch so that SS knows to calculate an F for that season, but this catch amount is ignored in the log likelihood. The amount of discarded catch can be entered as a discard observation(s). Bycatch fleets have selectivity, which must be specified or estimated if observations of the size or age composition of the discards is entered.

- Because there is no retained catch amount to match, the F for bycatch only fleets must be by the continuous F method (F\_method = 2).
- MSY and yield per recruit are calculated in terms of dead catch, and they currently include catch from bycatch fleets. So the search for  $F_{MSY}$  scales the bycatch F along with the F for the fleets that retain catch.

## Indices

Indices are data that are compared to aggregate quantities in the model. Typically the index is a measure of fish abundance, but this data section also allows for the index to be related to a fishing fleet's F, or to another quantity estimated by the model. The first section of the "Indices" setup contains the fleet ID, Units, and error distribution for each fleet that has index data.

CPUE and Survey Abundance Observations:

Fleet/ Survey	Units	Error Distribution	SD Report
1	1	0	0
2	1	0	0
...	...	...	...

## Units

The options for units for input data are:

- 0 = numbers,
  - 1 = biomass,
  - 2 = F.
- Note the F option can only be used for a fishing fleet and not for a survey, even if the

survey selectivity is mirrored to a fishing fleet. The values of these effort data are interpreted as proportional to the level of the fishery F values. No adjustment is made for differentiating between continuous F values versus exploitation rate values coming from Pope's approximation. A normal error structure is recommended so that the input effort data are compared directly to the model's calculated F, rather than to  $\log_e(F)$ . The resultant proportionality constant has units of  $1/Q$ .

- $\geq 30$  special survey types. These options bypass the calculation of survey selectivity so no selectivity parameters should be entered and especially not estimated. The expected values for these types are:
  - 30 = spawning biomass (e.g. for an egg and larvae survey),
  - 31 =  $\exp(\text{recruitment deviation})$ , useful for environmental index affecting recruitment,
  - 32 = spawning biomass \*  $\exp(\text{recruitment deviation})$ , for a pre-recruit survey occurring before density-dependence,
  - 33 = recruitment, age-0 recruits,
  - 34 = depletion (spawning biomass/virgin spawning biomass). Special survey option 34 automatically adjusts phases of parameters. There are options for additional control over this in the control file Q setup section under the link information column where:
    - \* 0 = add 1 to phases of all parameters; only R0 active in new phase 1; mimics the default option of previous model versions,
    - \* 1 = only R0 active in phase 1; then finish with no other parameters becoming active; useful for data-limited draws of other fixed parameters. Essentially, this option allows SS to mimic DB-SRA,
    - \* 2 = no phase adjustments, can be used when profiling on fixed R0.
  - 35 = survey of a deviation vector ( $e(\text{survey}(y)) = f(\text{parm\_dev}(k, y))$ ), can be used for an environmental time-series with soft linkage to the index. The selected deviation vector is specified in Q section of the control file. The index of the dev vector to which the index is related is specified in the 2nd column of the Q setup table (see [Catchability](#)).

## Error Distribution

The options for error distribution form are:

- -1 = normal error,
- 0 = lognormal error,

- $>0$  = Student's t-distribution in log space with degrees of freedom equal to this value. For  $DF > 30$ , results will be nearly identical to that for lognormal distribution. A DF value of about 4 gives a fat-tail to the distribution. The se values entered in the data file must be the standard error in  $\log_e$  space.

Abundance indices typically have a lognormal error structure with units of standard error of  $\log_e(\text{index})$ . If the variance of the observations is available only as a CV, then the value of se can be approximated as  $\sqrt{(\log_e(1 + (CV)^2))}$  where CV is the standard error of the observation divided by the mean value of the observation.

For the normal error structure, the entered values for se are interpreted directly as a se in arithmetic space and not as a CV. Thus switching from a lognormal to a normal error structure forces the user to provide different values for the se input in the data file.

If the data exist as a set of normalized Z-scores, you can either: assert a lognormal error structure after entering the data as  $\exp(\text{Z-score})$  because it will be logged by SS. Preferably, the Z-scores would be entered directly and the normal error structure would be used.

## Enable SD Report

Indices with SD Report enabled will have the expected values for their historical values appear in the ss.std and ss.cor files. The default value is for this option is 0.

- 0 = SD Report not enabled for this index,
- 1 = SD Report enabled for this index.

## Data Format

Year	Month	Fleet/Survey	Observation	SE
1991	7	3	80000	0.056
1995	7.2	3	65000	0.056
...	...	...	...	...
2000	7.1	3	42000	0.056
-9999	1	1	1	1

- For fishing fleets, catch-per-unit-effort (CPUE) is defined in terms of retained catch (biomass or numbers).
- For fishery independent surveys, retention/discard is not defined so CPUE is implicitly in terms of total CPUE.

- If a survey has its selectivity mirrored to that of a fishery, only the selectivity is mirrored so the expected CPUE for this mirrored survey does not use the retention curve (if any) for the fishing fleet.
- If the fishery or survey has time-varying selectivity, then this changing selectivity will be taken into account when calculating expected values for the CPUE or survey index.
- Year values that are before start year or after end year are excluded from model, so the easiest way to include provisional data in a data file is to put a negative sign on its year value.
- Duplicate survey observations are not allowed.
- Observations can be entered in any order, except if the super-year feature is used.
- Observations that are to be included in the model but not included in the negative log likelihood need to have a negative sign on their fleet ID. Previously the code for not using observations was to enter the observation itself as a negative value. However, that old approach prevented use of a Z-score environmental index as a “survey”. This approach is best for single or select years from an index rather than an approach to remove a whole index. Removing a whole index from the model should be done through the use of lambdas at the bottom of the control file which will eliminate the index from model fitting.
- Super-periods are turned on and then turned back off again by putting a negative sign on the season. Previously, super-periods were started and stopped by entering -9999 and the -9998 in the SE field. See the [Data Super-Period](#) section of this manual for more information.
- Research Note: If the statistical analysis used to create the CPUE index of a fishery has been conducted in such a way that its inherent size/age selectivity differs from the size/age selectivity estimated from the fishery’s size and age composition, then you may want to enter the CPUE as if it was a separate survey and with a selectivity that differs from the fishery’s estimated selectivity. The need for this split arises because the fishery size and age composition should be derived through a catch-weighted approach (to appropriately represent the removals by the fishery) and the CPUE should be derived through an area-weighted approach to better serve as a survey of stock abundance.

## Discard

If discard is not a feature of the model specification, then just a single input is needed:

---

0	Number of fleets with discard observations
---	--

---

If discard is being used, the input syntax is:



1	Number of fleets with discard observations			
Fleet	Units	Error Distribution		
1	2	-1		
Year	Month	Fleet	Observation	Standard Error
1980	7	1	0.05	0.25
1991	7	1	0.10	0.25
-9999	1	1	0	0

## Discard Units

The options are:

- 1 = values are amount of discard in either biomass or numbers according to the selection made for retained catch,
- 2 = values are fraction (in biomass or numbers) of total catch discarded; biomass/number selection matches that of retained catch,
- 3 = values are in numbers (thousands) of fish discarded, even if retained catch has units of biomass.

## Discard Error Distribution

The four options for discard error are:

- >0 = degrees of freedom for Student's t-distribution used to scale mean body weight deviations. Value of error in data file is interpreted as CV of the observation,
- 0 = normal distribution, value of error in data file is interpreted as CV of the observation,
- -1 = normal distribution, value of error in data file is interpreted as standard error of the observation,
- -2 = lognormal distribution, value of error in data file is interpreted as standard error of the observation in log space,
- -3 = truncate normal distribution (new with SS v.3.30, needs further testing), value of error in data file is interpreted as standard error of the observation. This is a good option for low observed discard rates.

## Discard Notes

- Since discard refers to catch, its time units are in seasons, not months.
- Year values that are before start year or after end year are excluded from model, so the easiest way to include provisional data in a data file is to put a negative sign on its year value.
- Negative value for fleet causes it to be included in the calculation of expected values, but excluded from the log likelihood.
- Zero (0.0) is a legitimate discard observation, unless lognormal error structure is used.
- Duplicate discard observations are not allowed.
- Observations can be entered in any order, except if the super-period feature is used.
- Note that in the control file you will enter information for retention such that 1-retention is the amount discarded. All discard is assumed dead, unless you enter information for discard mortality. Retention and discard mortality can be either size-based or age-based (new with SS v.3.30).

## Cautionary Note

The use of CV as the measure of variance can cause a small discard value to appear to be overly precise, even with the minimum standard error of the discard observation set to 0.001. In the control file, there is an option to add an extra amount of variance. This amount is added to the standard error, not to the CV, to help correct this problem of underestimated variance.

## Mean Body Weight or Length

This is the overall mean body weight or length across all selected sizes and ages. This may be useful in situations where individual fish are not measured but mean weight is obtained by counting the number of fish in a specified sample, e.g. a 25 kg basket. Observations can be in terms of mean length by setting switching the partition code to a negative value (e.g. -0, -1, -2) rather than 0, 1, and 2 typically used with the mean body weight approach.

### Mean Body Weight Data Section:

1	Use mean body size data (0/1)					
30	Degrees of freedom for Student's t-distribution used to evaluate mean body weight deviation. This is not a conditional input, must be here even if there are no mean body weight observations.					
Year	Month	Fleet	Partition	Type	Observation	Standard Error
1990	7	1	0	1	4.0	0.95
1990	7	1	0	1	1.0	0.95
-9999	0	0	0	0	0	0

### Partition

Mean weight data and composition data require specification of what group the sample originated from (e.g. discard, retained, discard + retained).

- 0 = whole catch in units of weight (discard + retained),
- 1 = discarded catch in units of weight,
- 2 = retained catch in units of weight,
- -0 = whole catch in units of length (discard + retained),
- -1 = discarded catch in units of length,
- -2 = retained catch in units of length.

### Type

Specify the type of data:

- 1 = mean length,
- 2 = mean body weight.

### Observation - Units

Units must correspond to the units of body weight, normally in kilograms, (or mean length in cm). The expected value of mean body weight (or mean length) is calculated in a way that incorporates effect of selectivity and retention.

## Error

Error is entered as the CV of the observed mean body weight (or mean length)

## Population Length Bins

The first part of the length composition section sets up the bin structure for the population. These bins define the granularity of the age-length key and the coarseness of the length selectivity. Fine bins create smoother distributions, but a larger and slower running model. First read a single value to select one of three population length bin methods, then any conditional input for options 2 and 3:

1	Use data bins to be read later. No additional input here.	
2	generate from bin width min max, read next:	
	2	Bin width
	10	Lower size of first bin
	82	Lower size of largest bin
The number of bins is then calculated from: $(\text{max Lread} - \text{min Lread})/(\text{bin width}) + 1$		
3	Read 1 value for number of bins, and then read vector of bin boundaries	
	25	Number of population length bins to be read
	26 28 30 ...	Vector containing lower edge of each population size bin

## Notes

For option 2, bin width should be a factor of min size and max size. For options 2 and 3, the population length bins must not be wider than the length data bins, but the boundaries of the bins do not have to align. The transition matrix between population and data length bins is output to echoinput.sso.

The mean size at settlement (virtual recruitment age) is set equal to the min size of the first population length bin.

When using more, finer population length bins, SS will create smoother length selectivity curves and smoother length distributions in the age-length key, but run slower (more calculations to do).

The mean weight-at-length, maturity-at-length and size-selectivity are based on the mid-length of the population bins. So these quantities will be rougher approximations if broad bins are defined.

Provide a wide enough range of population size bins so that the mean body weight-at-age will be

calculated correctly for the youngest and oldest fish. If the growth curve extends beyond the largest size bin, then these fish will be assigned a length equal to the mid-bin size for the purpose of calculating their body weight.

While exploring the performance of models with finer bin structure, a potentially pathological situation has been identified. When the bin structure is coarse (note that some applications have used 10 cm bin widths for the largest fish), it is possible for a selectivity slope parameter or a retention parameter to become so steep that all of the action occurs within the range of a single size bin. In this case, the model will see zero gradient of the log likelihood with respect to that parameter and convergence will be hampered.

ALK Tolerance: A value read near the end of the starter.ss file defines the degree of tail compression used for age-length key. If this is set to 0.0, then no compression is used and all cells of the age-length key are processed, even though they may contain trivial (e.g.  $1 \times 10^{-13}$ ) fraction of the fish at a given age. With tail compression of, say 0.0001, SS will at the beginning of each phase calculate the min and max length bin to process for each age of each morphs ALK and compress accordingly. Depending on how many extra bins are outside this range, you may see speed increases near 10-20%. Large values of ALK tolerance, say 0.1, will create a sharp end to each distribution and likely will impede convergence. Try out ALK tolerance.

## Length Composition Data Structure

Enter a code to indicate whether or not length composition data will be used:

---

1	Use length composition data (0/1)
---	-----------------------------------

---

If the value 0 is entered, then skip all length related inputs below and skip to the age data setup section. Otherwise continue:

Specify bin compression and error structure for length composition data for each fleet:

Min. Tail Compress.	Constant added to prop.	Combine males & females	Compress. Bins	Comp. Error Dist.	Dirichlet Param. Select	Min. Sample Size
0	0.0001	0	0	0	0	1
0	0.0001	0	0	0	0	1

---

## Minimum Tail Compression

Compress tails of composition until observed proportion is greater than this value; negative value causes no compression; Advise using no compression if data are very sparse, and especially if the set-up is using age composition within length bins because of the sparseness of these data.

## Added Constant to Proportions

Constant added to observed and expected proportions at length and age to make logL calculations more robust. Tail compression occurs before adding this constant. Proportions are renormalized to sum to 1.0 after constant is added.

## Combine Males % Females

Combine males into females at or below this bin number. This is useful if the sex determination of very small fish is doubtful so allows the small fish to be treated as combined sex. If Combine Males & Females > 0, then add males into females for bins 1 through this number, zero out the males, set male data to start at the first bin above this bin. Note that Combine Males & Females > 0 is entered as a bin index, not as the size associated with that bin. Comparable option is available for age composition data.

## Compress Bins

This options allows for the compression of length or age bins beyond a specific length or age by each data source. As an example, a value of 5 in the compress bins column would condense the final five length bins for the specified data source.

## Composition Error Distribution

The options are:

- 0 = Multinomial Error,
- 1 = Dirichlet Multinomial Error.
  - The Dirichlet Multinomial Error distribution requires the addition of a parameter lines for the natural log of the effective sample size multiplier ( $\theta$ ) at the end of the selectivity parameter section in the control file. See the [Dirichlet parameter](#) in the control file for information regarding setup.
  - The Parameter Select option needs be used to specified which data sources should be weighted together or separate.

## Dirichlet Parameter Select

Value that indicates the groups of composition data for estimation of the Dirichlet parameter for weighting composition data.

- 0 = Default,
- 1-N = Only used for the Dirichlet option. Set to a sequence of numbers from 1 to N where N is

the total number of combinations of fleet and age/length. That is, if you have 3 fleets with length data, but only 2 also have age data, you would have values 1 to 3 in the length comp setup and 4 to 5 in the age comp setup. You can also have a data weight that is shared across fleets by repeating values in Parameter Select.

## Minimum Sample Size

The minimum value (floor) for all sample sizes. This value must be at least 0.001. Conditional age-at-length data may have observations with sample sizes less than 1. SS v.3.24 has an implicit minimum sample size value of 1.

## Dirichlet Parameter Number and Effective Sample Sizes

If the Dirichlet multinomial error distribution is selected, indicate here which of a list of Dirichlet multinomial parameters will be used for this fleet. So each fleet could use a unique Dirichlet multinomial parameter, or all could share the same, or any combination of unique and shared. The requested number of Dirichlet multinomial parameters will be read from the control file. Please note that age-compositions Dirichlet multinomial parameters are continued after length-compositions, so a model with one fleet and both data types would presumably require two new Dirichlet multinomial parameters.

The Dirichlet estimates the effective sample size as  $N_{eff} = \frac{1}{1+\theta} + \frac{N\theta}{1+\theta}$  where  $\theta$  is the estimated parameter and  $N$  is the input sample size. Stock Synthesis estimates the log of the Dirichlet multinomial parameter such that  $\hat{\theta}_{fishery} = e^{-0.6072} = 0.54$  where assuming  $N = 100$  for the fishery would result in an effective sample size equal to 35.7.

This formula for effective sample size implies that, as the Stock Synthesis parameter log\_Theta goes to large values (i.e., 20), then  $N_{eff}$  will converge to the input sample size ( $N_{input}$ ). In this case, small changes in the value of the log\_Theta parameter has no action, and the derivative of the negative log-likelihood is zero with respect to the parameter, which means the Hessian will be singular and cannot be inverted. To avoid this non-invertible Hessian when the log\_Theta parameter becomes large, turn it off while fixing it at the high value. In summary, we recommend setting the upper bound for the Dirichlet multinomial parameter log\_Theta to a high value (i.e., 20-25), and then if any fleet has an estimate of log\_Theta > 15 then turn that Dirichlet multinomial parameter off while starting it at the estimated high value. This is equivalent to turning off down-weighting of fleets where evidence suggests that  $N_{eff} = N_{input}$ .

For additional information about the Dirichlet multinomial please see Thorson et al. (2017).

## Length Composition Data

Specify the length composition data:

30	Number of length bins for data
26 28 30 ... 88 90	Vector of length bins associated with the length data

Example of a single length composition observation:

Year	Month	Fleet	Sex	Partition	Nsamp	data vector
1986	1	1	3	0	20	<female then male data>
...	...	...	...	...	...	...
-9999	0	0	0	0	0	0

### Sex

If model has only one sex defined in the set-up, all observations must have sex set equal to 0 or 1. In a 2 sex model, the data vector always has female data followed by male data, even if only one of the two sexes has data that will be used.

- Sex = 0 means combined male and female (must already be combined and information placed in the female portion of the data vector) (male entries must exist for correct data reading, then will be ignored).
- Sex = 1 means female only (male entries must exist for correct data reading, then will be ignored).
- Sex = 2 means male only (female entries must exist and will be ignored after being read).
- Sex = 3 means data from both sexes will be used and they are scaled so that they together sum to 1.0; i.e. sex ratio is preserved.

### Partition

Partition indicates samples from either discards, retained, or combined.

- 0 = combined,
- 1 = discard,



- 2 = retained.

## Excluding Data

- If the value of year is negative, then that observation is not transferred into the working array. This feature is the easiest way to include observations in a data file but not to use them in a particular model scenario.
- If the value of fleet is negative, then the observation is processed and its expected value and log likelihood is calculated, but this log likelihood is not included in the total log likelihood. This feature allows the user to see the fit to a provisional observation without having that observation affect the model.

## Note

SS v.3.30 no longer requires that the number of length composition data lines be specified. Entering -9999 at the end of the data matrix will indicate to the model the end of length composition lines to be read.

Each observation can be stored as one row for ease of data management in a spreadsheet and for sorting of the observations. However, the 6 header values, the female vector and the male vector could each be on a separate line because ADMB reads values consecutively from the input file and will move to the next line as necessary to read additional values.

The composition observations can be in any order and replicate observations are allowed (unlike survey and discard data). However, if the super-period approach is used, then each super-periods' observations must be contiguous in the data file.

## Age Composition Option

The age composition section begins by reading the number of age bins. If the value 0 is entered for the number of age bins, then SS skips reading the bin structure and all reading of other age composition data inputs.

---

17	Number of age' bins; can be equal to 0 if age data not used; do not include a vector of agebins if Nage' bins is set equal to 0.
----	--

---

## Age Composition Bins

If a positive number of age bins is read, then SS reads the bin definition next.

---

1 2 3 ... 20 25	Vector of ages
-----------------	----------------

---

The bins are in terms of observed age (here age') and entered as the lower edge of each bin. Each ageing imprecision definition is used to create a matrix that translates true age structure into age' structure. The first and last age' bins work as accumulators. So in the example any age 0 fish that are caught would be assigned to the age' = 1 bin.

## Ageing Error

Here, the capability to create a distribution of age' (e.g. age with possible bias and imprecision) from true age is created. One or many age error definitions can be created. For each, there is input of a vector of mean age' and standard deviation of age'. For one definition, the input vectors can be replaced by vectors created from estimable parameters. In the future, capability to read a full age' – age matrix could be created. The dimension of the ageing error matrix requires the column length match the population maximum age specified at the top of the data file. However, the maximum age for binning of age data may be lower than the population maximum age.

---

2	Number of ageing error matrices to generate				
Age-0	Age-1	Age-2	...	Max Age	
-1	-1	-1	...	-1	#Mean Age
0.001	0.001	0.001	...	0.001	#SD
0.5	1.5	2.3	...	Max Age + 0.5	#Mean Age
0.5	0.65	0.67	...	4.3	#SD Age

---

The above table shows the values for the first 3 ages for each of two age transition definitions: the first defines a matrix with no bias and negligible imprecision and the second shows a small negative bias beginning at age 2.

## Note

- In principle, one could have year or laboratory specific matrices.

- For each matrix, enter a vector with mean age' for each true age; if there is no ageing bias, then set age' equal to true age + 0.5. Alternatively, -1 value for mean age' means to set it equal to true age plus 0.5. The addition of +0.5 is needed so that fish will get assigned to the intended integer age'.
- The length of the input vector is Nage+1, with the first entry being for age 0 fish and the last for fish of age Nage. The following line is a vector with the standard deviation (stddev) of age' for each true age.
- SS is able to create one ageing error matrix from parameters, rather than from an input vector. The range of conditions in which this new feature will perform well has not been evaluated, so it should be considered as a preliminary implementation and subject to modification.
  - To invoke this option, for the selected ageing error vector, set the standard deviation of ageing error to a negative value for age 0. This will cause creation of an ageing error matrix from parameters and any age or size-at-age data that specify use of this age error pattern will use this matrix. Then in the control file, add 7 parameters below the cohort growth dev parameter. These parameters are described in the control file section of this manual.

Specify bin compression and error structure for age composition data for each fleet:

Min. Tail Compress.	Constant added to prop.	Combine males & females	Comp. Error Dist.	Dirichlet Param. Select	Min. Sample Size
0	0.0001	1	0	0	1
0	0.0001	1	0	0	1

Specify method by which length bin range for age obs will be interpreted:

- |   |  |
|---|--|
| 1 | Bin method for age data  |
|   | 1 = value refers to population bin index   |
|   | 2 = value refers to data bin index   |
|   | 3 = value is actual length (which must correspond to population length bin boundary) |

An example age composition observation:

Year	Month	Fleet	Sex	Partition	Age Err	Lbin lo	Lbin hi	Nsamp	Data Vector
1987	1	1	3	0	2	-1	-1	79	<enter data values>
-9999	0	0	0	0	0	0	0	0	0

## Note

- Syntax for Sex, Partition, and data vector are same as for length.
- Age error (Age Err) identifies which ageing error matrix to use to generate expected value for this observation.
- The data vector has female values then male values, just as for the length composition data.
- As with the length comp data, a negative value for year causes the observation to not be read into the working matrix, a negative value for fleet causes the observation to be included in expected values calculation, but not in contribution to total logL, a negative value for month causes start-stop of super-period.
- Lbin lo, and Lbin hi are the range of length bins that this age composition observation refers to. Normally these are entered with a value of -1 and -1 to select the full size range. Whether these are entered as population bin number, length data bin number, or actual length is controlled by the value of the length bin range method above.
  - Entering value of 0 or -1 for Lbin lo converts Lbin lo to 1;
  - Entering value of 0 or -1 for Lbin hi converts Lbin hi to Maxbin;
  - It is strongly advised to use the “-1” codes to select the full size range. If you use explicit values, then the model could unintentionally exclude information from some size range if the population bin structure is changed.
  - In reporting to the comp\_report.sso, the reported Lbin\_lo and Lbin\_hi values are always converted to actual length.

## Conditional Age-at-Length

Use of conditional age'-at-length will greatly increase the total number of age' composition observations and associated model run time, but it is a superior approach for several reasons. First, it avoids double use of fish for both age' and size information because the age' information is considered conditional on the length information. Second, it contains more detailed information about the relationship between size and age so provides stronger ability to estimate growth parameters, especially the variance of size-at-age. Lastly, where age data are collected in a length-stratified program, the conditional age'-at-length approach can directly match the protocols of the sampling program.

In a two sex model, it is best to enter these conditional age'-at-length data as single sex observations (sex =1 for females and = 2 for males), rather than as joint sex observations (sex = 3). Inputting joint sex observations comes with a more rigid assumption about sex ratios within each length bin. Using separate vectors with sex = 1 and 2 allows 100% of the expected comp to be fit to 100% observations within each sex, whereas with sex=3, you would have a bad fit if the sex ratio were out of balance with the model expectation, even if the observed proportion at age within each sex exactly matched the model expectation for that age. Additionally, inputting the conditional age-at-length data as single sex observations isolates the age composition data from any sex selectivity as well.

When Lbin\_lo and Lbin\_hi are used to select a subset of the total size range, the expected value for these age' data is calculated within that specified size range, so is age' conditional on length.

## Mean Length or Body Weight-at-Age

SS also accepts input of mean length-at-age' or mean body weight-at-age'. This is done in terms of age', not true age, to take into account the effects of ageing imprecision on expected mean size-at-age'. If the value of "Age Err" is positive, then the observation is interpreted as mean length-at-age'. If the value of "Age Err" is negative, then the observation is interpreted as mean body weight-at-age' and the abs(Age Err) is used as Age Err.

---

1      Use mean size-at-age observation (0 = none, 1 = read data matrix)

An example observation:

---

Yr	Month	Fleet	Sex	Part.	Age Err.	Ignore	Data Vector (Female - Male)	Sample Size (Female - Male)
1989	7	1	3	0	1	999	<Mean Size values>	<Sample Sizes>
...								
-9999	7	1	3	0	1	999		

---

## Note

- Negatively valued mean size entries will be ignored in fitting.
- Nfish value of 0 will cause mean size value to be ignored in fitting.
- Negative value for year causes observation to not be included in the working matrix.
- Each sexes' data vector and N fish vector has length equal to the number of age' bins.
- The "Ignore" column is not used but still needs to have default values in that column.
- Where age data are being entered as conditional age'-at-length and growth parameters are being estimated, it may be useful to include a mean length-at-age vector with nil emphasis to provide another view on the model's estimates.
- An experiment that may be of interest might be to take the body weight-at-age data and enter it to SS as empirical body weight-at-true age in the wtatage.ss file, and to contrast results to entering the same body weight-at-age data here and to attempt to estimate growth parameters, potentially time-varying, that match these body weight data.

## Environmental Data

SS accepts input of time series of environmental data. Parameters can be made to be time-varying by making them a function of one of these environmental time series.

Parameter values can be a function of an environmental data series:

---

1	Number of environmental variables
---	-----------------------------------

---

COND > 0 Example of 2 environmental observations:

Year	Variable	Value
1990	1	0.10
1991	1	0.15
-9999	0	0

---

## Note

- Any years for which environmental data are not read are assigned a value of 0.0.
- It is permissible to include a year that is one year before the start year in order to assign

environmental conditions for the initial equilibrium year. But this works only for recruitment parameters, not biology or selectivity parameters.

- Environmental data can be read for up to 100 years after the end year of the model. Then, if the recruitment-environment link has been activated, the future recruitments will be influenced by any future environmental data. This could be used to create a future "regime shift" by setting historical values of the relevant environmental variable equal to zero and future values equal to 1, in which case the magnitude of the regime shift would be dictated by the value of the environmental linkage parameter. Note that only future recruitment and growth can be modified by the environmental inputs; there are no options to allow environmentally-linked selectivity in the forecast years.
- Note that some model derived quantities like summary biomass and recruitment deviation are assigned to some negative valued environmental variables. This is a stepping stone towards creating ability for parameters to be density-dependent.

## Generalized Size Composition Data

A flexible feature with SS is a generalized approach to size composition information. It was designed initially to provide a means to include weight frequency data, but was implemented to provide a generalized capability. The user can define as many size frequency methods as necessary.

- Each method has a specified number of bins.
- Each method has "units" so the frequencies can be in units of biomass or numbers.
- Each method has "scale" so the bins can be in terms of weight or length (including ability to convert bin definitions in pounds or inches to kg or cm).
- The composition data is input as females then males, just like all other composition data in SS. So, in a two-sex model, the new composition data can be combined sex, single sex, or both sex.
- If a retention function has been defined, then the new composition data can be from the combined discard + retained, discard only or retained only.

Example entry:

---

0	N of size frequency methods
---	-----------------------------

---

COND > 0

25	15	#Nbins per method
2	3	#Units per each method (1 = biomass, 2 = numbers)
3	3	#Scale per each method (1 = kg, 2 = lbs, 3 = cm, 4 = inches)
1e-9	1e-9	#Min compression to add to each observation (entry for each method)
2	2	#N observations per weight frequency method

---

Then enter the lower edge of the bins for each method. The two row vectors shown below contain the bin definitions for methods 1 and 2 respectively:

---

-26	28	30	32	34	36	38	40	42	...	60	62	64	68	72	76	80	90
-26	28	30	32	34	36	38	40	42	44	46	48	50	52	54			

---

## Note

- There is no tail compression for generalized size frequency data.
- Super-period capability is enabled in same way as for length and age composition data.
- There are two options for treating fish that in population size bins that are smaller than the smallest size frequency bin.
  - Option 1: By default, these fish are excluded (unlike length composition data where the small fish are automatically accumulated up into the first bin.
  - Option 2: If the first size bin is given a negative value, then: accumulation is turned on and the negative of the entered value is used as the lower edge of the first size bin;
- By choosing units=2 and scale=3, the size comp method can be nearly identical to the length comp method if the bins are set identically;
- Bin boundaries can be real numbers so obviously do not have to align with population length bin boundaries, SS interpolates as necessary;
- Size bins cannot be defined to be narrower than the population binwidth; an untrapped error will occur;
- Because the transition matrix can depend upon weight-at-length, it is calculated internally for each sex and for each season because weight-at-length can differ between sexes and can vary



seasonally.

An example observation is below. Note that its format is identical to the length composition data, including sex and partition options, except for the addition of the first column to indicate the size frequency method.

Method	Year	Month	Fleet	Sex	Part	Sample Size	<composition females then males>
1	1975	1	1	3	0	43	<data>
1	1977	1	1	3	0	43	<data>
1	1979	1	1	3	0	43	<data>
1	1980	1	1	3	0	43	<data>

## Tag-Recapture Data

An ability to analyze tag-recapture data is available with SS. Each released tag group is characterized by an area, time, sex and age at release. Each recapture event is characterized by a time and fleet. Because SS fleet's each operate in only one area, it is not necessary to record the area of recapture. Inside the model, the tagged cohort is apportioned across all growth patterns in that area at that time (with options to apportion to only one sex or to both). The tag cohort x growth pattern then behaves according to the movement and mortality of that growth pattern. The number of tagged fish is modeled as a negligible fraction of the total population. This means that a tagging event does not move fish from an untagged group to a tagged group. Instead it acts as if the tags are seeded into the population with no impact at all on the total population abundance or mortality. The choice to require assignment of a predominant age at release for each tag group is a pragmatic coding and model efficiency choice. By assigning a tag group to a single age, rather than distributing it across all possible ages according to the size composition of the release group, it can be tracked as a single diagonal cohort through the age x time matrix with minimal overhead to the rest of the model. Tags are considered to be released at the beginning of a season (period) and recaptures follow the timing of the fleet that made the recapture.

Example set-up for tagging data:

1	#Do tags - if this value is 0, then omit all entries below							
COND = 1 All subsequent tag-recapture entries must be omitted if "Do Tags" = 0								
3	#Number of tag groups							
12	#Number of recapture events							
2	#Mixing latency period: N periods to delay before comparing observed to expected recoveries (0 = release period)							
10	#Max periods (months) to track recoveries, after which tags enter accumulator							
#Release Data								
#TG	Area	Year	Month	<tfill>	Sex	Age	N Release	
1	1	1980	1	999	0	24	2000	
2	1	1995	1	999	1	24	1000	
3	1	1985	1	999	2	24	10	
#Recapture Data								
#TG	Year		Month		Fleet		Number	
1	1982		1		1		7	
1	1982		1		2		5	
1	1985		1		2		0	
2	1997		1		1		6	
2	1997		2		1		4	
3	1986		1		1		7	
3	1986		2		1		5	

## Note

- The release data must be enter in TG order.
- <tfill> values are place holders and are replaced by program generated values for model time.
- Analysis of the tag-recapture data has one -logL component for the distribution of recaptures across areas and another negative log likelihood component for the decay of tag recaptures from a group over time, hence informative about mortality. More on this in the control file.

## Stock Composition Data

It is sometimes possible to observe the fraction of a sample that is composed of fish from different stocks. These data could come from genetics, otolith microchemistry, tags or other means. The growth pattern feature in SS allows definition of cohorts of fish that have different biological characteristics and which are independently tracked as they move among areas. SS now incorporates the capability to calculate the expected proportion of a sample of fish that come from different growth patterns. In the inaugural application of this feature, there was a 3 area model with one stock spawning and recruiting in area 1, the other stock in area 3, then seasonally the stocks would move into area 2 where stock composition observations were collected, then they moved back to their natal area later in the year.

Stock composition data can be entered in SS as follows:

1	#Do morphcomp (if zero, then do not enter any further input below)							
COND = 1								
3	#Number of observations							
2	#Number of stocks							
0.0001	#Minimum Compression							
#Year	Month	Fleet	Part	Nsamp	Data Vector			
1980	1	1	0	36	0.4	0.6	...	
1981	1	1	0	40	0.44	0.62	...	
1982	1	1	0	50	0.49	0.50	...	

### Note

- The N stocks entered with these data must match the N growth patterns in the control file.
- The expected value is combined across sexes.
- The "partition" flag is included here in the data, but cannot be used because the expected value is calculated before the catch is partitioned into discard and retained components.
- Note that there is a specific value of mincomp to add to all values of observed and expected.

## Selectivity Empirical Data

It is sometimes possible to conduct field experiments or other studies to provide direct information about the selectivity of a particular length or age relative to the length or age that has peak selectivity, or to have a prior for selectivity that is more easily stated than a prior on a highly transformed selectivity parameter. This section provides a way to input data that would be compared to the specified derived value for selectivity. This is a placeholder at this time and will be fully implemented soon.

Selectivity data can be entered in SS as follows:

---

0	#Do data read for selectivity (if zero, then do not enter any further input below)						
	#Year	Month	Fleet	Age/Size	Bin #	Datum	Datum SE

---

End of Data File

---

999	#End of data file marker
-----	--------------------------

---

## Excluding Data

Data that are before the model start year or greater than the retrospective year are not moved into the internal working arrays at all. So if you have any alternative observations that are used in some model runs and not in others, you can simply give them a negative year value rather than having to comment them out. The first output to data.ss\_new has the unaltered and complete input data. Subsequent reports to data.ss\_new produce expected values or bootstraps only for the data that are being used.

Data that are to be included in the calculations of expected values, but excluded from the calculation of negative log likelihood, are flagged by use of a negative value for fleet ID.

## Data Super-Periods

The super-period capability allows the user to introduce data that represent a blend across a set of time steps and to cause the model to create an expected value for this observation that uses the same set of time steps. The option is available for all types of data and a similar syntax is used. Super-periods are started with a negative value for month, and then stopped with a negative value for month, placeholder observations within the super-period are designated with a negative fleet field.

The standard error or Nsamp field is now used for weighting of the expected values. An error message is generated if the super-period does not contain exactly one observation with a positive fleet field.

All super-period observations must be contiguous in the data file. All but one of the observations in the sequence will have a negative value for fleet ID so the data associated with these dummy observations will be ignored. The observed values must be combined outside of the model and then inserted into the data file for the one observation with a positive fleet ID.

An expected value for the observation will be computed for each selected time period within in the super-period. The expected values are weighted according to the values entered in the standard error (or Nsamp) field for all observations except the single observation holding the combined data. The expected value for that year gets a relative weight of 1.0. So in the example below, the relative weights are: 1982, 1.0 (fixed); 1983, 0.85; 1985, 0.4; 1986, 0.4. These weights are summed and rescaled to sum to 1.0, and are output in the echoinput.sso file.

Not all time steps within the extent of a super-period need be included. For example, in a 3 season model a super-period could be set up to combine information from season 2 across 3 years, e.g. skip over the season 1 and season 2 for the purposes of calculating the expected value for the super-period. The key is to create a dummy observation (negative fleet value) for all time steps, except 1, that will be included in the super-period and to include one real observation (positive fleet value; which contains the real combined data from all the specified time steps).

Super-period example:

#Year	Month	Fleet	Obs	SE	Comment
1982	-2	3	34.2	0.3	Start super-period. This observation has positive fleet value, so is expected to contain combined data from all identified periods of the super-period. The standard error (SE) entered here is use as the SE of the combined observation. The expected value for the survey in 1982 will have a relative weight of 1.0 (default) in calculating the combined expected value.
1983	2	-3	55	0.3	In super-period; entered observation is ignored. The expected value for the survey in 1983 will have a relative weight equal to the value in the standard error field (0.85) in calculating the combined expected value.
1985	2	-3	88	0.40	Note that 1984 is not included in the super-period Relative weight for 1985 is 0.4
1986	-2	-3	88	0.40	End super-period

A time step that is within the time extent of the super-period can still have its own separate observation. In the above example, the survey observation in 1984 could be entered as a separate observation, but it must not be entered inside of the contiguous block of super-period observations. For composition data (which allow for replicate observations), a particular time steps' observations could be entered as a member of a super-period and as a separate observation.

The super-period concept can also be used to combine seasons within a year with multiple seasons. This usage could be preferred if fish are growing rapidly within the year so their effective age selectivity is changing within year as they grow; fish are growing within the year so fishery data collected year round have a broader size-at-age modes than a mid-year model approximation can produce; and it could be useful in situations with very high fishing mortality.

## Control File

### Overview of Control File

These listed model features are denoted in the control file in the following order:

1. Number of growth patterns and platoons

2. Design matrix for assignment of recruitment to area/settlement event/growth pattern
3. Design matrix for movement between areas
4. Definition of time blocks that can be used for time-varying parameters
5. Controls for all time-varying parameters
6. Specification for growth and fecundity
7. Natural mortality and growth parameters for each sex x growth pattern
8. Maturity, fecundity and weight-length for each sex
9. Recruitment distribution parameters for each area, settlement event, growth pattern
10. Cohort growth deviation
11. Movement between areas
12. Catch Multiplier
13. Fraction female
14. Setup for any MG parameters are time-varying
15. Seasonal effects on biology parameters
16. Spawner-recruitment parameters
17. Setup for any SR parameters are time-varying
18. Recruitment deviations
19. F ballpark value in specified year
20. Method for calculating fishing mortality (F)
21. Initial equilibrium F for each fleet
22. Catchability (Q) setup for each fleet and survey
23. Catchability parameters
24. Setup for any Q parameters are time-varying

25. Length selectivity, retention, discard mortality setup for each fleet and survey
26. Age selectivity setup for each fleet and survey
27. Parameters for length selectivity, retention, discard mortality for each fleet and survey
28. Parameters for age selectivity, retention, discard mortality for each fleet and survey
29. Setup for any selectivity parameters are time-varying
30. Tag-recapture parameters
31. Variance adjustments
32. Lambdas for likelihood components

The order in which they appear in the control file has grown over time rather opportunistically, so it may not appear particularly logical at this time, especially various aspects of recruitment distribution and growth. When the same information is entered via the SS GUI, it is organized more logically and then written in this form to the text control file.

## Parameter Line Elements

The primary role of the SS control file is to define the parameters to be used by the model. The general syntax of the 14 elements of a long parameter line is described here. The first seven elements of a parameter line are used for time-varying parameters that cannot themselves be time-varying and will be referred to as a short parameter line. Three types of time-varying properties can be applied to a base parameter: blocks or trend, environmental linkage, and random deviation. Each parameter line contains:



Column	Element	Description
1	LO	Minimum value for the parameter
2	HI	Maximum value for the parameter
3	INIT	Initial value for the parameter. If the ss.par file is read, it overwrites these INIT values.
4	PRIOR	Expected value for the parameter. This value is ignored if the prior type is 0 (no prior) or 1 (symmetric beta).
5	PRIOR STDEV	Standard deviation for the prior, used to calculate likelihood of the current parameter value. This value is ignored if prior type is 0.
6	PRIOR TYPE	0 = none, 1 = symmetric beta, 2 = full beta, 3 = lognormal without bias adjustment, 4 = lognormal with bias adjustment, 5 = gamma, 6 = normal.
7	PHASE	Phase in which parameter begins to be estimated. A negative value causes the parameter to retain its INIT value (or value read from the ss.par file).

Note that relative to SS v.3.24, the order of Prior StDev and Prior Type have been switched and the Prior Type options have been renumbered.

Short parameter lines have only the above 7 elements. The full parameter line syntax for the mortality-growth, spawn-recruitment, selectivity, and Q sections provides additional controls to give the parameter time-varying properties. These are listed briefly below and described in more detail in the section time varying parameter options found in the [Time-Varying parameters](#) section.

Column	Element	Description
8	Env Var & Link	Create a linkage to an input environmental time-series
9	Dev Link	Invokes use of the deviation vector in the linkage function
10	Dev min yr	Beginning year for the deviation vector
11	Dev max yr	Ending year for the deviation vector
12	Dev Phase	Phase for estimation for elements in the deviation vector
13	Block	Specify time block or trend to be applied
14	Block Function	Function form for the block offset

## Terminology

Where the term COND appears in the value column of this documentation (it does not actually appear in the control file), it indicates that the following section is omitted except under certain conditions, or that the factors included in the following section depend upon certain conditions. In most cases, the description in the Definition column is the same as the label output to the control.ss\_new file.

## Beginning of Control File Inputs

Typical Value	Description and Options
#C comment	Comments beginning with #C at the top of the file will be retained and included in output.
0	0 = do not read the wtatage.ss file, 1 = read the wtatage.ss file, also read and use the growth parameters, 2 = Future option to read the wtatage.ss file, then omit reading and using growth parameters and all length-based data.

Typical Value	Description and Options
2	<p>N growth patterns (GP)</p> <p>These are collections of fish with unique biological characteristics (growth, M, weight-length, reproduction). The GP x Sex x Settlement Events constitute unique morphs that are tracked in SS. They are assigned these characteristics at birth and retain them throughout their lifetime. At recruitment, morph members are distributed across areas (if any) and they retain their biological characteristics even if they move to another area in which a different cohort with different biological characteristics might predominate. For example, one could assign a fast-growing morph to recruit predominately in a southern areas and a slow-growing morph to a northern area. The natural mortality and growth parameters are specified for each growth pattern in the MG parameters section in the order of females growth pattern 1 to growth pattern N followed by males growth pattern 1 to growth pattern N.</p>
3	<p>Number of platoons within a morph.</p> <p>This allows exploration of size-dependent survivorship. A value of 1 will not create additional platoons. Odd-numbered values of 3 - 5 will break the overall morph into that number of platoons. More platoons slows model execution, so values above 5 not advised. The fraction of each morph assigned to each platoon is custom-input or designated to be a normal approximation. When multiple platoons are designated, an additional input is the ratio of between platoon to within platoon variability in size-at-age. This is used to partition the total growth variability. For the platoons, their size-at-age is calculated as a factor (determined from the between-within variability calculation) times the size-at-age of the central morph which is determined from the growth parameters for that Growth Pattern x Sex.</p>
COND > 1	Following 2 lines are conditional on N platoons > 1
0.7	Platoon between/within stdev ratio. Ratio of the amount of variability in length-at-age between platoons to within platoons.
0.2 0.6 0.2	Distribution among platoons. Enter custom vector or enter -1 to first value of vector to get a normal approximation: (0.15, 0.70, 0.15) for 3 platoons, (0.031, 0.237, 0.464, 0.237, 0.031) for 5 platoons.

## Empirical Weight-at-Age

With version 3.04, SS added the capability to read empirical body weight at age for the population and each fleet, in lieu of generating these weights internally from the growth parameters, weight-at-length, and size-selectivity. The values are read from a separate file named, wtatage.ss. This file is only required to exist if this option is selected. See the section on [weight-at-age](#) for additional information on file formatting for empirical weight-at-age.

## Recruitment Timing and Distribution

In older versions of SS one value of spawning biomass was calculated annually at the beginning of one specified spawning season and this spawning biomass produces one annual total recruitment value and this annual recruitment was distributed among seasons, areas, and growth types according to other model parameters.

In SS v.3.30, more control of the seasonal timing is provided and there now is an explicit time delta between spawning and recruitment. Spawning still occurs just once per year, but its timing can be at any specified time, not just the beginning of a season. Recruitment of the progeny from an annual spawning enter the population in one or more settlement events.

Example set-up where there are multiple settlement events:

3	Number of recruitment settlement events		
0	Unused option		
Growth Pattern	Month	Area	Age (for each settlement assignment)
1	11.0	1	0
1	12.0	1	0
1	1.0	1	1

## Recruitment Timing and Settlement

Details regarding recruitment timing and settlement:

- Recruitment happens in specified settlement events (growth pattern, Month, Area);
- Number of unique settlement timings calculated at runtime;
- Now there is explicit elapsed time between spawning and recruitment;
- Growth and natural mortality of the platoon begins at time of settlement, which is its real age 0.0 for growth; but pre-settlement fish exist from the beginning of the season of settlement, so

can be caught if selected;

- Age at recruitment now user-controlled (should be 0 if in year of spawning)
- All fish become integer age 1 (for age determination) on their first January 1st;
- Recruitment can occur >12 months after spawning

The distribution of recruitment among these settlement events is controlled by recruitment apportionment parameters. There must be a parameter line for each GP, then for each area, then for each settlement. All of these are required, but only those GP x area x settlements designated to receive recruits in the recruitment design matrix will have the parameter used in the recruitment distribution calculation. For the recruitment apportionment, the parameter values are the  $\ln(\text{apportionment weight})$ . The sum of all apportionment weights is calculated for each pattern x area x settlements that have been designated to receive recruits in the recruitment design matrix. Then the apportionment weights are scaled to sum to 1.0 so that the total recruitment from the spawning event is distributed among the cells designated to receive recruitment. These distribution parameters can be time-varying, so the fraction of the recruits that occur in a particular GP, area, or settlement can change from year to year.

## Recruitment Distribution and Parameters

- SS processes the parameter values according to the following equation:

$$\text{apportionment}_i = \frac{e^{p_i}}{\sum_{j=1}^N e^{p_j}} \quad (1)$$

- Set the value for one of these parameters to 0.0 and not estimate it so that other parameters will be estimated relative to its fixed value.
- Give the estimated parameters a min-max of something like -5 and 5, so they have a good range relative to the base parameter.
- In order to get a different distribution of recruitments in different years, you will need to make at least one of the recruitment distribution parameters time-varying.
- In a seasonal model, all cohorts graduate to the age of 1 when they first reach January 1, even if the seasonal structure of the model has them being born in the late fall. In general, this means that SS operates under the assumption that all age data have been adjusted so that fish are age 0 at the time of spawning and all fish graduate to the next age on January 1. This can be problematic if the ageing structures deposit a ring at another time of year. Consequently, you may need to add or subtract a year to some of your age data to make it conform to the SS structure, or you may need to define the SS calendar year to start at the beginning of the season

at which ring deposition occurs. Talk with your ageing lab about their criteria for seasonal ring deposition.

- Seasonal recruitment is coded to work smoothly with growth. If the recruitment occurring in each season is assigned the same growth pattern, then each seasonal cohort's growth trajectory is simply shifted along the age/time axis. At the end of the year, the early born cohorts will be larger, but all are growing with the same growth parameters so all will converge in size as they approach their common Lmax.
- At the time of settlement, fish are assigned a size equal to the lower edge of the first population size bin and they grow linearly until they reach the age A1. SS generates a warning if the first population length bin is greater than 10 cm as this seems an unreasonably large value for a larval fish. A1 is in terms of real age elapsed since birth. All fish advance to the next integer age on January 1, regardless of birth season. For example, consider a 2 season model with some recruitment in each season and with each season's recruits coming from the same GP. At the end of the first year, the early born fish will be larger but both of the seasonal cohorts will advance to an integer age of 1 on Jan 1 of the next year. The full growth curve is still calculated below A1, but the size-at-age used by SS is the linear replacement. Because the linear growth trajectory can never go negative, there is no need for the additive constant to the standard deviation (necessary for the growth model used in SS2 V1.x), but the option to add a constant has been retained in the model.

Typical Value	Description and Options
1	Recruitment distribution method. This section controls which combinations of Growth Pattern x Area x Settlement will get a portion of the total recruitment coming from each spawning. Options: 1 = use the SS v.3.24 or earlier setup, 2 = main effects for GP, settle timing, and area, 3 = each settle entity, 4=no parameters (only if Growth Pattern x Settlement x Area = 1).
1	Spawner-Recruitment, options: 1 = global, 2 = by area (by area is not yet implemented; there is a conceptual challenge to doing the equilibrium calculation when there is fishing).
1	Number of recruitment settlement assignments. Must be at least 1 even if only 1 settlement and 1 area because the timing of that settlement must be specified.

Typical Value	Description and Options
0	Year x Area x Settlement Event Interaction Requested (only for recruitment distribution method = 1).
1 5.5 1 0	Recruitment assignment to growth pattern, month, area, and age (for each settlement event). Here settlement is set to mid-May (month 5.5). Note: Normally the calendar age at settlement is 0 if settlement happens between the time of spawning and the end of that year, and at age 1 if settlement is in the year after spawning. In SS v.3.24, settlement always happened at age 0 even if in following year. That is illogical, but this age option allows replication of SS v.3.24 for testing purposes.

## Movement

Here we define movement among the areas. This is a box transfer with no explicit adjacency of areas, so fish can move from any area to any other area in each time step. While not incorporated yet, there is a desire for future versions of SS to have the capability to allow sex-specific movement, and also to allow some sort of mirroring so that sexes and growth patterns can share the same movement parameters if desired.

Typical Value	Description and Options
COND: only if areas > 1	
4	Enter Number of movement definitions.
1.0	First age that moves. This value is a real number, not an integer, to allow for an in-year start to movement in a multi-season model. It is the real age at the beginning of a season, even though movement does not occur until the end of the season. For example, in a setup with two 6-month seasons a value of 0.5 will cause the age 0 fish to not move when they complete their first 6 month season of life, and then to move at the end of their second season because they start movement capability when they reach the age of 0.5 years (6 months).
1 1 1 2 4 10	The four requested movement definitions appear here. Each definition specifies: season, morph, source area, destination age1, age2. The rate of movement will be controlled by the movement parameters later. Here the age1 and age2 controls specify the range over which the movement parameters are interpolated with movement constant below age1 and above age2.
1 1 2 1 4 10	
1 2 1 2 4 10	
1 2 2 1 4 10	

Typical Value	Description and Options

Two parameters will be entered later for each growth pattern, area pair and season.

- movement is constant at P1 below the specified minage for movement change, constant at P2 above maxage for movement change, and linearly interpolated for intermediate ages;
- For each source area the implicit movement parameter value is 0.0, but this default value is replaced if the stay movement is selected to have an explicit pair of parameter (e.g. specify movement rate for area 1 to area 1).
- the parameter is exponentiated so that a movement parameter value of 0 becomes 1.0;
- for each source area, all movement rates are then summed and divided by this sum so that 100% of the fish are accounted for in the movement calculations;

$$\text{rate}_i = \frac{e^{p_i}}{\sum_{j=1}^N e^{p_j}} \quad (2)$$

- at least one movement parameter must be fixed so that all other movement parameters are estimated relative to it. This is achieved naturally by not specifying the stay rate parameter so it has a fixed value of 0.0;
- the resultant movement rates are multiplied by season duration in a seasonal model;

## Time Blocks

Typical Value	Description and Options
3	Number of block patterns. These patterns can be referred to in the parameter sections to create a separate parameter value for each block.
COND > 0: 3 2 1	Following inputs are omitted if N Block patterns equals 0. Blocks per pattern
1975 1985 1986 1990 1995 2001	Beginning and ending years for blocks in design 1; years not assigned to a block period retain the baseline value for a parameter that uses this pattern.



1987 1990      Beginning and ending years for blocks in design 2.  
1995 2001

1999 2002      Beginning and ending years for blocks in design 3.

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When using time blocks, it is important to consider which parameters will affect which years of the time series. There are three main situations:

1. Offset approach: One or more time blocks are created and cover all or a subset of the years. Each block gets a parameter that is used as an offset from the base parameter. In this situation you typically will allow SS to estimate the base parameter and each of the offset parameters. In years not covered by blocks, the base parameter alone is used. However, if blocks cover all the years, then the value of the block parameter is completely correlated with the mean of the block offsets, so model convergence and variance estimation could be affected. The recommended approach when using offsets is to not have all the years be covered by blocks when doing offsets, or to fix the base parameter value at a reasonable level when doing offsets for all years.
2. Replacement approach-Option A: Here time blocks are created which cover a subset of the years. The base parameter is used in the non-block years and the value of that base parameter is replaced by the block parameter in each respective block. In this situation, you typically allow SS to estimate the base parameter and each of the block parameters.
3. Replacement-Option B: Here replacement time blocks are created for all the years. In this case the base parameter is simply a placeholder that is always replaced by a block parameter. In this situation, do not allow SS to estimate the base parameter and only estimate the corresponding block replacement parameters, otherwise, the search algorithm will be attempting to estimate parameters that do not contribute to the log-likelihood, so model convergence and variance estimation could be effected. Note however, that the minimum and maximum for the base parameter are used as checks on the minimum and maximum of the blocks.

Regardless of the block set-up approach, special consideration should be given regarding which parameter values are should be applied during forecast years. The model will default to use all base parameter values during the forecast period. However, there are controls in the forecast file which allow the user to specify specific parameter years to be applied during the forecast period for selectivity, relative F, and recruitment.

## Time-varying Parameter Controls

In SS v.3.30, several changes are introduced to the implementation of time-varying parameters:

- Time-varying parameters for biology, spawner-recruitment, catchability, and selectivity are implemented using the same approach and share code.
- The block feature that allowed input of one block parameter line and replication of that line by SS as often as needed has been replaced. Now there is a complete time-varying parameter auto-generation capability.
- The logistic bound constraint is no longer implemented due to the challenges it created to interpreting parameter values. Instead, the auto-generate feature now creates bounds on time-varying parameters for blocks such that the combination of a bounded value of the time-varying parameter and the base parameter will not violate the base parameter bounds.
- For more information on the implementation of time-varying parameters, see the [Using Time-varying Parameters](#) section

Typical Value	Description and Options
1	Environmental/Block/Deviation adjust method for all time-vary parameters. 1 = warning relative to base parameter bounds, 3 = no bound check). Note: logistic bound check from previous SS versions (e.g., SS v.3.24) is no longer an option.
0 0 0 0 0	Five values control auto-generation for: 1-biology, 2-spawn-recruitment, 3-catchability, 4-tag (future), 5-selectivity.  The accepted values are: 0 = auto-generate all time-varying parameters, 1 = read each time-varying parameter line, 2 = read each line and auto-generation if read value for parameter min = -12345.

## Biology

### Natural Mortality

Natural mortality (M) has some options that are referenced to integer age, and some to real age since settlement. So, if M varies by age, M will change by season and cohorts born early in the year will have different M than late born cohorts.

Lorenzen natural mortality is based on the concept that natural mortality varies over the life cycle of

a fish, which is driven by physiological and ecological processes. So, natural mortality is scaled by the length of the fish.

Typical Value	Description and Options
1	Natural Mortality Options: 0 = A single parameter, 1 = N breakpoints, 2 = Lorenzen, 3 = Read age specific M and do not do seasonal interpolation. 4 = Read age specific and do seasonal interpolation, if appropriate.
COND = 0	No additional natural mortality controls.
COND = 1	
4	Number of breakpoints. Then read a vector of ages for these breakpoints. Later, per sex x GP, read N parameters for the natural mortality at each breakpoint.
2.5 4.5 9.0 15.0	Vector of age breakpoints.
COND = 2	
4	Reference age for Lorenzen Natural Mortality: read one additional integer value that is the reference age. Later read one parameter for each sex x growth pattern that will be the M at the reference age. Other ages will have an M scaled to its body size-at-age. However, if platoons are used, all will have the same M as their growth pattern. Lorenzen M calculation will be updated if the starting year growth parameters are active, but if growth parameters vary during the time-series, the M is not further updated. So be careful in using Lorenzen when there is time-varying growth.
COND = 3 or 4	Do not read any natural mortality parameters. With option 2, these M values are held fixed for the integer age (no seasonality or birth season considerations). With option 4, there is seasonal interpolation based on real age, just as in options 1 and 2.
0.20 0.25 ... 0.20 0.23 ...	Age-specific M values: row 1 is female growth pattern 1, row 2 is female 2 growth pattern 2, row 3 is male growth pattern1, etc.

## Growth

### Timing

When fish recruit at the real age of 0.0 at settlement, they have body size equal to the lower edge of the first population size bin. The fish then grow linearly until they reach a real age equal to the input value “growth\_age\_for\_L1” and have a size equal to the parameter value for L1. As they age further, they grow according the selected growth equation. The growth curve is calibrated to go through the size L2 when they reach the age “Growth\_age\_for\_L2”.

## Linf

If “Growth\_age\_for\_L2” is set equal to 999, then the size L2 is used as Linf. If MGparm\_def option = 1 (direct estimate, not offsets), then setting a male growth or natural mortality parameter value to 0.0 and not estimating it will cause SS to use the corresponding female parameter value for the males. This check is done on a parameter, by parameter basis and is probably most useful for setting male L1 equal to female L1, then letting males and females have separate K and Linf parameters.

## Schnute growth function

The Schnute implementation of a 3-parameter growth function is invoked by entering 2 in the grow type field. Then a fourth parameter is read after reading the von Bertalanffy K parameter. When this fourth parameter has a value of 1.0, it is equivalent to the standard von Bertalanffy growth curve. When this function was first introduced in SS, it required that A0 be set to 0.0.

## Mean size-at-maximum age

The mean size of fish in the max age bin depends upon how close the growth curve is to Linf by the time it reaches max age AND the mortality rate of fish after they reach max age. SS provides an option for the mortality rate to use in this calculation during the initial equilibrium year. This must be specified by the user and should be reasonably close to M plus initial F. In SS v.3.30, this uses the von Bertalanffy growth out to 3\*nages and decays the numbers at age by  $\exp(-\text{value set here})$ . For subsequent years of the time series, SS should update the size-at-maxage according to the weighted average mean size of fish already at max age and the size of fish just graduating into max age. Unfortunately, this updating is only happening in years with time-varying growth. Hope to fix that in the future.

## Age-specific K

This option creates age-specific K multipliers for each age of a user-specified age range, with independent multiplicative factors for each age in the range and for each growth pattern / sex. The null value is 1.0 and each age's K is set to the next earlier age's K times the value of the current age's multiplier. Each of these multipliers is entered as a full parameter line, so inherits all time-varying capabilities of full parameters. The lower end of this age range cannot extend younger than the specified age for which the first growth parameter applies. This is a beta model feature, so examine output closely to assure you are getting the size-at-age pattern you expect. Beware of using this option in a model with seasons within year because the K deviations are indexed solely by integer age

according to birth year. There is no offset for birth season timing effects, nor is there any seasonal interpolation of the age-varying K.

## Growth cessation

A growth cessation model was developed for the application to tropical tuna species (Maunder et al., 2018). Growth cessation allows for a linear relationship between length and age, followed by a marked reduction of growth after the onset of sexual maturity by assuming linear growth for the youngest individuals and then a logistic function to model the decreasing growth rate at older ages.

Typical Value	Description and Options
1	<p>Growth Model:</p> <p>1 = von Bertalanffy (2 parameters),</p> <p>2 = Schnute's generalized growth curve (aka Richards curve) with 3 parameters. Third parameter has null value of 1.0,</p> <p>3 = von Bertalanffy with age-specific K multipliers for specified range of ages,</p> <p>4 = age specific K. Set base K as K for age = nages and working backwards and the age-specific K = K for the next older age * multiplier,</p> <p>5 = age specific K. Set base K as K for nages and work backwards and the age-specific K = base K * multiplier.</p> <p>8 = growth cessation. Decreases the K for older fish. If implemented, the Amin and Amax parameters, the next two lines, need to be set at 0 and 999 respectively. The mortality-growth parameter section requires the base K parameter line which is interpreted as the steepness of the logistic function that models the reduction in the growth increment by age followed by a second parameter line which is the parameter related to the maximum growth rate.</p>
1.66	Growth Amin (A1): Reference age for first size-at-age (post-settlement) parameter.
25	Growth Amax (A2): Reference age for second size-at-age parameter (999 to use as L infinity).
0.20	<p>Exponential decay for growth above maximum age (plus group: fixed at 0.20 in SS v.3.24; should approximate initial Z).</p> <p>Alternative Options:</p> <p>-998 = Disable growth above maximum age (plus group) similar to earlier versions of SS (prior to SS v.3.24),</p>

Typical Value	Description and Options
	-999 = Replicate the simpler calculation done in SS v.3.24.
0	Placeholder for future growth feature.
COND >= 3	Growth option age-specific K
2	Number of ( <i>k</i> ) multipliers to read
5	Minimum age for age-specific K
7	Maximum age for age-specific K
0	Standard deviation added to length-at-age: Enter 0.10 to mimic SS2 V1.xx. Recommend using a value of 0.0.
1	<p>CV Pattern (cannot be time-varying)</p> <p>0: <math>CV=f(LAA)</math>, so the 2 parameters are in terms of CV of the distribution of length-at-age and the interpolation between these 2 parameters is a function of mean length-at-age,</p> <p>1: <math>CV=f(A)</math>, so interpolation is a function of age,</p> <p>2: <math>SD=f(LAA)</math>, so parameters define the standard deviations of length-at-age and interpolation is a function of mean length-at-age,</p> <p>3: <math>SD=f(A)</math>,</p> <p>4: Lognormal distribution of size-at-age. Input parameters will specify the standard deviation of log size-at-age (e.g., entered values will typically be between 0.05 and 0.15). A bias adjustment is applied so the lognormal distribution of size-at-age will have the same mean size as when a normal distribution is used.</p>

## Maturity-Fecundity

Typical Value	Description and Options
2	<p>Maturity Option:</p> <p>1 = length logistic,</p> <p>2 = age logistic,</p> <p>3 = read age-maturity for each female growth pattern,</p> <p>4 = read an empirical age-maturity vector for all ages,</p> <p>5 = disabled,</p> <p>6 = read vector of length-based maturity values,</p>

Typical Value	Description and Options
	Note: need to read 2 parameters even if option 3 or 4 is selected.
COND = 3 or 4 0 0.05 0.10 ...	Maturity Option Vector of age-specific maturity or fecundity. One row of length Nages + 1 for each female growth pattern.
1	First Mature Age: Overridden if maturity option is 3 or 4 or if empirical wtatage.ss is used, but still must exist here. Otherwise, all ages below the first mature age will have maturity set to zero.
1	Fecundity Option (irrelevant if maturity option is 4 or wtatage.ss is used): 1 = to interpret the 2 egg parameters as linear eggs/kg on body weight (current SS default), so fecundity = $wt * (a + b * wt)$ , so value of a=1, b=0 causes eggs to be equivalent to spawning biomass, 2 = to set fecundity = $a * L^b$ , 3 = to set fecundity = $a * W^b$ , so values of a=1, b=1 causes fecundity to be equiv to spawning biomass, 4 = fecundity = $a + b * L$ , 5 = Eggs = $a + b * wt$ .

## Hermaphroditism

Typical Value	Description and Options
0	Hermaphroditism Option: 0 = not used, 1 = invoke female to male age-specific function, -1 = invoke male to female age-specific function, Note: this creates the annual, age-specific fraction that change sex, it is not the fraction that is each sex.
COND = 1	Read 2 lines below if hermaphroditism. is selected; also read 3 parameters after reading the male weight-length parameter.
-1	Hermaphroditism Season: -1 to do transition at the end of each season (after mortality and before movement), <positive integer> to select just one season,

Typical Value	Description and Options
1	Include males in spawning biomass, 0 = no males in spawning biomass, 1 = simple addition of males to females, xx = more options to come later.

## Parameter offset method

Typical Value	Description and Options
2	Parameter Offset Method:  1 = direct assignment, 2 = for each growth pattern x sex, parameter defines offset from sex 1, offsets are in exponential terms, so for example: $M_{old\ male} = M_{old\ female} * exp(M_{old\ male})$ , 3 = for each growth pattern x sex, parameter defines offset from growth pattern 1 sex 1. For females, given that "natM option" is breakpoint and there are two breakpoints, parameter defines offset from early age (e.g., $M_{old\ female} = M_{young\ female} * exp(M_{old\ female})$ ). For males, given that "natM option" is breakpoint and there are two breakpoints, parameter is defined as offset from females AND from early age (e.g., $M_{old\ male} = M_{young\ female} * exp(M_{young\ male}) * exp(M_{old\ male})$ ).

## Catch Multiplier

These parameter lines are only included in the control file if the catch multiplier field in the data file is set to 1 for a fleet:

$$C_{adj} = C_{exp} * c_{mult} \quad (3)$$

where  $C_{exp}$  is the expected catch from the fishing mortality and  $c_{mult}$  is the catch multiplier. It has year-specific, not season-specific, time-varying capabilities. In the catch likelihood calculation, expected catch is multiplied by the catch multiplier by year and fishery to get  $C_{adj}$  before being compared to the observed retained catch, so  $C_{adj}$  value of 1.1 means that the observed catch is 10% greater than modeled catch.



## Ageing Error Parameters

These parameters are only included in the control file if one of the ageing error definitions in the data file has requested this feature (by putting a negative value for the ageing error of the age zero fish of one ageing error definition). As of version 3.30.12, these parameters now have time-varying capability. Seven additional full parameter lines are required. The parameter lines specify:

- age at which the estimated pattern begins (just linear below this age), this is the start age.
- bias at start age (as additive offset from unbiased age')
- bias at maxage (as additive offset from unbiased age')
- power function coefficient for interpolating between those 2 values (value of 0.0 produces linear interpolation in the bias)
- standard deviation at age
- standard deviation at max age
- power function coefficient for interpolating between those 2 values

Code for implementing vectors of mean age' and standard deviation of age' within SS can be located in [the appendix](#) on page 203.

## Sex ratio

The last line in the mortality-growth parameter section allows the user to fix or estimate the sex ratio between female and male fish. The parameter is specified in the fraction of female fish. The default option is a sex ratio of 0.50 with this parameter not being estimated. Estimation of the sex ratio is a new feature within SS and should be done with care with the user checking that the answer is reflective of the data.

As of v.3.30.12, this parameter now has time-varying capability similar to other parameters in the mortality-growth section.

## Read Biology Parameters

Next, SS reads the mortality-growth (MG) parameters in generally the following order (may vary based on selected options):

Parameter	Description
Females	Female natural mortality and growth parameters in the following order by growth pattern.
natM	Natural mortality for female growth pattern 1, where the number of natural mortality parameters depends on the option selected.
Lmin	Length at Amin (units in cm) for female, growth pattern 1.
Lmax	Length at Amax (units in cm) for female, growth pattern 1.
VBK	Von Bertalanffy growth coefficient (units are per year) for females, growth pattern 1.
COND if growth type =2	
Richards Coefficient	Only include this parameter if Richards growth function is used. If included, a parameter value of 1.0 will have a null effect and produce a growth curve identical to Bertalanffy.
COND if growth type >=3	Age-Specific K
K deviations for first age in range	
K deviations for next age in range	
...	
K deviations for last age in range	
CV young	Variability for size at age $\leq$ AFIX (units are fraction) for females, growth pattern 1. Note that CV cannot vary over time, so do not set up env-link or a deviation vector. Also, units are either as CV or as standard deviation, depending on assigned value of CV pattern.
CV old	Variability for size at age $\geq$ AFIX (units are fraction) for females, growth pattern 1. For intermediate ages, do a linear interpolation of CV on means size-at-age. Note that the units for CV will depend on the CV pattern and the value of MGparm as offset. The CV value cannot vary over time.
WtLen scale	Coefficient to convert length in cm to weight in kg for females.
WtLen exp	Exponent in to convert length to weight for females.
Mat-50	Maturity logistic inflection (in cm or years). Where female maturity-at-length (or age) is a logistic function: $M_l = 1/(1 + \exp(\alpha * (l_a - \beta)))$ where $\alpha$ is the slope, $l_a$ is the size-at-age, and $\beta$ is the inflection of the maturity curve.
Mat-slope	Logistic slope (must have negative value).

Parameter	Description
Eggs-alpha	Two fecundity parameters; usage depends on the selected fecundity option. Must be included here even if vector is read in the control section above.
Eggs-beta	
COND: GP > 1	Repeat female parameters in the above order for growth pattern 2.
Males	Male natural mortality and growth parameters in the following order by growth pattern.
natM	Natural mortality for male GP1, where the number of natural mortality parameters depends on the option selected.
Lmin	Length at Amin (units in cm) for male, GP1
Lmax	Length at Amax (units in cm) for male, GP1
VBK	Von Bertalanffy growth coefficient (units are per year) for males, growth pattern1.
COND if growth type = 2	
Richards Coefficient	Only include this parameter if Richards growth function is used. If included, a parameter value of 1.0 will have a null effect and produce a growth curve identical to Bertalanffy.
COND if growth type = 3	Age-Specific K
K deviations for first age in range	
K deviations for next age in range	
...	
K deviations for last age in range	
CV young	Variability for size at age $\leq$ AFIX (units are fraction) for males, GP1. Note that CV cannot vary over time, so do not set up env-link or a dev vector. Also, units are either as CV or as standard deviation, depending on assigned value of CV pattern.
CV old	Variability for size at age $\geq$ AFIX (units are fraction) for males, GP1. For intermediate ages, do a linear interpolation of CV on means size-at-age. Note that the units for CV will depend on the CV pattern and the value of MGparm as offset.
COND: GP > 1	Repeat male parameters in the above order for growth pattern 2.
WtLen scale	Coefficient to convert length in cm to weight in kg for males.

Parameter	Description
WtLen exp	Exponent in to convert length to weight for males.
COND: GP > 1	Repeat male parameters in the above order for growth pattern 2.
COND: Hermaphroditism	3 parameters define a normal distribution for the transition rate of females to males (or vice versa).
Inflect Age	Hermaphrodite inflection age.
StDev	Hermaphrodite standard deviation (in age) .
Asmp Rate	Hermaphrodite asymptotic rate.
Recr Dist GP	Recruitment apportionment by growth pattern, if multiple growth patterns, multiple entries required.
Recr Dist Area	Recruitment apportionment by area, if multiple areas, multiple entries required
Recr Dist Seas	Recruitment apportionment by season, if multiple seasons, multiple entries required
COND: If recruitment distribution interaction = 1 (on).	
N patterns x N areas x N seasons	Note that the order of recruitment distribution parameters has areas then seasons for main effect, and seasons then areas for interactions.
Cohort growth deviation	Set equal to 1.0 and do not estimate; it is deviations from this base that matter.
2 x N selected movement pairs	Movement parameters
COND: The following lines are only required when the associated features are turned on.	
Ageing Error	Turned on in the data file.
Catch	For each fleet selected for this option in the data file.
Multiplier	
Fraction female	Fraction female by growth pattern, if multiple growth patterns, multiple entries required.

Example format for MG parameter section with 2 sexes, 2 areas. Parameters marked with COND are conditional on selecting that feature:

LO	HI	INIT	Prior Value	<other entries>	Block Fxn	Parameter Label
0	0.50	0.15	0.1	...	0	#NatM_p_1_Fem_GP_1
0	45	21	36	...	0	#L_at_Amin_Fem_GP_1
40	90	70	70	...	0	#L_at_Amax_Fem_GP_1
0	0.25	0.15	0.10	...	0	#VonBert_K_Fem_GP_1
0.10	0.25	0.15	0.20	...	0	#CV_young_Fem_GP_1
0.10	0.25	0.15	0.20	...	0	#CV_old_Fem_GP_1
-3	3	2e-6	0	...	0	#Wtlen_1_Fem
-3	4	3	3	...	0	#Wtlen_2_Fem
50	60	55	55	...	0	#Mat50%_Fem
-3	3	-0.2	-0.2	...	0	#Mat_slope_Fem
-5	5	0	0	...	0	#Eggs/kg_inter_Fem
-50	5	0	0	...	0	#Eggs/kg_slope_wt_Fem
0	0.50	0.15	0.1	...	0	#NatM_p_1_Mal_GP_1
0	45	21	36	...	0	#L_at_Amin_Mal_GP_1
40	90	70	70	...	0	#L_at_Amax_Mal_GP_1
0	0.25	0.15	0.10	...	0	#VonBert_K_Mal_GP_1
0.10	0.25	0.15	0.20	...	0	#CV_young_Mal_GP_1
0.10	0.25	0.15	0.20	...	0	#CV_old_Mal_GP_1
-3	3	2e-6	0	...	0	#Wtlen_1_Mal
-3	4	3	3	...	0	#Wtlen_2_Mal
0	0	0	0	...	0	#RecrDist_GP_1
0	0	0	0	...	0	#RecrDist_Area_1
0	0	0	0	...	0	#RecrDist_Area_2
0	0	0	0	...	0	#RecrDist_Settlement_1
0.2	5	1	1	...	0	#CohortGrowDev
-5	5	-4	1	...	0	#Move_A_seas1_GP1_from_1to2 (COND)
-5	5	-4	1	...	0	#Move_B_seas1_GP1_from_1to2 (COND)
-99	99	1	0	...	0	#AgeKeyParm1 (COND)
-99	99	0.288	0	...	0	#AgeKeyParms 2 to 5 (COND)
-99	99	0.715	0	...	0	#AgeKeyParm6 (COND)
0.2	3.0	1.0	0	...	0	#Catch_mult_fleet1 (COND)
0.001	0.999	0.5	0.5	...	0	#FracFemale_GP_1

## Time-Varying Biology Parameters

Any of the parameters defined above can be made time-varying through linkage to an environmental data series, through time blocks or trend, or by setting up annual deviations. The options for making biology, spawner-recruitment, catchability and selectivity parameters change over time is detailed in the section labeled Time-Varying Parameters. After reading the biology parameters above, which will include possible instructions to create environmental link, blocks, or deviation vectors, then read the following section. Note that all inputs in this section are conditional (COND) on entries in the biology parameter section. So if no biology parameters invoke any time-varying properties, this section is left blank (or completely commented out with #).

When time-varying growth is used, there are some additional considerations to be aware of:

- Growth deviations propagate into the forecast. The user can select which growth parameters get used during the forecast by setting the end year of the last block. If the last block ends in the model's end year, then the growth parameters in effect during the forecast will revert to the "no-block" baseline level. By setting the end year of the last block to end year (endyr) + 1, the model will continue the last block's growth parameter levels throughout the forecast.
- The equilibrium benchmark quantities (MSY, F40%, etc.) previously used end year (endyr) body size-at-age, which is a disequilibrium vector. There is a capability to specify a range of years over which to average the size-at-age used in the benchmark calculations.
- An addition issue occurred in versions prior to 3.20. Its description is retained here, but it was resolved with the growth code modification for version 3.20.
  - Issue for versions prior to 3.20: When the growth reference ages have  $A1 > 0$  and  $A2 < 999$ , the effect of time-varying  $K$  has a non-intuitive aspect. This occurs because the virtual size at age 0.0 and the actual  $L_{inf}$  are calculated annually from the current  $L1$ ,  $L2$  and  $K$  parameters. Because these calculated quantities are outside the age range  $A1$ ,  $A2$ , a reduction in  $K$  will cause an increase in the calculated size-at-age 0.0 that year. So there is a ripple effect as the block's growth parameters affect the young cohorts in existence at the time of the change. The workaround for this is to set  $A1=0$  and  $A2=999$ . However, this may create another incompatibility because the size-at-age 0.0 cannot be allowed to be negative and should not be allowed to be less than the size of the first population length bin. Therefore, previous use of  $A1=2$  might have implied a virtual size at age 0.0 that was negative (which is ok), but setting  $A1=0$  does not allow the size at age= $A1$  to be negative.

Time-varying parameter specification:

---

			Prior	Prior	Prior		
LO	HI	INIT	Value	SD	Type	Phase	Parameter Label

---

COND: Only if MG parameters are time-varying

LO	HI	INIT	Prior Value	Prior SD	Prior Type	Phase	Parameter Label
-99	99	1	0	0.01	0	-1	#Wtlen_1_Fem_ENV_add
-99	99	1	0	0.01	0	-1	#Wtlen_2_Fem_ENV_add

## Seasonal Biology Parameters

Seasonal effects are available for weight-length parameters and for the growth K. Seasonality is not needed for the maturity and fecundity parameters because spawning is only defined to occur in one season. Seasonal L1 may be implemented at a later date. The seasonal parameter values adjust the base parameter value for that season.

$$P' = P * \exp(\text{seas\_value}) \quad (4)$$

Control file continued:

Value	Description
0 0 0 0 0 0 0 0 0 0	Seasonality for selected biology parameters (not a conditional input). Read 10 integers to specify which biology parameters have seasonality: fem-wtlen1, fem-wtlen2, mat1, mat2, fec1, fec2, male-wtlen1, male-wtlen2, L1, K. Reading a positive value selects that factor for seasonality.
COND: If any factors have seasonality, then read N seasons parameters that define the seasonal offsets from the base parameter value.	
<short parameter line(s)>	Read N seasons short parameter lines for each factor selected for seasonality. The parameter values define an exponential offset from the base parameter value.

## Spawner-Recruitment

The spawner-recruitment section starts by specification of the functional relationship that will be used.

Control file continued:

Value	Label	Description
3	Spawner- Recruitment Relationship	<p>The options are:</p> <p>1: null,</p> <p>2: Ricker: 2 parameters: <math>\log(R_0)</math> and steepness,</p> <p>3: Standard Beverton-Holt, 2 parameters: <math>\log(R_0)</math> and steepness,</p> <p>4: Ignore Steepness and no bias adjustment. Use this in conjunction with very low emphasis on recruitment deviations to get CAGEAN-like unconstrained recruitment estimates, 2 parameters, but only uses the first on),</p> <p>5: <a href="#">Hockey stick</a>: 3 parameters: <math>\log(R_0)</math>, steepness, and <math>R_{\min}</math> for <math>\ln(R_0)</math>, fraction of virgin SSB at which inflection occurs, and the R level at SSB=0.0.</p> <p>6: Beverton-Holt with flat-top beyond Bzero, 2 parameters: <math>\log(R_0)</math> and steepness,</p> <p>7: <a href="#">Survivorship function</a>: 3 parameters: <math>\log(R_0)</math>, <math>z_{frac}</math>, and <math>\beta</math>. Suitable for sharks and low fecundity stocks to assure recruits are <math>\leq</math> population production.</p> <p>8: <a href="#">Shepherd</a>: 3 parameters: <math>\log(R_0)</math>, steepness, and shape parameter, <math>c</math>.</p> <p>9 (beta): <a href="#">Shepherd re-parameterization</a>: 3 parameters: <math>\log(R_0)</math>, steepness, and shape parameter, <math>c</math>.</p> <p>10 (beta): <a href="#">Ricker re-parameterization</a>: 3 parameters: <math>\log(R_0)</math>, steepness, and Ricker power, <math>\gamma</math>. This SRR is was added to version 3.30.11 and is in beta mode.</p>
1	Equilibrium recruitment	<p>Use steepness in initial equilibrium recruitment calculation</p> <p>0 = none</p> <p>1 = use steepness</p>
0	Future Feature	Reserved for the future option to make realized $\sigma_R$ a function of the stock-recruitment curve.

The number of parameters needed by each relationship is stored internally. In SS v.3.24 and before, only a short parameter line was used for the spawner-recruitment section. SS v.3.30 now requires long parameter lines in the spawner-recruitment section because it now uses the same time-varying parameter approach as the biology and selectivity parameters. This generic time-varying approach replaces the SR envlink concept in SS v.3.24. Also the R1 offset was effectively a block to implement a regime shift for the initial equilibrium year. Now in v.3.30, the R1 offset parameter is replaced by a



parameter termed "regime shift". The SR regime parameter is intended to have a base value of 0.0 and not be estimated. Similar to the cohort-growth deviation, it serves simply as a base for adding time-varying adjustments. This regime shift parameter can have blocks, environmental links or random deviations.

If a SS v.3.24 model implement the R1 offset approach this can be mimicked in v.3.30 by the SR regime parameter. For any given year, including startyr - 1, the R0 is replaced by  $R0 * \exp(SRRegime_y)$ . So to mimic the R1\_offset, you need to put a block on SR\_regime for y = startyr - 1. But if SR\_regime has some change during your main time series, that change will be filtered through the stock-recruit relationship into an impact on the numbers at age for whatever years are impacted. This can also apply to the forecast. A block on SR\_regime is also easier than some of the old dummy environmental variables that were created in the past to adjust recruitment up and down for long periods.

If the R0 or steepness parameters are time-varying, then SS will use the current year's parameters to calculate recruits as a function of the spawning biomass. If the SR regime parameter is time-varying, then SS applies this offset after calculating recruits as function of spawning biomass. The expected deviations can no longer be linked to "env": instead the environmental effect will be on the "regime".

Read the required number of long parameter set-up lines (e.g. LO, HI, INIT, PRIOR, PRIOR TYPE, SD, PHASE, ..., and BLOCK TYPE). These parameters are:

Value	Label	Description
8.5	log(R0)	Log of virgin recruitment level.
0.60	Steepness	Steepness of S-R, bound by 0.2 and 1.0 for the Beverton-Holt.
COND:		If SRR = 5, 7, or 8
	3rd Parameter	Optional depending on which SRR function is used.
0.60	$\sigma_R$	Standard deviation of log recruitment. This parameter has two related roles. It penalizes deviations from the spawner-recruitment curve, and it defines the offset between the arithmetic mean spawner-recruitment curve (as calculated from log(R0) and steepness) and the expected geometric mean (which is the basis from which the deviations are calculated. Thus the value of $\sigma_R$ must be selected to approximate the true average recruitment deviation.

Value	Label	Description
0	Regime Parameter	This replaces the R1 offset parameter. It can have a block for the initial equilibrium year, so can fully replicate the functionality of the previous R1 offset approach. The SR regime parameter is intended to have a base value of 0.0 and not be estimated. Similar to cohort-growth deviation, it serves simply as a based for adding time-varying adjustments. This concept is similar to the old environment effect on deviates feature in SS v.3.24 and earlier.
0	Autocorrelation	Autocorrelation in recruitment.

Example set-up of the spawner-recruitment section:

LO	HI	INIT	PRIOR	<other entries>	Block Fxn	Parameter Label
3	31	8.81	10.3	...	0	#SR_LN(R0)
0.2	1	0.61	0.70	...	0	#SR_BH_steep
0	2	0.60	0.80	...	0	#SR_sigmaR
-5	5	0	0	...	0	#SR_regime
-99	99	0	0	...	0	#SR_autocorr

- The R0, steepness, and regime shift parameters can be time-varying by blocks, trends, environmental linkages, or random deviation. However, not all of these options make sense for all parameters. Before discussing these, another important change must be noted.
- The  $\sigma_R$  and autocorrelation parameters can not be time-varying.
- In SS v.3.24, the R0 and steepness parameter was used for both the virgin calculation and for the MSY (benchmark) calculations. In SS v.3.30, these usages are more explicitly defined. The value of R0 and steepness in the initial year is used for virgin and for calculation the denominator in depletion estimates. The average value of R0 and steepness in the range of years specified as the benchmark years 9 and 10 (see forecast.ss) is used for MSY type calculations. So, for example, a long-term climate effect could cause R0 to change over time and  $B_{MSY}$  could now be calculated for some future range of years.
- Since R0 can be time-varying, what is regime shift for? Regime shift is for multi-year or environmentally driven deviations from R0 without changing R0 itself. Then the recruitment

deviations are annual deviations from the current regime and these recruitment deviations can have autocorrelation.

- Warning: Use these options judiciously because the same algebraic effect on the calculated recruitment can be achieved by different combinations of these options.
- Preliminary recommendation: Use block, trend or environmental effects on R0 only for very long-term and highly persistent effects; use time-vary effects on regime shift for transitory, but multi-year deviations from R0.
- The time-vary parameter lines are short lines because they themselves cannot be time-varying.
- The order of time-vary parameters are; R0, steepness, then regime shift. The number of time-varying parameters from each of these can range from zero to many.
- Note that setting a block for just the initial equilibrium year is equivalent to R1\_offset. If R1 offset is being used in SS v.3.24, then sstrans.exe will automatically add a new block for the initial equilibrium year so that you can easily re-implement a R1 offset effect.

Control file continued:

Value	Label	Description
1	Do Recruitment Deviations	<p>This selects the way in which recruitment deviations are coded:</p> <p>0: None (so all recruitments come from S-R curve),</p> <p>1: Deviation vector (previously the only option). Here the deviations are encoded as a deviation vector, so ADMB enforces a sum-to-zero constraint.</p> <p>2: Simple deviations. Here the deviations do not have an explicit constraint to sum to zero, although they still should end up having close to a zero sum. The difference in model performance between options (1) and (2) has not been fully explored to date.</p> <p>3: Deviation vector (added in v.3.30.13) where the estimated recruitment is equal to the R0 adjusted for blocks multiplied by a simple deviation vector of unconstrained deviations. The negative log-likelihood from the deviation vector is equal to the log of the estimated recruitment divided by the expected recruitment by year adjusted for the spawner-recruit curve, regimes, environmental parameters, and bias-adjustment. The negative log-likelihood between option 2 and 3 is approximately equal.</p> <p>4: Similar to option 3 but includes a penalty based on the sum of the deviations (added in v.3.30.13).</p>

Value	Label	Description
		Note: As of version 3.30.13 there is now an option to retain the last deviation estimated and apply that value into the forecast period. To specify this option add the value 2 before the deviation vector option (i.e., 21, 22, 23, or 24).
1971	Main recruitment deviations begin year	If begin year is less than the model start year, then the early deviations are used to modify the initial age composition. However, if set to be more than Nages before start year, it is changed to equal Nages before start year.
1999	Main recruitment deviations end year	If recruitment deviations end year is later than retro year, it is reset to equal retro year.
3	Main recruitment deviations phase	
1	Advanced Options	0: Use default values for advanced options 1: Read values for the 11 advanced options.
COND = 1 Beginning of advanced options		
1950		Early Recruitment Deviation Start Year: 0: skip (default), +year: absolute year (must be less than begin year of main recruitment deviations), -integer: set relative to main recruitment deviations start year. Note: because this is a deviation vector, it should be long enough so that recruitment deviations for individual years are not unduly constrained.
6		Early Recruitment Deviation Phase: Negative value: default value to not estimate early deviations. Users may want to set to a late phase if there is not much early data.
0		Forecast Recruitment Phase: 0 = Default value.

Value	Label	Description
		Forecast recruitment deviations always begin in the first year after the end of the main recruitment deviations. Recruitment in the forecast period is deterministic derived from the specified stock-recruitment relationship. Setting their phase to 0 causes their phase to be set to max lambda phase +1 (so that they become active after rest of parameters have converged.). However, it is possible here to set an earlier phase for their estimation, or to set a negative phase to keep the forecast recruitment deviations at a constant level.
1		Forecast Recruitment Deviations Lambda: 1 = Default value. This lambda is for the log-likelihood of the forecast recruitment deviations that occur before endyr + 1. Use a larger value here if solitary, noisy data at end of time series cause unruly recruitment deviation estimation.
1956		Last year with no bias adjustment.
1970		First year with full bias adjustment.
2001		Last year with full bias adjustment.
2002		First recent year with no bias adjustment. These four entries control how the bias adjustment is phased in and then phased back out when the model is searching for the maximum log-likelihood. Bias adjustment is automatically turned off when in MCMC mode. For intervening years between the first and second years in this list, the amount of bias adjustment that will be applied is linearly phased in. The first year with full bias adjustment should be a few years into the data-rich period so that SS will apply the full bias-correction only to those recruitment deviations that have enough data to inform the model about the full range of recruitment variability. Defaults for the four year values: start year – 1000, start year – Nages, main recruitment deviation final year, end year + 1. See <a href="#">Recruitment Likelihood with Bias Adjustment</a> for more information.
0.85		Max Bias Adjustment: Value for the maximum bias adjustment during the MLE mode. A value of -1 will set the bias adjustment to 1.0 for all years with estimated recruitment deviations. Likewise, all estimated recruitment deviations, even those within a ramped era, switch to maxbias=1.0 during MCMC.
0		Period For Recruitment Cycles:

Value	Label	Description
		Use this when SS is configured to model seasons as years and there is a need to impose a periodicity to the expected recruitment level. If value is >0, then read that number of full parameter lines below define the recruitment cycle
-5		Minimum Recruitment Deviation: Min value for recruitment deviation. Negative phase = Default value.
5		Maximum Recruitment Deviation: Max value for recruitment deviation. Late Phase = Default value (e.g., 5)
2		Number of Explicit Recruitment Deviations to Read: 0: Default, do not read any recruitment deviations; Integer: read this number of recruitment deviations.
End of advanced options		
COND = If N recruitment cycle is > 0, enter N full parameter lines below.		
	<parameter line>	Full parameter line for each of the N periods of recruitment cycle.
COND = If N explicit recruitment deviations is > 0, then enter N lines below.		
1977	3.0	Enter year and deviation.
1984	3.0	Two example recruitment deviations being read. Note: SS will rescale the entire vector of recrdevs after reading these deviations, so by reading two positive values, all other recrdevs will be scaled to a small negative value to achieve a sum to zero condition before starting model estimation.

## Spawner-Recruitment Function

The number of age-0 fish is related to spawning biomass according to a stock-recruitment relationship. SS has the option of the Beverton-Holt, Ricker, Hockey-Stick, and a survival-based stock recruitment relationship.

### Beverton-Holt

The Beverton-Holt Stock Recruitment curve is calculated as:

$$R_y = \frac{4hR_0SB_y}{SB_0(1-h) + SB_y(5h-1)} e^{-0.5b_y\sigma_R^2 + \tilde{R}_y} \quad \tilde{R}_y \sim N(0; \sigma_R^2) \quad (5)$$

where  $R_0$  is the unfished equilibrium recruitment,  $SB_0$  is the unfished equilibrium spawning biomass (corresponding to  $R_0$ ),  $SB_y$  is the spawning biomass at the start of the spawning season during year  $y$ ,  $h$  is the steepness parameter,  $b_y$  is the bias adjustment fraction applied during year  $y$ ,  $\sigma_R$  is the standard deviation among recruitment deviations in log space, and  $\tilde{R}_y$  is the lognormal recruitment deviation for year  $y$ . The bias-adjustment factor (Methot et al., 2011) ensures unbiased estimation of mean recruitment even during data-poor eras in which the maximum likelihood estimate of the recruitment deviation is near 0.0.

## Ricker

The Ricker Stock Recruitment curve is calculated as:

$$R_y = \frac{R_0SB_y}{SB_0} e^{h(1-SB_y/SB_0)} e^{-0.5b_y\sigma_R^2 + \tilde{R}_y} \quad \tilde{R}_y \sim N(0; \sigma_R^2) \quad (6)$$

## Hockey-Stick

The hockey-stick recruitment curve is calculated as:

$$R_y = R_{\min}R_0 + \frac{SB_y}{hSB_0}(R_0 - R_{\min}(join) + R_0(1 - join)) \quad (7)$$

where  $R_{\min}$  is the minimum recruitment level predicted at a spawning size of zero and is set by the user in the control file,  $h$  is defined as the fraction of  $SB_0$  below which recruitment declines linearly, and  $join$  is defined as:

$$join = \left[ 1 + e^{1000 * \frac{(SB_0 - hSB_0)}{SB_0}} \right]^{-1} \quad (8)$$

## Survivorship

The survivorship stock recruitment relationship based on Taylor et al. (2013) is a stock-recruitment model that enables explicit modeling of survival between embryos and age 0 recruits, and allows the description of a wide range of pre-recruit survival curves based. The model is especially useful for low fecundity species that produce relatively few offspring per litter and exhibit a more direct connection between spawning output and recruitment than species generating millions of eggs.

Survival-based recruitment is constrained so that the recruitment rate cannot exceed fecundity. The relationship between survival and spawning output is based on parameters which are on a log scale. These are:

$$z_0 = -\log(S_0) \quad (9)$$

which is the negative of the log of the equilibrium survival  $S_0$ , and can be thought of as a pre-recruit instantaneous mortality rate at equilibrium, and

$$z_{\min} = -\log(S_{\max}) = z_0(1 - z_{\text{frac}}) \quad (10)$$

which is the negative of the log of the maximum pre-recruit survival rate ( $S_{\max}$ , the limit as spawning output approaches 0), and is parameterized as a function of  $z_{\text{frac}}$  (which represents the reduction in mortality as a fraction of  $z_0$ ) so the expression is well defined over the parameter range  $0 < z_{\text{frac}} < 1$ .

Recruitment at age 0 for each year in the time series is calculated as:

$$R_y = SB_y e^{\left(-z_0 + (z_0 - z_{\min}) \left(1 - (SB_y/SB_0)^\beta\right)\right)} e^{\tilde{R}_y} \quad \tilde{R}_y \sim N(0; \sigma_R^2) \quad (11)$$

where  $SB_y$  is the spawning output in year  $y$ ,  $\beta$  is a parameter controlling the shape of density-dependent relationship between relative spawning depletion  $SB_y/SB_0$  and pre-recruit survival (with limit  $\beta < 1$ ),  $\tilde{R}_y$  is the recruitment in year  $y$ , and  $\sigma_R$  is the standard deviation of recruitment in log space.

As implemented in Stock Synthesis, the parameters needed to apply the stock-recruitment relationship based on the pre-recruit survival are  $\log(R_0)$ ,  $z_{\text{frac}}$ , and  $\beta$ . The value of  $\log(R_0)$  defines the equilibrium quantities of  $SB_0$ ,  $S_0$ , and  $z_0$  for a given set of biological inputs (either estimated or fixed), regardless of the values of  $z_{\text{frac}}$  and  $\beta$ .

The interpretation of the quantity  $z_0 = -\log(S_0)$  as pre-recruit instantaneous mortality rate at unfished equilibrium is imperfect because the recruitment in a given year is calculated as a product of the survival fraction  $S_y$  and the spawning output  $SB_y$  for that same time period so that there is not a 1-year lag between quantification of eggs or pups and recruitment at age 0, which is when recruits are calculated within Stock Synthesis. However, if age 0 or some set of youngest ages is not selected by any fishery or survey, then density dependent survival may be assumed to occur anywhere before the first appearance of any cohort in the data or model expectations. In such cases, the upper limit on survival up to age  $a$  is given by  $S_{\max} e^{-aM}$ .

Nevertheless, interpreting  $z_0$  as an instantaneous mortality helps with the understanding of  $z_{\text{frac}}$ . This parameter controls the magnitude of the density-dependent increase in survival associated with a reduction in spawning output. It represents the fraction by which this mortality-like rate is reduced as spawning output is reduced from  $SB_0$  to 0. This is approximately equal to the increase in survival as a fraction of the maximum possible increase in survival. That is:

$$z_{\text{frac}} = \frac{\log(S_{\max}) - \log(S_0)}{-\log(S_0)} \approx \frac{S_{\max} - S_0}{1 - S_0} \quad (12)$$

For example, if  $S_0 = 0.4$ ,  $z_{\text{frac}} = 0.8$ , then the resulting fraction increase in survival is  $(S_{\max} - S_0)/(1 - S_0) = 0.72$ .

The parameter  $\beta$  controls the point where survival changes fastest as a function of spawning depletion. A value of  $\beta = 1$  corresponds to a linear change in log survival and an approximately linear relationship between survival and spawning depletion. Values of  $\beta < 1$  have survival increasing fastest



at low spawning output (concave decreasing survival) whereas  $\beta > 1$  has the increase in survival occurring fastest closer to the unfished equilibrium (convex decreasing survival).

The steepness ( $h$ ) of the spawner-recruit curve (defined as recruitment relative to  $R_0$  at a spawning depletion level of 0.2) based on pre-recruit survival can be derived from the parameters discussed above according to the relationship and associated inequality:

$$h = 0.2e^{z_0 z_{\text{frac}}(1-0.2^\beta)} < 0.2e^{z_0} = \frac{1}{5S_0} = \frac{SB_0}{5R_0} \quad (13)$$

Unlike the Beverton-Holt stock-recruitment relationship, recruitment can increase above  $R_0$  for stocks that are below  $SB_0$  and thus the steepness is not fundamentally constrained below 1. However, in many cases, steepness will be limited well below 1 by the inequality above, which implies an inverse relationship between the maximum steepness and equilibrium survival. Specifically, the inequality above bounds steepness below 1 for all cases where  $S_0 > 0.2$ , which are those with the lowest fecundity, an intuitively reasonable result. For example, with  $S_0 = 0.4$ , the steepness is limited below 0.5, regardless of the choice of  $z_{\text{frac}}$  or  $\beta$ . This natural limit on steepness may be one of the most valuable aspects of this stock-recruitment relationship.

Code for the survival based recruitment can be found in [Appendix C](#).

## Shepherd

The Shepherd stock recruit curve is calculated as:

$$R_y = \left( \frac{SB_y}{SB_0} \right) \frac{5h_{adj}R_0(1 - 0.2^c)}{(1 - 5h_{adj}0.2^c) + (5h_{adj} - 1)\left(\frac{SB_y}{SB_0}\right)^c} e^{-0.5b_y\sigma_R^2 + \tilde{R}_y} \quad \tilde{R}_y \sim N(0; \sigma_R^2) \quad (14)$$

where  $c$  is the shape parameter for the stock recruitment curve, and  $h_{adj}$  is the transformed steepness parameter defined as:

$$h_{adj} = 0.2 + \left( \frac{h - 0.2}{0.8} \right) \left( \frac{1}{5 * 0.2^c} - 0.2 \right) \quad (15)$$

## Shepherd Re-parameterization

The Shepherd stock recruit curve re-parameterized version. More details can be found in Punt and Cope.

$$R_y = \frac{R_0 SB_y}{SB_0} \left( \frac{5h(1 - 0.2^c)}{1 - 5h0.2^c + (5h - 1)(SB_y/SB_0)^c} \right) \quad (16)$$

where  $c$  is the shape parameter for the stock recruitment curve.

## Ricker Re-parameterization

The Ricker stock recruit curve re-parameterized version. More details can be found in Punt and Cope.

$$R_y = R_0 * (1 - temp) * e^{\ln(5h)(1-SB_y/SB_0)^\gamma / 0.8^\gamma} \quad (17)$$

where  $\gamma$  is the Ricker shape parameter and  $temp$  is defined as:

$$temp = \begin{cases} 1 - SB_y/SB_0 & \text{if } 1 - SB_y/SB_0 > 0 \\ 0.001 & \text{if } 1 - SB_y/SB_0 \leq 0 \end{cases} \quad (18)$$

where  $temp$  stabilizes recruitment at  $R_0$  if  $SB_y > SB_0$ .

## Recruitment Eras

Conceptually, SS treats the early, data-poor period, the main data-rich period, and the recent/forecast time period as three eras along a continuum. The user has control of the break year between eras. Each era has its own vector. The early era is defined as a vector (prior to V3.10 this was a deviation vector) so it can have zeros during the earliest years not informed by data and then a few years with non-zero values without imposing a zero-centering on this collection of deviations. The main era can be a vector of simple deviations, or a deviation vector but it is normally implemented as a deviation vector so that the spawner-recruitment function is its central tendency. The last era does not force a zero-centered deviation vector so it can have zeros during the actual forecast and non-zero values in last few years of the time series. The early and last eras are optional, but their use can help prevent SS from balancing a preponderance of negative deviations in early years against a preponderance of positive deviations in later years. When the 3 eras are used, it would be typically to turn on the main era during an early model phase, turn on the early era during a later phase, then have the last era turn on in the final phase.

## Recruitment Likelihood with Bias Adjustment

For each year in the total recruitment deviation time series (early, mid, late/forecast) the contribution of that year to the log-likelihood is equal to:  $dev^2 / (2.0 * sigmaR^2) + offset * \log(sigmaR)$ ; where offset is the recruitment bias adjustment between the arithmetic and geometric mean of expected recruitment for that year. With this approach, years with a zero or small offset value do not contribute to the second component.  $\sigma_R$  may be estimable when there is good data to establish the time series of recruitment deviations.

The recruitment bias adjustment implemented in SS is based upon the work documented in Methot et al. (2011) and following the work of Maunder and Deriso (2003). The concept is based upon the following logic.  $\sigma_R$  represents the true variability of recruitment in the population. It provides the

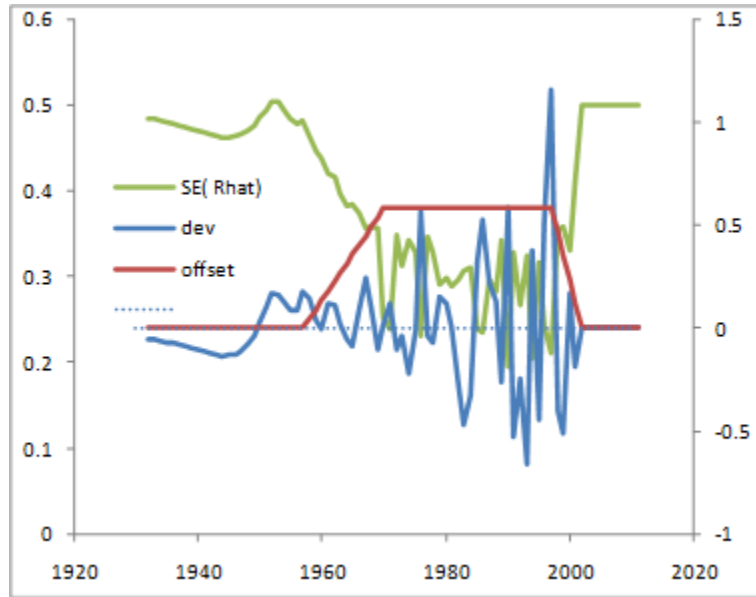
constraining penalty for the estimates of recruitment deviations and it is not affected by data. Where data that are informative about recruitment deviations are available, the total variability in recruitment,  $\sigma_R$ , is partitioned into a signal (the variability among the recruitment estimates) and the residual, the variance of each recruitment estimate (see equation below). Where there are no data, no signal can be estimated and the individual recruitment deviations collapse towards 0.0 and the variance of each recruitment deviation approaches  $\sigma_R$ . Conversely, where there highly informative data about the recruitment deviations, then the variability among the estimated recruitment deviations will approach  $\sigma_R$  and the variance of each recruitment deviation will approach zero. Perfect data will estimate the recruitment time series signal perfectly. Of course, we never have perfect data so we should always expect the estimated signal (variability among the recruitment deviations) to be less than the true population recruitment variability.

$$SE(\hat{r}_y)^2 + SD(\hat{r})^2 = \left( \left( \frac{1}{\sigma_d^2} + \frac{1}{\sigma_R^2} \right)^{-1/2} \right)^2 + \left( \frac{\sigma_R^2}{(\sigma_R^2 + \sigma_d^2)^{1/2}} \right)^2 = \sigma_R^2 \quad (19)$$

The correct offset (bias adjustment) to apply to the expected value for recruitment is based on the concept that a time series of estimated recruitments should be mean unbiased, not median unbiased, because the biomass of a stock depends upon the cumulative number of recruits, which is dominated by the large recruitments. The degree of offset depends upon the degree of recruitment signal that can be estimated. Where no recruitment signal can be estimated, the median recruitment is the same as the mean recruitment, so no offset is applied. Where lognormal recruitment signal can be estimated, the mean recruitment will be greater than the median recruitment. The value

$$b_y = \frac{E\left( SD(\hat{r}_y) \right)^2}{\sigma_R^2} = 1 - \frac{SE(\hat{r}_y)^2}{\sigma_R^2} \quad (20)$$

of the offset then depends upon the partitioning of  $\sigma_R$  into between and within recruitment variability. The most appropriate degree of bias adjustment can be approximated from the relationship among  $\sigma_R$ , recruitment variability (the signal), and recruitment residual error.



Because the quantity and quality of data varies during a time series, SS allows the user to control the rate at which the offset is ramped in during the early, data-poor years, and then ramped back to zero for the forecast years.

On output SS calculates the mean bias adjustment during the early and main eras and compares it to the RMSE of estimated recruitment deviations in the report.sso file. A warning is generated if the RMSE is small and the bias adjustment is larger than 2.0 times the ratio of  $rmse^2$  to  $\sigma R^2$ .

In MCMC mode, the model still draws recruitment deviations from the lognormal distribution, so the full offset is used such that the expected mean recruitment from this lognormal distribution will stay equal to the mean from the spawner-recruitment curve. When SS reaches the MCMC and MCEVAL phases, all bias adjustment values are set to 1.0 for all active recruitment deviations because the model is now re-sampling from the full lognormal distribution of each recruitment.

## Recruitment Autocorrelation

The autocorrelation parameter is implemented. It is not performance tested and it has no effect on the calculation of the offsets described in the section above.

## Recruitment Cycle

When SS is configured such that seasons are modeled as years, the concept of season within year disappears. However, there may be reason to still want to model a repeating pattern in expected

recruitment to track an actual seasonal cycle in recruitment. If the recruitment cycle factor is set to a positive integer, this value is interpreted as the number of time units in the cycle and this number of full parameter lines will be read. The cyclic effect is modeled as an  $\exp(p)$  factor times  $R_0$ , so a parameter value of 0.0 has nil effect. In order to maintain the same number of total recruits over the duration of the cycle, a penalty is introduced so that the cumulative effect of the cycle produces the same number of recruits as  $N_{cycles} * R_0$ . Because the cyclic factor operates as an exponential, this penalty is different than a penalty that would cause the sum of the cyclic factors to be 0.0. This is done by adding a penalty to the parameter likelihood, where:

$$\begin{aligned} X &= \sum(e^p) \\ Y &= N_{cycle} \\ Penalty &= 100000 * (X - Y)^2 \end{aligned} \tag{21}$$

## Initial Age Composition

A non-equilibrium initial age composition is achieved by setting the first year of the recruitment deviations before the model start year. These pre-start year recruitment deviations will be applied to the initial equilibrium age composition to adjust this composition before starting the time series. The model first applies the initial  $F$  level to an equilibrium age composition to get a preliminary  $N$ -at-age vector and the catch that comes from applying the  $F$ 's to that vector, then it applies the recruitment deviations for the specified number of younger ages in this vector. If the number of estimated ages in the initial age composition is less than  $N_{ages}$ , then the older ages will retain their equilibrium levels. Because the older ages in the initial age composition will have progressively less information from which to estimate their true deviation, the start of the bias adjustment should be set accordingly.

## Fishing Mortality Method

There are three methods available for calculation of fishing mortality. These are: Pope's approximation, continuous  $F$  with each  $F$  as a model parameter, and a hybrid method that does a Pope's approximation to provide initial values for iterative adjustment of the continuous  $F$  values to closely approximate the observed catch. With the hybrid method, the final values are in terms of continuous  $F$ , but do not need to be specified as full parameters. In a 2 fishery, low  $F$  case, the hybrid method is just as fast as the Pope approx. and produces identical result. When  $F$  is very high, the problem becomes quite stiff for Pope's and the hybrid method so convergence may slow. It may be better to use  $F$  option 2 (continuous  $F$  as full parameters) in these high  $F$  cases.  $F$  as parameter is also preferred for situations where catch is known imprecisely and you are willing to accept a solution in which the final  $F$  values do not reproduce the input catch levels exactly. For the  $F$  as parameter approach, there is an option to do early phases using hybrid, then switch to  $F$  as parameter in later phases and transfer the hybrid  $F$  values to the parameter initial values.

Option 1 (Pope's approx) still exists, but it is recommended to switch to option 3.

Control file continued:

Typical Value	Description and Options
0.2	F ballpark This value is compared to the sum of the F's for the specified year. The sum is over all seasons and areas. In older versions of SS, the lambda was automatically set to 0.0 in the final phase, the user now has control over whether to reduce the <a href="#">lambda</a> in later phases.
-1990	F ballpark year Negative value disable F ballpark.
3	F Method 1 = Pope's (discrete), 2 = Baranov (continuous) F as a parameter, 3 = Hybrid F (recommended).
2.9	Maximum F This maximum is applied within each season and area. A value of 0.9 is recommended for F method 1, and a value of about 4 is recommended for F method 2 and 3.
COND: F method = 1, no additional input for Pope's approximation.	
COND: F method = 2:	
0.10 1 1	Initial F value, Phase, N F detail setup lines to read. Starting value for each F. Initializing value for each F parameter. For phases prior to the phase of the F value becoming active, SS will use the hybrid option and the F values so calculated become the starting values for the F parameters when this phase is reached.
If F method = 2 and N for F detail is > 0	
1 1980 1 0.20 0.05 4	fleet, year, season, F, SE, phase - these values override the catch se values in the data file and the overall starting F value and phase read just above.
COND: Fmethod = 3	

Typical Value	Description and Options
4	Number of tuning iterations in hybrid method. A value of 2 or 3 is sufficient with a single fleet and low Fs. A value of 5 or so may be needed to match the catch near exactly when there are many fleets and high F.

## Initial Fishing Mortality

Read a short parameter setup line for each fishery. The parameters are the fishing mortalities for the initial equilibrium. Do not try to estimate parameters for fisheries with zero initial equilibrium catch. If there is catch, then give a starting value greater than zero and it generally is best to estimate the parameter in phase 1.

In SS3.30, the initial equilibrium year has explicit seasons, so the needed initial F values will also be by season. Initial F values are only needed for fleet/seasons that have catch. So if no fleet/season combo has catch, then no parameters are needed.

It is possible to use the initial F method to achieve an estimate of the initial equilibrium Z in cases where the initial equilibrium catch is unknown. To do this:

- Include a positive value for the initial equilibrium catch;
- Set the lambda for the logL for initial equilibrium catch to a nil value (hence causing SS to ignore the lack of fit to the input catch level;
- Allow the initial F parameter to be estimated. It will be influenced by the early age and size comps which should have some information about the early levels of Z.

## Catchability

Catchability is the scaling factor that relates a model quantity to the expected value for some type of data (index). Typically this is used to converted selected numbers or biomass for a fleet into the expected value for a survey or CPUE by that fleet. In SS, the concept has been extended so that, for example, a time series of an environmental factor could be treated as a survey of the time series of deviations for some parameter. This flexibility means that a family of link functions beyond simple proportionality is needed.

For each fishery and survey with an index, enter a row with the entries as described below:

1. Fleet Number
2. Link type or index of dev vector: An assumed functional form between Q, the expected value, and the survey observation.
  - (a) 1 = simple Q, proportional assumption about Q:  $y = q * x$ .
  - (b) 2 = mirror simple Q, 1 mirrored parameter.
  - (c) 3 = Q with power, 2 parameters establish a parameter for non-linearity in survey-abundance linkage. Assumes proportional with offset and power function:  $y = qx^c$  where  $q = \exp(\ln Q_{base})$  thus the  $c$  is not related to expected biomass but vulnerable biomass to Q. Therefore,  $c < 0$  leads to hyper-stability and  $c > 0$  leads to hyper-depletion.
  - (d) 4 = mirror Q with offset (2 parameter lines required). The mirrored Q with offset for with be reported as base Q + offset value. Mirror in Q must refer to a lower number fleet relative to the fleet with the mirrored Q. See [mirrored Q with offset](#) below for example set up.
  - (e) If the parameter is for an index of a dev vector (index units = 35), use this column to enter the index of the dev vector to which the index is related
3. Extra input for link (i.e. mirror fleet)
  - (a) >0 = mirror the Q from another (lower numbered survey designated by abs(value))
4. Do extra SD
  - (a) 0 = skip (typical)
  - (b) 1 = estimate a parameter that will contain an additive constant to be added to the input standard deviation of the survey variability. This extra SD approach accomplishes the same thing in principle as the older code, but may not give exactly the same answer as the older code. The newer code for extra SD estimation is recommended.
5. Bias adjustment
  - (a) 0 = no bias adjustment applied
  - (b) 1 = apply bias adjustment
6. Q float
  - (a) 0 = no float (parameter is estimated)



(b) 1 = float (analytical solution is used, but parameter line still required)

(c) Additional information regarding the use of and appropriate application of float in Q can be found in the [Float Q](#) section below.

For a setup with a single survey, the Q setup matrix could be:

Fleet Num.	Link Type	Link Info	Extra SD	Bias Adjust	Float	Label
3	1	0	1	1	0	#Survey
-9999	0	0	0	0	0	#End Read

LO	HI	INIT	<other entries>	PHASE	<other entries>	Block Fxn	Parameter Label
-5	5	-0.12	...	1	...	0	#Survey1 LnQ base
0	0.5	0.1	...	-1	...	0	#Survey1 Extra SD

If the Q base parameter specifies that it is time-varying by the annual dev method, short parameter lines to specify the specifications of the deviation vector come after all the base Q parameters.

## Mirrored Q with offset

Below is an example setup for fleets with a mirrored Q and offset from another fleet:

For a setup with a single survey, the Q setup matrix could be:

Fleet Num.	Link Type	Link Info	Extra SD	Bias Adjust	Float	Label
1	1	0	1	0	0	#Fleet 1
2	4	2	0	0	0	#Fleet 2
-9999	0	0	0	0	0	#End Read

A long parameter line is expected for each link parameter (i.e. Q) and for the

LO	HI	INIT	<other entries>	PHASE	<other entries>	Block Fxn	Parameter Label
-7	5	0.51	...	1	...	0	#Fleet 1 LnQ base
0	0.5	0.1	...	-1	...	0	#Fleet 1 Extra SD
-7	5	-6	...	-1	...	0	#Fleet 2 LnQ base
-8	5	-7	...	-1	...	0	#Fleet 2 Mirror Q offset

## Float Q

The use and development of float in Q has evolved over the life of SS. The original difference in earlier versions of SS (early SS v.3.24 versions and before) is that with Q "floated" the units of the survey or fishery CPUE are treated as dimensionless so the Q is adjusted within each model iteration to maintain a mean difference of 0.0 between observed and expected (usually in log space). But with Q as a parameter one gets the ability to interpret the absolute scaling of Q and put a prior on it to help guide the model solution. Also, with Q as a parameter the code allows for Q to be time-varying.

Then midway through the evolution of the SS v.3.24 code lineage a new Q option was introduced based on user recommendations. This option allowed Q to float and to compare the resulting Q value to a prior, hence the information in that prior would pull the model solution in direction of a floated Q that came close to the prior.

Currently, in 3.30, that float with prior capability is fully embraced. All fleets that have any survey or CPUE options need to have a catchability specification and get a base Q parameter in the list. Any of these Q's can be either:

- Fixed: by not floating and not estimating.
- Floating: not estimated as an active parameter, set phase to negative, and not capable of being time-varying. Can have a prior, or not. Future versions of SS may allow Q to be time-varying and then rescaling that Q vector according to the float logic but this is not yet currently implemented.
- Estimated as active parameter: so not floating. Can be time-varying and can have a prior.

Q relates the units of the survey or CPUE to the population abundance, not the population density per unit area. But many surveys and most fishery CPUE is a proportional to mean fish density per unit area. This does not have any impact in a one area model because the role of area is absorbed into the value of Q. In a multi-area model, one may want to assert that the relative difference in CPUE

between two areas is informative about the relative abundance between the areas. However, CPUE is a measure of fish density per unit area, so one may want to multiply CPUE by area before putting the data into SS so that asserting the same  $Q$  for the two areas will be informative about relative abundance.

In SS v.3.30.13, a new catchability option has been added that allows  $Q$  to be mirrored and to add an offset to  $\ln(Q)$  of the primary area when calculating the  $\ln(Q)$  for the dependent area. The offset is a parameter and, hence, can be estimated and have a prior. This option allows the CPUE data to stay in density units and the effect of relative stock area is contained in the value of the  $\ln(Q)$  offset.

## Conversion issues between SS v.3.24 and v.3.30

In SS v.3.24 it was common to use the deviation approach and this deviation approach in SS v.3.24 was implemented as if it was survey specific blocks. In some cases, only one year's deviation was made active in order to implement, in effect, a block for  $Q$ . `sstrans.exe` cannot convert this, but an analogous approach is available in SS v.3.30 because true blocks can now be used, as well as env links and annual deviations. Also note that deviations in SS v.3.24 were survey specific (so no parameter for years with no survey). In SS v.3.30, deviations are always year-specific, so you might have a deviation created for a year with no survey.

## Selectivity and Discard

For each fleet and survey, read a definition line for size selectivity and retention. The four values read from each line are:

### Pattern

Valid length selectivity pattern code.

- Discard (0/1/2/3/4 or -index) If value is 1, then program will read 4 retention parameters after reading the specified number of selectivity parameters and all discarded fish are assumed dead. If the value is 2, then the program will read 4 retention parameters and 4 discard mortality parameters. If the value is 3, then no additional parameters are read and all fish are assumed discarded and dead. If the value is 4, then the program will read 7 retention parameters (for dome-shaped retention) and 4 discard mortality parameters. If the value is a negative number, then it will mirror the retention and discard mortality pattern of the lower numbered fleet.
- Male (0/1/2/3/4) If value is 1, then program will read 4 additional parameters to define the male selectivity relative to the female selectivity. Anytime the male selectivity is caused to be greater than 1.0; the entire male/female matrix of selectivity values is scaled by the max so that

the realized max is 1.0. Hopefully this does not cause gradient problems. If the value is 2, then the main selectivity parameters define male selectivity and female selectivity is estimated as an offset from male selectivity. This alternative is preferable if female selectivity is less than male selectivity. The option 3 is only available if the selectivity pattern is 1, 20, or 24 and it causes the male selectivity parameters to be offset from the female parameters, rather than the male selectivity being an offset from the female selectivity.

- Special (0/value). This value is used in different ways depending on the context. If the selectivity type is to mirror another selectivity type, then put the index of that source fleet or survey here. It must refer to a lower numbered fleet/survey. If the selectivity type is 6 (linear segment), then put the number of segments here. If the selectivity type is 7, then put a 1 here to keep selectivity constant above the mean average size for old fish of morph 1.

For each fleet and survey, read a definition line for age selectivity. The 4 values to be read are the same as for the size-selectivity. However, the retention value must be set to 0.

Example Setup for Size Selectivity:				
Pattern	Discard	Male	Special	Label
1	2	0	0	#Fishery1
1	0	0	0	#Survey1
0	0	0	0	#Survey2

Age Selectivity Types:				
Pattern	Discard	Male	Special	Label
11	0	0	0	#Fishery1
11	0	0	0	#Survey1
11	0	0	0	#Survey2

## Reading the Selectivity and Retention Parameters

Read the required number of parameter setup lines as specified by the definition lines above. The complete order of the parameter setup lines is:

1. Size selectivity for fishery 1
2. Retention for fishery 1 (if discard specified)

3. Discard Mortality for fishery 1 (if discard specified)
4. Male offsets for size selectivity for fishery 1 (if offsets used)
5. <repeat for additional fleets and surveys>
6. Age selectivity for fishery 1
7. Male offsets for age selectivity for fishery 1 (if offsets used)
8. <repeat for additional fleets and surveys>.

The list of parameters to be read from the above setup would be:

LO	HI	INIT	PRIOR	<other entries>	Block Fxn	Parameter Label
19	80	53.5	50	...	0	#SizeSel p1 fishery 1
0.01	60	18.9	15	...	0	#SizeSel p2 fishery 1
20	70	38.6	40	...	0	#Retain p1 fishery 1
0.1	10	6.5	1	...	0	#Retain p2 fishery 1
0.001	1	0.98	1	...	0	#Retain p3 fishery 1
-10	10	1	0	...	0	#Retain p4 fishery 1
0.1	1	0.6	0.6	...	0	#DiscMort p1 fishery 1
-2	2	0	0	...	0	#DiscMort p2 fishery 1
20	70	40	40	...	0	#DiscMort p3 fishery 1
0.1	10	1	1	...	0	#DiscMort p4 fishery 1
19	80	53.5	50	...	0	#SizeSel p1 survey 1
0.01	60	18.9	15	...	0	#SizeSel p2 survey 1
0	40	0	5	...	0	#AgeSel p1 fishery 1
0	40	40	5	...	0	#AgeSel p2 fishery 1
0	40	0	5	...	0	#AgeSel p1 survey 1
0	40	40	5	...	0	#AgeSel p2 survey 1
0	40	0	5	...	0	#AgeSel p1 survey 2
0	40	0	5	...	0	#AgeSel p2 survey 2

## Selectivity Patterns

The currently defined selectivity patterns, and corresponding required number of parameters, are:

## SIZE BASED SELECTIVITY

Pattern	N Parameters	Description
0	0	Selectivity = 1.0 for all sizes.
1	2	Logistic selectivity.
2	8	Discontinued: Double logistic with defined peak (uses IF joiners). Use pattern 8 instead.
3	6	Discontinued
4	0	Discontinued: Set size selectivity equal to female fecundity. Use <a href="#">special survey pattern 30</a> located in the index section within the data file instead.
5	2	Mirror another selectivity. The two parameters select bin range.
6	2 + special value	Non-parametric
7	8	Discontinued: Double logistic with defined peak, uses smooth joiners; special = 1 causes constant selectivity above $L_{inf}$ for morph 1. Use pattern #8.
8	8	Double logistic, with defined peak, uses smooth joiners; special=1 causes constant selectivity above $L_{inf}$ for morph 1.
9	6	Simple double logistic with no defined peak.
15	0	Mirror another selectivity (same as for age selectivity).
21	1 + special value	Non-parametric size selectivity
22	4	Double normal; similar to CASAL.
23	6	Same as the double normal pattern 24 except the final selectivity is now directly interpreted as the terminal selectivity value. Cannot be used with Pope's F method because maximum selectivity may be greater than 1.
24	6	Double normal with defined initial and final selectivity level – Recommended option. Test using SELEX-24.xls.
25	3	Exponential-logistic.
27	3 + 2*N nodes	Cubic spline with N nodes.
42	5 + 2*x	Selectivity pattern 27 but with 2 additional scaling parameters.

Pattern	N Parameters	Description
43	4 + x	Selectivity pattern 6 but with 2 additional scaling parameters.

#### AGE BASED SELECTIVITY

Pattern	N Parameters	Description
0	0	Selectivity = 1.0 for ages 0+.
10	0	Selectivity = 1.0 for all ages beginning at age 1. If it is desired that age-0 fish be selected, then use pattern #11 and set minimum age to 0.0.
11	2	Selectivity = 1.0 for a specified age range.
12	2	Logistic selectivity.
13	8	Double logistic, IF joiners. Use discouraged. Use pattern 18 instead.
14	nages + 1	Separate parameter for each age (empirical), value at age is $\frac{1}{1+exp(-x)}$ .
15	0	Mirror another age-specific selectivity pattern.
16	2	Coleraine single Gaussian
17	nages + 1	Empirical as a random walk from previous age. For all ages in the population beginning with Amin = 1 for the fishery and 2 for the survey, there is a corresponding set of selectivity parameters for each fleet, $p_a$ .
18	8	Double logistic, with defined peak, uses smooth joiners.
19	6	Simple double logistic with no defined peak.
20	6	Double normal with defined initial and final level. Recommended option. Test using SELEX-24.xls.
26	3	Exponential logistic.
27	3 + 2*N nodes	Cubic spline in age based on N nodes.
41	2 + nages + 1	Selectivity pattern 17 but with 2 additional scaling parameters.
42	5 + 2*N nodes	Selectivity pattern 27 but with 2 additional scaling parameters.

Pattern	N Parameters	Description
44	4 + nages	Similar to age selectivity pattern 17 but with separate parameters for males and with revised controls.
45	4 + nages	Similar to age selectivity pattern 14 but with separate parameters for males and with revised controls.

## Special Selectivity Options

Special selectivity options (type 30 in size based selectivity) are no longer specified within the control file. Specifying the use of one of these selectivity types is now done within the data file by selecting the survey "units" (see the section on [Index units](#)).

## Selectivity Pattern Details

### Pattern 1 (size) and 12 (age) - Simple Logistic

Within SS logistic selectivity for the primary sex (if selectivity varies by sex) is formulated as:

$$S_l = \frac{1.0}{1 + \exp(-\ln(19)(L_l - p1)/p2)} \quad (22)$$

where  $L_l$  is the length bin. If age based selectivity is selected then the length bin is replaced by the age vector. If sex specific selectivity is specified the non-primary sex the p1 and p2 parameters are estimated as offsets. Note that with a large p2 parameter, selectivity may not reach 1.0 at the largest size bin. The parameters are:

- p1 - size/age at inflection
- p2 - width for 95% selection; a negative width causes a descending curve.

### Pattern 5 (size) - Mirror Selectivity

Two parameters select the min and max bin number (not min max size) of the source pattern. If first parameter has value  $\leq 0$ , then interpreted as a value of 1 (e.g. first bin). If second parameter has value  $\leq 0$ , then interpreted as nlength (e.g. last bin). The source pattern must have a lower type number

### Pattern 6 (size) - Non-parametric Selectivity

Non-parametric size selectivity uses a set of linear segments. The first way point is at Length = p1 and the last way point is at Length = p2. The total number of way points is specified by the value of



the Special factor in the selectivity set-up, so the N intervals is one less than the number of way points. Intermediate way points are located at equidistant intervals between p1 and p2. Parameters 3 to N are the selectivity values at the way points, entered as logistic, e.g.  $1/(1 + \exp(-x))$ . Ramps from 10cm to p3 if  $L < p1$ . Constant at Np if  $L > p2$ . Note that prior to version 3.03 the way points were specified in terms of bin number, rather than length.

### Pattern 8 (size) and 18 (age) - Double Logistic

- p1 – PEAK: size (age) for peak. Should be an integer and should be at bin boundary and not estimated. But options 7 and 18 may allow estimation.
- p2 – INIT: selectivity at length bin=1 (minL) or age=0.
- p3 – INIT: selectivity at length bin=1 (minL) or age=0. A logit transform ( $1/(1 + \exp(-x))$ ) is used so that the transformed value will be between 0 and 1. So a p1 value of -1.1 will be transformed to 0.25 and used to set the selectivity equal to 0.5 at a size (age) equal to 0.25 of the way between minL and PEAK.
- p4 – SLOPE1: log(slope) of left side (ascending) selectivity.
- p5 – FINAL: logit transform for selectivity at maxL (or maxage).
- p6 – INFL2: logit transform for size(age) at right side selectivity equal to half way between PEAK+PEAKWIDTH and maxL (or max age).
- p7 – SLOPE2: log(slope) of right side (descending) selectivity
- p8 – PEAKWIDTH: in width of flattop.

### Pattern 14 (age) - Revise Age

Age-selectivity pattern 14 to allow selectivity-at-age to be the same as selectivity at the next younger age. When using this option, the range on each parameter should be approximately -5 to 9 to prevent the parameters from drifting into extreme values with nil gradient. SS calculates the age-based selectivity as where  $a = 1$  to  $a = Amax + 1$ :

$$S_a = \frac{1}{1 + \exp(-(p(a+1) + temp))} \quad (23)$$

### Pattern 17 (age) - Random Walk

This selectivity pattern provides for a random walk in  $\ln(\text{selectivity})$ . For each age  $a \geq A_{\min}$ , where  $A_{\min}$  is the minimum age for which selectivity is allowed to be non-zero, there is a selectivity parameter,  $p_a$ , controlling the changing selectivity from age  $a - 1$  to age  $a$ .

The selectivity at age  $a$  is computed as

$$S_a = \exp(S'_a - S'_{\max}), \quad (24)$$

where

$$S'_a = \sum_{i=A_{\min}}^a p_i \quad (25)$$

and

$$S'_{\max} = \max\{S'_a\}. \quad (26)$$

Selectivity is fixed at  $S_a = 0$  for  $a < A_{\min}$ .

This formulation has the properties that the maximum selectivity equals 1, positive values of  $p_a$  are associated with increasing selectivity between ages  $a - 1$  and  $a$ , and negative values are associated with decreasing selectivity between those ages and  $p_a = 0$  gives constant selectivity.

The condition that maximum selectivity equals 1 results in one fewer degree of freedom than the number of estimated  $p_a$ . Therefore, at least one parameter should be fixed at an arbitrary value, typically  $p_{A_{\min}} = 0$ .

In typical usage:

- First parameter (for age 0) could have a value of -1000 so that the age 0 fish would get a selectivity of 0.0;
- Second parameter (for age 1) could have a value of 0.0 and not be estimated, so age 1 is the reference age against which subsequent changes occur;
- Next parameters get estimated values. To assure that selectivity increases for the younger ages, the parameter min for these parameters could be set to 0.0 or a slightly negative value.
- If dome-shaped selectivity is expected, then the parameters for older ages could have a range with the max set to 0.0 so they cannot increase further.
- To keep selectivity at a particular age the same as selectivity at the next younger age, set its parameter value to 0.0 and not estimated. This allows for all older ages to have the same selectivity.
- To keep a constant rate of change in selectivity across a range of ages, use the -999 flag to keep the same rate of change in  $\ln(\text{selectivity})$  as for the previous age.
- Code for implementing random walk selectivity within SS can be found in [Appendix C](#).

## Pattern 9 (size) and 19 (age) - Simple Double Logistic with no defined peak

- p1 - INFL1: ascending inflection size (in cm)
- p2 - SLOPE1: ascending slope
- p3 - INFL2: descending inflection size (in cm)
- p4 - SLOPE2: descending slope
- p5 - first BIN: bin number for the first bin with non-zero selectivity (must be an integer bin number, not a size)
- p6 - offset: enter 0 if P3 is independent of P1; enter 1 if P3 is an offset from P1

## Pattern 22 (size) - Double Normal with Plateau

- p1 - PEAK1: beginning size for the plateau (in cm)
- p2 - PEAK2: ending size for the plateau. Calculated as a fraction of the distance between PEAK1 and 99% of the lower edge of the last size bin in the model. Transformed as  $(1/(1+\exp(-p2)))$ . So a value of 0 results in PEAK2 being halfway between PEAK1 and 99% of the last bin
- p3 - upslope:  $\ln(\text{variance})$  on ascending side
- p4 - downslope:  $\ln(\text{variance})$  on descending side

## Pattern 23 (size) and 24 (size) - Double Normal Selectivity

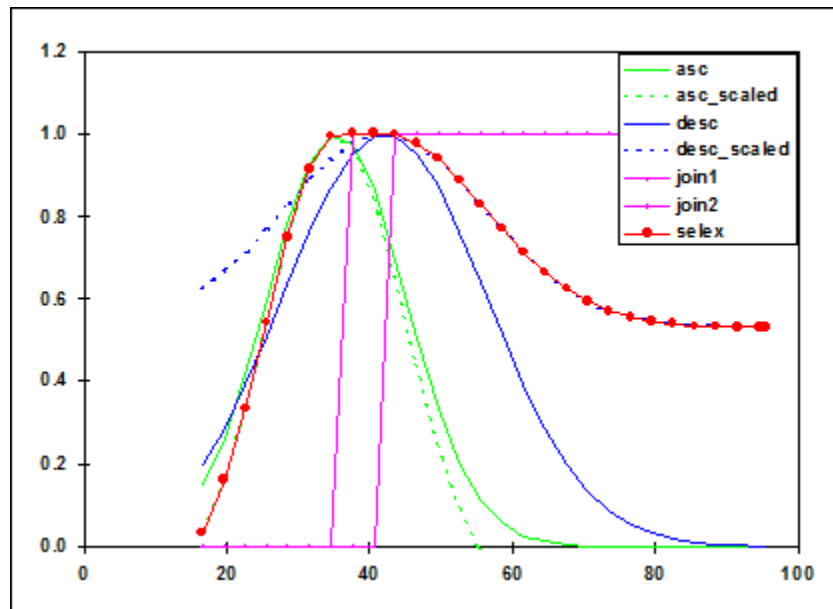
- p1 - PEAK: beginning size for the plateau (in cm)
- p2 - TOP: width of plateau, as logistic between PEAK and MAXLEN
- p3 - ASC-WIDTH: parameter value is  $\ln(\text{width})$
- p4 - DESC-WIDTH: parameter value is  $\ln(\text{width})$
- p5 - INIT: selectivity at first bin, as logistic between 0 and 1.
- p6 - FINAL: selectivity at last bin, as logistic between 0 and 1. (for pattern 24) or
- p6 - FINAL: selectivity at last bin, as absolute value, so can be  $>1.0$ . (for pattern 23). Warning: Do not allow this value to go above 1.0 if the F\_method uses Pope's approximation. OK to go

above 1.0 when F is in exponential form. When this parameter is above 1.0, the overall selectivity pattern will have an intermediate plateau at 1.0 (according to peak and top), then will ascend further to the final value.

Notes for Double Normal Selectivity:

- See spreadsheet SELEX-24.xls for parameterization example.
- For the initial selectivity parameter (parameter 5)
  - -999 or -1000: ignore the initial selectivity algorithm and simply decay the small fish selectivity according to P3,
  - < -1000: ignore the initial selectivity algorithm as above and then set selectivity equal to  $1.0e-06$  for size bins 1 through bin = -1001 –value. So a value of -1003 would set selectivity to a nil level for bins 1 through 2 and begin using the modeled selectivity in bin 3.
- For the final selectivity parameter (parameter 6)
  - -999 or -1000: ignore the final selectivity algorithm and simply decay the large fish selectivity according to parameter 4,
  - < -1000: set selectivity constant for bins greater than bin number = -1000 – value.

Selectivity pattern 24, double normal, showing sub-functions and steep logistic joiners:



## Pattern 15 (age) - Mirror

No parameters. Whole age range is mirrored from a user-specified fleet.

## Pattern 16 - Gaussian (similar to Coleraine)

- p1 – age below which selectivity declines
- p2 – scaling factor for decline

## Pattern 9 (size) and 19 (age) - Simple Double Logistic

- p1 – ascending inflection age/size
- p2 – ascending slope
- p3 – descending inflection age/size
- p4 – descending slope
- p5 – age or size at first selection; this is a specification parameter, so must not be estimated. Enter integer that is age for pattern 19 and is bin number for pattern 9
- p6 – (0/1) where a value of 0 causes the descending inflection to be a standalone parameter, and a value of 1 causes the descending inflection to be interpreted as an offset from the ascending inflection. This is a specification parameter, so must not be estimated.

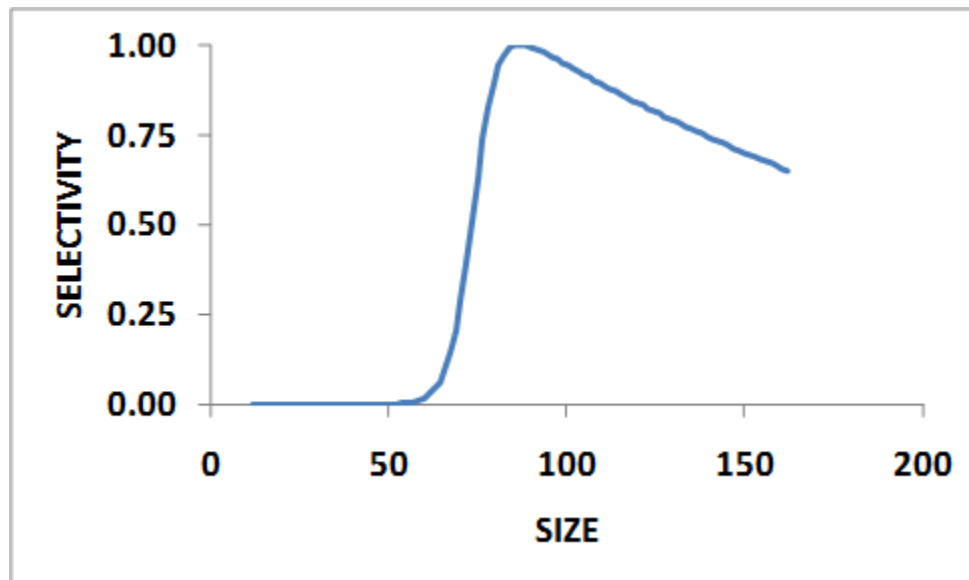
A value of 1.0e-6 is added to the selectivity for all ages, even those below the minage.

## Pattern 25 (size) and 26 (age) - Exponential logistic

- p1 – ascending rate, min: 0.02, max: 1.0, reasonable start value: 0.1
- p2 – peak, as fraction of way between min size and max size. Parameter min value: 0.01; max: 0.99; reasonable start value: 0.5
- p2 – minsize + p2\*(maxsize-minsize)
- p3 – descending rate, min: 0.001, max: 0.5, reasonable start value: 0.01. A value of 0.001 provides a nearly asymptotic curve. Values above 0.2 provide strongly dome-shaped function in which the p3 and p1 parameters interact strongly.

$$\frac{e^{p3 \cdot p1(p2' - size)}}{1 - p3(1 - e^{p1(p2' - size)})} \quad (27)$$

Example: Exponential logistic selectivity with  $p1 = 0.30$ ,  $p2 = 0.50$ , and  $p3 = 0.02$ :



### Pattern 27 (size and age)- Cubic Spline

This selectivity pattern uses the ADMB implementation of the cubic spline function. This function requires input of the number of nodes, the positions of those nodes, the parameter values at those nodes, and the slope of the function at the first and last node. In SS, the number of nodes is specified in the "special" column of the selectivity set-up. The pattern number 27 is used to invoke cubic spline for size selectivity and for age selectivity; the input syntax is identical.

For a 3 node setup, the SS input parameters would be:

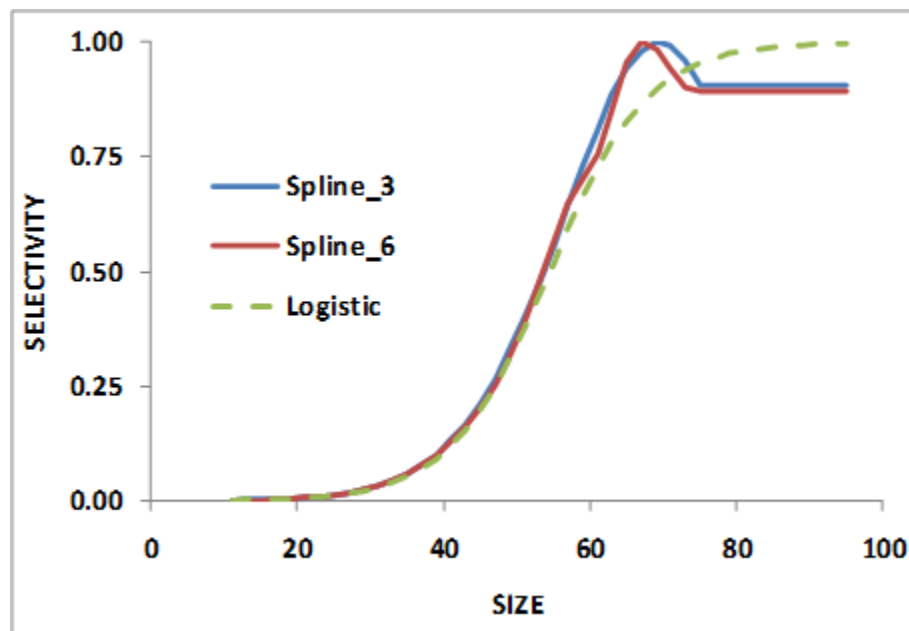
- $p1$  – code for initial set-up (0, 1 or 2) as explained below
- $p2$  – gradient at the first node (should be a small positive value)
- $p3$  – gradient at the last node (should be zero or a small negative value)
- $p4$ - $p6$  – the nodes in units of cm; must be in rank order and inside of the range of the population length bins. These must be held constant (not estimated, e.g. negative phase value) during a model run.
- $p7$ - $p9$  – the values at the nodes. Units are  $\ln(\text{selectivity})$ .

Notes:

- There must be at least 3 nodes.
- One of these selectivity parameter values should be held constant so others are estimated relative to it.
- Selectivity is forced to be constant for sizes greater than the size at the last node
- The overall selectivity curve is scaled to have a peak equal to 1.0.
- Terminal nodes cannot be at the min or max population length bins.

Code for implementing cubic spline selectivity within SS can be found in [the appendix](#) on page 203.

The figure below compares a 3 node and a 6 node cubic spline with a 2 parameter logistic function. In fitting these functions, the 2 cubic spline approaches fit slightly better than the logistic, presumably because the data were slightly indicative of a small dome in selectivity.



Auto-Generation of Cubic Spline Control File Set-Up: A New SS feature pioneered with the cubic spline function is a capability to produce more specific parameter labels and to auto-generate selectivity parameter setup. The auto-generation feature is controlled by the first selectivity parameter value for each fleet that is specified to use the cubic spline. There are 3 possible values for this setup parameter:

- 0: no auto-generation, process parameter setup as read.
- 1: auto-generate the node locations based on the specified number of nodes and on the

cumulative size distribution of the data for this fleet/survey.

- 2: auto-generate the nodes and also the min, max, prior, init, and phase for each parameter.

With either the auto-generate option #1 or #2, it still is necessary to include in the parameter file placeholder rows of values so that the `init_matrix` command can input the current number of values because all selectivity parameter lines are read as a single matrix dimensioned as N parameters x 14 columns. The read values of min, max, init, prior, prior type, prior stddev, and phase will be overwritten.

Cumulative size and age distribution is calculated for each fleet, summing across all samples and both sexes. These distributions are output in `echoinput.sso` and in a new `OVERALL_COMPS` section of `report.sso`.

When the nodes are auto-generated, the first node is placed at the size corresponding to the 2.5% percentile of the cumulative size distribution, the last is placed at the 97.5% percentile of the size distribution, and the remainder are placed at equally spaced percentiles along the cumulative size distribution. These calculated node values are output into `control.ss_new`. So, the user could extract these nodes from `control.ss_new`, edit them to desired values, then, insert them into the input control file. Remember to turn off auto-generation in the revised control file.

When the complete auto-generation is selected, the `control.ss_new` would look like the table below:

LO	HI	INIT	<other entries>	Block Fxn	Parameter Label
0	2	2.0	...	0	#SizeSpline Code
-0.001	1	0.13	...	0	#SizeSpline GradLo
-1	0.001	-0.03	...	0	#SizeSpline GradHi
11	95	38	...	0	#SizeSpline Knot1
11	95	59	...	0	#SizeSpline Knot2
11	95	74	...	0	#SizeSpline Knot3
-9	7	-3	...	0	#SizeSpline Value1
-9	7	-1	...	0	#SizeSpline Value2
-9	7	-0.78	...	0	#SizeSpline Value3

### Pattern 41 (age) - Random Walk with User-Defined Scaling

Selectivity pattern 17 with two additional parameters. The two additional parameters are the bin numbers to define the range of bins for scaling. All of the selectivity values will be scaled (divided) by the mean value over this range. The low and high bin numbers are defined before the other selectivity parameters.



LO	HI	INIT	<other entries>	Block Fxn	Parameter Label
0	20	10	...	0	#AgeSel_ScaleAgeLo
0	20	20	...	0	#AgeSel_ScaleAgeHi

### Pattern 42 (size and age) - Cubic Spline with User-Defined Scaling

Selectivity pattern 27 with two additional parameters. The two additional parameters are the bin numbers to define the range of bins for scaling. All of the selectivity values will be scaled (divided) by the mean value over this range. The low and high bin numbers are defined before the other selectivity parameters.

LO	HI	INIT	<other entries>	Block Fxn	Parameter Label
0	20	10	...	0	#AgeSpline_ScaleAgeLo
0	20	20	...	0	#AgeSpline_ScaleAgeHi

### Pattern 43 (size) - Non-parametric with User-Defined Scaling

Selectivity pattern 6 with two additional parameters. The two additional parameters are the bin numbers to define the range of bins for scaling. All of the selectivity values will be scaled (divided) by the mean value over this range. The low and high bin numbers are defined before the other selectivity parameters.

LO	HI	INIT	<other entries>	Block Fxn	Parameter Label
1	80	50	...	0	#SizeSel_ScaleBinLo
1	80	70	...	0	#SizeSel_ScaleBinHi

### Pattern 44 (age)

Similar to pattern 17 but with separate parameters for males and females. This selectivity pattern provides for a random walk in  $\ln(\text{selectivity})$ . In typical usage:

- p1 - First parameter (for age 0) could have a value of -1000 so that the age 0 fish would get a selectivity of 0.0.
- p2 - The first age for which mean selectivity = 1.
- p3 - The last age for which mean selectivity = 1.

- p4 - Male mean selectivity relative to the female selectivity mean entered as  $\ln(\text{ratio})$  for the male relative female selectivity.
- p5-p<sub>n</sub> - Additional parameter lines for the log of the selectivity change between ages corresponding to the user specified number of changes in the "special" column for the selectivity specification for each sex with females entered first then males.
- -999 input indicates to the model to keep the change unchanged from the previous age (keeps same rate of change).
- -1000 input indicates used only for male selectivity indicates to the model to set the change in male selectivity equal to the female change in selectivity.

An example specification and setup for this selectivity option where selectivity is dome-shaped, peaking at age 2 with female and male selectivity are equal with 4 change points per sex:

#Pattern	Discard	Male	Special
44	0	0	4

LO	HI	INIT	<other entries>	Block Fxn	Parameter Label
0	20	0	...	0	#first selex age
0	20	2	...	0	#first age peak selex (mean)
0	20	2	...	0	#last age peak selex (mean)
-1	2	-0.001	...	0	#male $\ln(\text{ratio})$
-10	10	3.01	...	0	#female $\ln(\text{selex})$ change 1
-10	10	1.56	...	0	#female $\ln(\text{selex})$ change 2
-10	10	-0.15	...	0	#female $\ln(\text{selex})$ change 3
-10	10	-0.15	...	0	#female $\ln(\text{selex})$ change 4
-1000	10	-1000	...	0	#male $\ln(\text{selex})$ change 1
-1000	10	-1000	...	0	#male $\ln(\text{selex})$ change 2
-1000	10	-1000	...	0	#male $\ln(\text{selex})$ change 3
-1000	10	-1000	...	0	#male $\ln(\text{selex})$ change 4

### Pattern 45 (age) - Revise Age

Similar to pattern 14 but with separate parameters for males and females. Age-selectivity pattern 45

to allow selectivity-at-age to be the same as selectivity at the next younger age.

- p1 - is the first age with non-zero selectivity.
- p2 - The first age in mean for peak selectivity
- p3 - The last age in mean for peak selectivity
- p4 - The male mean selectivity relative to the female mean, entered as  $\ln(\text{ratio})$  for the male relative female selectivity
- -999 input indicates to the model to keep the change unchanged from the previous age (keeps same rate of change).
- -1000 input indicates used only for male selectivity indicates to the model to set the change in male selectivity equal to the female change in selectivity.

An example specification and setup for this selectivity option where selectivity is asymptotic, with female and male selectivity are equal with 4 change points per sex:

#Pattern	Discard	Male	Special
45	0	0	3

LO	HI	INIT	<other entries>	Block Fxn	Parameter Label
0	20	2	...	0	#first selex age
0	20	5	...	0	#first age peak selex (mean)
0	20	5	...	0	#last age peak selex (mean)
-1	2	-0.001	...	0	#male $\ln(\text{ratio})$
-10	10	-8.1	...	0	#female $\ln(\text{selex})$ change 1
-10	10	-4.1	...	0	#female $\ln(\text{selex})$ change 2
-10	10	-1.8	...	0	#female $\ln(\text{selex})$ change 3
-1000	10	-1000	...	0	#male $\ln(\text{selex})$ change 1
-1000	10	-1000	...	0	#male $\ln(\text{selex})$ change 2
-1000	10	-1000	...	0	#male $\ln(\text{selex})$ change 3

## Retention

Retention is defined as a logistic function of size. It does not apply to surveys. Four parameters (for asymptotic retention) or seven parameters (for dome-shaped retention) are used:

- p1 – ascending inflection
- p2 – ascending slope
- p3 – maximum retention (often a time-varying quantity to match the observed amount of discard)
- p4 – male offset to ascending inflection (arithmetic, not multiplicative)
- p5 – descending inflection
- p6 – descending slope
- p7 – male offset to descending inflection (arithmetic, not multiplicative)

$$\text{Retention} = \left( \frac{P3}{1 + e^{\frac{-(L-(P1+P4*male))}{P2}}} \right) * \left( 1 - \frac{1}{1 + e^{\frac{-(L-(P5+P7*male))}{P6}}} \right) \quad (28)$$

## Discard Mortality

Discard mortality is defined as a logistic function of size such that mortality declines from 1.0 to an asymptotic level as fish get larger. It does not apply to surveys and it does not affect the calculation of expected values for discard data. It is applied so that the total mortality rate is:

$$\text{deadfish} = \text{selex} * (\text{retain} + (1.0-\text{retain})*\text{discmort})$$

If discmort is 1.0, all selected fish are dead; if discmort is 0.0, only the retained fish are dead.

Four parameters are used:

- p1 – descending inflection
- p2 – descending slope
- p3 – maximum discard mortality
- p4 – male offset to descending inflection (arithmetic, not multiplicative)

Discard mortality is calculated as:

$$\text{Mortality} = \left( 1 - \frac{1 - P3}{1 + e^{\frac{-(L - (P1 + P4 * male))}{P2}}} \right) \quad (29)$$

## Male Selectivity

There are two approaches to specifying sex specific selectivity. One approach allows male selectivity to be specified as a fraction of female selectivity (or vice versa). This first approach can be used for any selectivity pattern. The other option allows for separate selectivity parameters for each sex plus an additional parameter to define the scaling of one sex's peak selectivity relative to the other sex's peak. This second approach has only been implemented for a few selectivity patterns.

Approach #1:

If the "domale" flag is set to 1, then the selectivity parameters define female selectivity and the offset defined below sets male selectivity relative to female selectivity. The two sexes switch roles if the "domale" flag is set to 2. Generally it is best to select the option so that the dependent sex has lower selectivity, thus obviating the need to rescale for selectivities that are greater than 1.0. Sex specific selectivity is done the same way for all size and age selectivity options.

- P1 – size (age) at which a dogleg occurs (set to an integer at a bin boundary and do not estimate)
- P2 – log(relative selectivity) at minL or age=0. Typically this will be set to a value of 0.0 (for no offset) and not estimated. It would be a rare circumstance in which the youngest/smallest fish had sex-specific selectivity.
- P3 – log(relative selectivity) at the dogleg
- P4 – log(relative selectivity) at maxL or max age.

For intermediate ages, the log values are linearly interpolated on size (age).

If selectivity for the dependent sex is greater than the selectivity for the first sex (which always peaks at 1.0), then the male-female selectivity matrix is rescaled to have a maximum of 1.0.

Approach #2:

A new sex selectivity option (3 or 4) has been implemented for size selectivity patterns 1 (logistic) and 23 and 24 (double normal) or age selectivity pattern 20 (double normal age). Rather than calculate male selectivity as an offset from female selectivity, here the male selectivity is calculated by making the male parameters an offset from the female parameters (option 3), or females are offset from males with option 4. The description below applies to option 3. If the size selectivity pattern is 1 (logistic), then read 3 parameters:

- male parameter 1 is added to the first selectivity parameter (inflection)

- male parameter 2 is added to the second selectivity parameter (width of curve)
- male parameter 3 is the asymptotic selectivity

If the size selectivity pattern is 20, 23 or 24 (double normal), then:

- male parameter 1 is added to the first selectivity parameter (peak)
- male parameter 2 is added to the third selectivity parameter (width of ascending side); then  $\exp(\text{this sum})$  per previous transform
- male parameter 3 is added to the fourth selectivity parameter (width of descending side); then  $\exp(\text{sum})$  per previous transform
- male parameter 4 is added to the sixth selectivity parameter (selectivity at final size bin); then  $1/(1+\exp(-\text{sum}))$  per previous transform
- male parameter 5 is the apical selectivity for males

Note that the male selectivity offsets currently cannot be time-varying (need to check on this). Because they are offsets from female selectivity, they inherit the time-varying characteristics of the female selectivity.

## Dirichlet Multinomial Error for Data Weighting

If the Dirichlet multinomial error distribution was selected in the data file for either length or age data weighting an additional parameter line is required immediately following the selectivity parameter block.

The list of parameters to be read from the above setup would be:

LO	HI	INIT	<other entries>	Block Fxn	Parameter Label
1	25	1	...	0	#ln(EffN mult) Age or Length 1
1	25	1	...	0	#ln(EffN mult) Age or Length 2

## Time-varying Options

The time-varying options for selectivity parameters are identical to the time-varying options for biology parameters. These options are described below in the [Using Time-Varying Parameter Options](#). After reading the selectivity parameters, which will include possible instructions to create

environmental link, blocks, or deviation vectors, then read the following section. Note that all inputs in this section are conditional (COND) on entries in the selectivity parameter section. So if no selectivity parameters invoke any time-varying properties, this section is left blank (or completely commented out with #).

Example short parameter lines for selectivity time-varying parameters:

LO	HI	INIT	PR		PRIOR		Label
			PRIOR	SD	TYPE	PHASE	
0.01	2.0	0.58	0.58	0.5	4	-5	#AgeSel_P4_Fishery_dev_se
1	80	70	70	0.5	4	-5	#AgeSel_P4_Fishery_dev_autocorr

## Two-Dimensional Auto-Regressive Selectivity

A new experimental feature added within SS v.3.30.03.02. Earlier versions do not have this feature and hence this input is not expected. This feature allows for auto-correlation by age and/or time. The age based random walk selectivity, pattern 17, should be selected to implement the semiparametric auto-regressive selectivity.

Typical Value		Description and Options								
1		Two-dimensional auto-regressive selectivity: 0 = Not used,  1 = Use 2D AR.								
COND = 1		Read the following long parameter lines:								
Fleet	Ymin	Ymax	Amin	Amax	Sigma Amax	Use Rho	Len(1)/ Age(2)	Phase	Before Range	After Range
1	1979	2015	2	10	1	1	2	5	1980	2007

Continued:

LO	HI	INIT	PRIOR	PRIOR		PHASE	LABEL
				SD	TYPE		
0	4	1	1	0.1	6	-4	#Sigma selex
-1	1	0	0	0.1	6	-4	#Rho year
-1	1	0	0	0.1	6	-4	#Rho age

#Terminator line of 11 in length indicates the end of parameter input lines

-9999	1	1	1	1	1	1	1	1	1	1
-------	---	---	---	---	---	---	---	---	---	---

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#### Parameter Definitions:

- Fleet: Fleet number to which semi-parametric deviations should be added
- Ymin: First year with deviations
- Ymax: Last year with deviations
- Amin: First integer age (or population length bin index) with deviations
- Amax: Last integer age (or population length bin index) with deviations
- Sigma Amax: Not currently implemented. It is recommended to set the Sigma Amax equal to the Amin value. In future, Sigma Amax will be set to last age (or population length bin index) for which a separate sigma should be read
- Use Rho: Use autocorrelation parameters
- Len(1)/Age(2): 1 or 2 to specify whether the deviations should be applied to length- or age-based selectivity
- Phase: Phase to begin estimation of the deviation parameters
- Before Range: How should selectivity be modeled in the years prior to Ymin? Available options are (0) apply no deviations, (1) use deviations from the first year with deviations (Ymin), and (3) use average across all years with deviations (Ymin to Ymax)
- After Range: Similar to Before Range but defines how selectivity should be modeled after Ymax

### Parameterizing the Two-Dimensional Autoregressive Selectivity

When the two-dimensional autoregressive selectivity feature is turned on for a fleet, the selectivity of which is calculated as a product of the assumed selectivity pattern and a non-parametric deviation term away from this assumed pattern:

$$\hat{S}_{a,t} = S_a \exp^{\epsilon_{a,t}} \quad (30)$$

where  $S_a$  is specified in the corresponding age/length selectivity types section and it can be either parametric (recommended) or non-parametric (including any of the existing selectivity options in Stock Synthesis);  $\epsilon_{a,t}$  is simulated as a two-dimensional first-order autoregressive (2D AR1) process:

$$vec(\epsilon) \sim MVN(\mathbf{0}, \sigma_s^2 \mathbf{R}_{total}) \quad (31)$$



where  $\epsilon$  is the two-dimensional deviation matrix and  $\sigma_s^2 \mathbf{R}_{\text{total}}$  is the covariance matrix for the 2D AR1 process. More specifically,  $\sigma_s^2$  quantifies the variance in selectivity deviations and  $\mathbf{R}_{\text{total}}$  is equal to the kronecker product ( $\otimes$ ) of the two correlation matrices for the among-age and among-year AR1 processes:

$$\mathbf{R}_{\text{total}} = \mathbf{R} \otimes \tilde{\mathbf{R}} \quad (32)$$

$$\mathbf{R}_{a,\tilde{a}} = \rho_a^{|a-\tilde{a}|} \quad (33)$$

$$\tilde{\mathbf{R}}_{t,\tilde{t}} = \rho_t^{|t-\tilde{t}|} \quad (34)$$

where  $\rho_a$  and  $\rho_t$  are the among-age year AR1 coefficients, respectively. When both of them are zero,  $\mathbf{R}$  and  $\tilde{\mathbf{R}}$  are two identity matrices and their Kronecker product,  $\mathbf{R}_{\text{total}}$ , is also an identity matrix. In this case selectivity deviations are essentially identical and mutually independent:

$$\epsilon_{a,t} \sim N(0, \sigma_s^2) \quad (35)$$

## Using the Two-Dimensional Autoregressive Selectivity

First, fix the two AR1 coefficients ( $\rho_a$  and  $\rho_t$ ) at 0 and tune  $\sigma_s$  iteratively to match the relationship:

$$\sigma_s^2 = SD(\epsilon)^2 + \frac{1}{(a_{\max} - a_{\min} + 1)(t_{\max} - t_{\min} + 1)} \sum_{a=a_{\min}}^{a_{\max}} \sum_{t=t_{\min}}^{t_{\max}} SE(\epsilon_{a,t})^2 \quad (36)$$

The minimal and maximal ages/lengths and years for the 2D AR1 process can be freely specified by users in the control file. However, we recommend specifying the minimal and maximal ages and years to cover the relatively "data-rich" age/length and year ranges only. Particularly we introduce:

$$b = 1 - \frac{1}{(a_{\max} - a_{\min} + 1)(t_{\max} - t_{\min} + 1)} \frac{\sum_{a=a_{\min}}^{a_{\max}} \sum_{t=t_{\min}}^{t_{\max}} SE(\epsilon_{a,t})^2}{\sigma_s^2} \quad (37)$$

as a measure of how rich the composition data is regarding estimating selectivity deviations. We also recommend using the Dirichlet-Multinomial method to "weight" the corresponding composition data while  $\sigma_s$  is interactively tuned in this step.

Second, fix  $\sigma_s$  at the value iteratively tuned in the previous step and estimate  $\epsilon_{a,t}$ . Plot both Pearson residuals and  $\epsilon_{a,t}$  out on the age-year surface to check their 2D dimensions. If their distributions seems to be not random but rather be autocorrelated (deviation estimates have the same sign several ages and/or years in a row), users should consider estimating and then including the autocorrelations in  $\epsilon_{a,t}$ .

Third, extract the estimated selectivity deviation samples from the previous step for estimating  $\rho_a$  and  $\rho_t$  externally by fitting the samples to a stand-alone model written in Template-Model Builder (TMB). In this model, both  $\rho_a$  and  $\rho_t$  are bounded between 0 and 1 via applying a logic transformation. If at least one of the two AR1 coefficients are notably different from 0, Stock

Synthesis should be run one more time by fixing the two AR1 coefficients at their values externally estimated from deviation samples. The Pearson residuals and  $\epsilon_{a,t}$  from this run are expected to distribute more randomly as the autocorrelations in selectivity deviations can be at least partially included in the 2D AR1 process.

## Tag Recapture Parameters

Specify if tagging data are being used:

Typical Value		Description and Options				
1		Tagging Data Present: 0 = No tagging data, 1 = Read following lines of tagging data.				
COND = 1 Read the following long parameter lines:						
LO	HI	INIT	PRIOR	<other entries>	Block Fxn	Parameter Label
-10	10	9	9	...	0	#TG loss init 1
-10	10	9	9	...	0	#TG loss init 2
-10	10	9	9	...	0	#TG loss init 3
-10	10	9	9	...	0	#TG loss chronic1
-10	10	9	9	...	0	#TG loss chronic2
-10	10	9	9	...	0	#TG loss chronic3
1	10	2	2	...	0	#TG loss overdispersion1
1	10	2	2	...	0	#TG loss overdispersion2
1	10	2	2	...	0	#TG loss overdispersion3
-10	10	9	9	...	0	#TG report fleet1
-10	10	9	9	...	0	#TG report fleet2
-4	0	0	0	...	0	#TG report decay1
-4	0	0	0	...	0	#TG report decay2

The tagging reporting rate parameter is transformed within SS during estimation to maintain a positive value and is reported according to the transformation:

$$\text{Tagging Reporting Rate} = \frac{e^{\text{input parameter}}}{1 + e^{\text{input parameter}}} \quad (38)$$

## Variance Adjustment Factors

When doing iterative re-weighting of the input variance factors, it is convenient to do this in the control file, rather than the data file. This section creates that capability.

Read variance adjustment factors to be applied:

Factor	Fleet	Value	Description
1	2	0.5	# Survey CV for survey/fleet 2
4	1	0.25	# Length data for fleet 1
4	2	0.75	# Length data for fleet 2
-9999	0	0	# End read

### Additive Survey CV - Factor 1

The survey input variance (labeled survey CV) is actually the standard deviation of the  $\ln(\text{survey})$ . The variance adjustment is added directly to this standard deviation. Set to 0.0 for no effect. Negative values are OK, but will crash if adjusted value becomes negative.

### Additive Discard - Factor 2

The input variance is the CV of the observation. Because this will cause observations of near zero discard to appear overly precise, the variance adjustment is added to the discard standard deviation, not to the CV. Set to 0.0 for no effect.

### Additive Mean Body Weight - Factor 3

The input variance is in terms of the CV of the observation. Because such data are typically not very noisy, the variance adjustment is added to the CV and then multiplied by the observation to get the adjusted standard deviation of the observation.

### Multiplicative Length Composition - Factor 4

The input variance is in terms of an effective sample size. The variance adjustment is multiplied times this sample size. Set variance adjustment to 1.0 for no effect.

### Multiplicative Age Composition - Factor 5

Age composition is treated the same way as length composition.

### Multiplicative Size-at-Age - Factor 6

Size-at-age input variance is the sample size for the N observations at each age. The variance adjustment is multiplied by these N values. Set to 1.0 for no effect.

### Multiplicative Generalized Size Composition - Factor 7

Generalized size composition input variance is the sample size for each observation. The variance adjustment for each fleet is multiplied by these sample sizes. Set to 1.0 for no effect.

### Variance Adjustment Usage Notes

The report.sso output file contains information useful for determining if an adjustment of these input values is warranted to better match the scale of the average residual to the input variance scale.

Because the actual input variance factors are modified, it is these modified variance factors that are used when creating parametric bootstrap data files. So, the control files used to analyze bootstrap generated data files should have the variance adjustment factors reset to null levels.

## Lambdas (Emphasis Factors)

These values are multiplied by the corresponding likelihood component to calculate the overall negative log likelihood to be minimized.

Typical Value	Description and Options
4	Max lambda phase: read this number of lambda values for each element below. The last lambda value is used for all higher numbered phases.
1	SD offset: 0 = The log(like) to omit the +log(s) term, 1 = The log(like) to include the log(s) term for CPUE, discard, growth CV, mean body weight, recruitment deviations. If you are estimating any variance parameters, SD offset must be set to 1.

### Lambda Usage Notes

If the CV for size-at-age is being estimated and the model contains mean size-at-age data, then the flag for inclusion of the +log(stddev) term in the likelihood must be included. Otherwise, the model will always get a better fit to the mean size-at-age data by increasing the parameter for CV of size-at-age.

The reading of the lambda values has been substantially altered with SS v.3.30. Instead of reading a

matrix containing all the needed lambda values, SS now just reads those elements that will be given a value other than 1.0. After reading the datafile, SS sets lambda equal to 0.0 if there are no data for a particular fleet/data type, and a value of 1.0 if data exist. So beware if your data files had data but you had set the lambda to 0.0 in a previous version of SS. First read an integer for the number of changes.

Read the lambda adjustments by fleet and data type:

Likelihood Component	Fleet	Phase	Lambda Value	SizeFreq Method
1	2	2	1.5	1
4	2	2	10	1
4	2	3	0.2	1
-9999	1	1	1	1

The codes for component are:

1 = survey	10 = recruitment deviations
2 = discard	11 = parameter priors
3 = mean weight	12 = parameter deviations
4 = length	13 = crash penalty
5 = age	14 = morph composition
6 = size frequency	15 = tag composition
7 = size-at-age	16 = tag negative binomial
8 = catch	17 = F ballpark
9 = initial equilibrium catch	18 = regime shift

## Controls for Variance of Derived Quantities

Additional standard deviation reported may be selected:

Typical Value	Description and Options
1	0 = No additional std dev reporting, 1 = read values below.
COND > 0 : Read the 4 following lines:	

Selex Type	Len/Age /Both	Year	Nselex Bins	Growth Pattern	N Growth Ages	NatAge Area	NatAge year	N Natage
1	1	-1	5	1	5	1	-1	5
Vector (length of 5) with selex std bin picks (-1 in first bin to self-generate).								
5	15	25	35	43				
Vector (length of 5) with growth std bin picks (-1 in first bin to self-generate).								
1	2	14	26	40				
Vector (length of 5) with NatAge std bin picks (-1 in first bin to self-generate).								
1	2	14	26	40				
<b>999</b>	#End of the control file input							

Where:

- Selex fleet: The index of the fleet to be output.
  - 0 = No selectivity variance output,
  - 1 = Selectivity variance output.
- Len/Age/Both:
  - 1 = Select length selectivity,
  - 2 = Select age selectivity,
  - 3 = Both length and age selectivity.
- Year:
  - year = Enter a value for the selected year,
  - -1 = To get the selectivity in the end year.
- N Selex bins: enter the number of bins for which selectivity will be output. This number controls the number of items to be read below, even if the Selex fleet is set to zero. In other

words, the read occurs even if the effect of the read is disabled.

- Growth pattern: growth pattern is the number of the growth pattern to be output. Note that in a multiple season model, SS will output the size-at-age for the last birth season that gets any recruits within the year. Also, if growth parameters are not estimated, then standard deviation output of mean size-at-age is disabled.
  - positive value = Growth pattern,
  - 0 = No variance output for size-at-age.
- N growth bins: Number of ages for which size-at-age variance is requested. This number controls the number of items to be read below, even if the growth pattern selection is set to zero. In other words, the read occurs even if the effect of the read is disabled.
- Area for Natage: specifies the area for which output of numbers at age is requested.
  - positive value = area to output
  - 0 = Disables this output,
  - -1 = Requests that numbers-at-age be summed across all areas. In all cases, numbers-at-age is summed across all growth patterns and platoons and output for each sex.
- NatAge Year: specifies the year for which numbers-at-age are output.
  - year = The year to output,
  - -1 = Requests output for year equal to end year + 1, hence the year that starts the forecast period.
- N Natage bins: as with the N growth bins.

## Using Time-Varying Parameters

The approach to allowing parameters to have time-varying values has been completely overhauled in the transition from SS v.3.24 to SS v.3.30. Fortunately, the sstrans.exe will do the conversion for you, but you should review the new control file closely before simply running with it, especially for time-varying catchability parameters.

### Time-Varying Parameter Change from Earlier SS Versions

In SS v.3.24, the group of biology parameters (termed MGparm) and the selectivity parameters used the same long parameter line approach, but it was implemented with entirely different code, and hence was inefficient. The spawner-recruitment parameters used short parameter lines and a different approach for linkage to an environmental variable and the R1 offset provided a limited type of block. The catchability parameters also used short parameter lines and had its own approach to doing environmental linkage and random deviations, but not blocks. Then finally, the tagging parameters had long parameter lines, but there was no code to interpret any time-varying info in those lines. The situation was begging for a more modular approach.

## Code Flow Version SS v.3.30

In SS v.3.30, mortality-growth, selectivity, stock recruitment relationship, catchability, and tag (soon but not as of v.3.30.12) base parameters all will use long parameter lines and will invoke blocks, trends, environmental linkages, and random deviations using identical syntax. As SS v.3.30 executes the SS\_readcontrol code, it calls a function in SS\_global called “create\_timevary” whenever a base parameter has any one of the 4 types of time-varying options. In fact, block/trend, env and devs all can be applied to the same base parameter. Only blocks and trends are mutually exclusive, but any combined effect could be used together judiciously. “Create\_timevary” creates all needed information to describe and index a list of time varying parameter specifications. in fact, if the auto-generation switch has been set to zero, then you will omit all of the needed parameters for implementing the time-varying effect and SS will auto-generate and use the needed parameters and write them out in the control.ss\_new file. Then as SS gets into iterative parameter updating it starts by calling a function in SS\_timevaryparm that processes each time-varying parameter specification (each of which can contain any combination of block/trend, env and dev specs) and creates a time-series of the parameter value that are used as SS subsequently loops through the years.

## Parameter Order

The order of parameters has changed and the re-ordering is handled by the sstrans.exe. Previously, for each of mortality-growth and selectivity parameters all environmental link parameters were listed first, then block/trend parameters and then deviation parameters. In SS v.3.30, these parameters are re-organized such that all parameters that affect a base parameter are clustered together with block/trend first, then environmental, then deviation. So, if mortality-growth (MG) base parameters 3 and 7 had time varying changes, the order would look like:

---

MG base parameter 3	Block parameter 3-1
	Block parameter 3-2
	Environmental link parameter 3-1
	Deviation se parameter 3
	Deviation rho parameter 3
MG base parameter 7	Block parameter 7-1
	Deviation se parameter 7



## Link Functions

The functional form by which a time-varying parameter,  $Q$ , changes a base parameter,  $P$ , is a link function:  $P'_y = f(P, Q)$ . Typically, this is additive or multiplicative function, but the parameter mirroring feature is essentially a link that takes no parameter. Another type of link in SS is between a model state variable, such as available biomass, and the expected value for a survey. Typically, this is a simple proportional link taking one parameter,  $q$ , but the  $q$  power feature is essentially a 2 parameter link function. So, a parameter link function can change  $q$  over time, and a survey link function then uses the annual value of  $q$  to link the annual value of a state variable to the expected value for a survey. In SS v.3.24, various usages of positive and negative codes and other conventions were used to invoke additive vs multiplication links and other options. But as SS v.3.30 builds capability to allow an environment index to be a “survey” of a parameter deviation, we need a larger family of link functions such as logistic and even dome-shaped.

The link specifications in SS v.3.30 has been updated from SS v.3.24. Take special note of the environmental linkage specification where two bits of information are coded into one number. The new specification has the environmental link function denoted by the first environmental index to use specified by two additional. (e.g., environmental link specification of 204 is parsed by SS to use link type 2 using environmental variable 4).

The new available options for time-varying parameters in SS v.3.30 are described below:

- Environmental Link and Variance - Element 8 in parameter setup
  - `env_data` is a `dvar_matrix` populated with the read environmental data for columns 1-N<sub>envvariables</sub> and derived quantities mapped to columns -1 to -4 to density-dependence:
    - \* -1; for log(relative spawning biomass);
    - \* -2; for `recdev`;
    - \* -3; for log(relative summary biomass) (e.g. `smrybio/smrybio` in initial equilibrium);
    - \* -4; for log(relative summary numbers).
  - So, environmental input 103 would use link type 1 and apply it to environmental data column 3 and environmental input -103 would use link type 1 and apply it to the "-3" column which is log(relative summary biomass).

- These four derived quantities are all calculated at the beginning of each year within the model, so they are available inside SS to use as the basis for time-varying parameter links without violating any order of operations rule.
- Deviation Link - Element 9 in parameter setup
  - 1 = multiplicative ( $P(y)^* = \exp(dev(y) * dev_{se})$ ,
  - 2 = additive ( $P(y)^+ = \exp(dev(y) * dev_{se})$ ,
  - 3 = random walk options are now implemented by using rho in the objective function. SS now expects the estimated deviations to be normal in distribution and the deviation values are multiplied by the standard error parameter as they are used,
  - 4 = zero reverting random walk with rho. The deviation parameter is now multiplied by the standard error parameter, rather than deviations being penalized according to a specified standard error (the approach in SS v.3.24).
  - The option of applying the final model year deviation value into the forecast period was added in v. 3.30.13. This new option is specified by selecting the appropriate deviation link option (1, 2, 3, or 4) and appending a 2 at the front (21, 22, 23, or 24) which will use the final year deviation value for all forecast years.
  - See [Deviation Link](#) to see the code behind each of these options
- Deviation Minimum Year - Element 10 in parameter setup
  - Year for deviations to start for parameter
- Deviation Maximum Year - Element 11 in parameter setup
  - Year for deviations to end for parameter
- Deviation Phase - Element 12 in parameter setup
  - integer, this available element in the long parameter line is now a deviation vector specific phase control
- Blocks - Element 13 in parameter setup. Currently, there are four options for applying blocks:
  - >0: block index for parameter
  - -1: trend with final as offset from base parameter and offset values is in log space, also inflection year is in log space and the offset from log(0.5). No additional parameter lines are required. Three parameters will be estimated; end trend parameter value logistic

offset, inflection year logistic offset, and slope.

- -2: trend with final as standalone value. No additional parameter lines are required. Three parameters will be estimated; end trend parameter value, inflection year, and slope.
- -3 end value is a fraction of base parameter maximum - minimum; inflection year is fraction of end year - start year. No additional parameter lines are required. Three parameters will be estimated; end trend parameter value as a fraction, inflection year as a fraction, and slope.
- Block Functional Form: Element 14 in parameter setup
  - 0: multiplicative ( $P_{block} = P_{base} * \exp(tv\_para)$ ),
  - 1: additive ( $P_{block} = P_{base} + tv\_para$ ),
  - 2: replace ( $P_{block} = tv\_para$ ),
  - 3: random walk across blocks ( $P_{block} = P_{block,-1} + tv\_para$ ),
  - 4: mean reverting random walk

## Block Trends

Additional information regarding the options for applying blocks (element 13):

- -1: Trend bounded by base parm min-max and parms in transformed units (use with caution),
  - Logistic approach to trend as offset from base parameter
  - Transform the base parameter

$$temp = -0.5 * \log \left( \frac{MGparm_1(j, 2) - MGparm_1(j, 1) + 0.0000002}{MGparm(j) - MGparm_1(j, 1) + 0.0000001} - 1 \right) \quad (39)$$

- Add the offset. Note, that offset values in in the transform space.

$$temp+ = MGparm(k + 1) \quad (40)$$

- Back transform

$$temp1 = MGparm_1(j, 1) + \frac{MGparm_1(j, 2) - MGparm_1(j, 1)}{1 + e^{-2*temp}} \quad (41)$$

## Parameter Priors

Priors on parameters fulfill two roles in SS. First, for parameters provided with an informative prior, SS is receiving additional information about the true value of the parameter. This information works with the information in the data through the overall log-likelihood function to arrive at the final parameter estimate. Second, diffuse priors provide only weak information about the value of a prior and serve to manage model performance during execution. For example, some selectivity parameters may become unimportant depending upon the values of other parameters of that selectivity function. In the double normal selectivity function, the parameters controlling the width of the peak and the slope of the descending side become redundant if the parameter controlling the final selectivity moves to a value indicating asymptotic selectivity. The width and slope parameters would no longer have any effect on the log-likelihood, so they would have no gradient in the log-likelihood and would drift aimlessly. A diffuse prior would then steer them towards a central value and avoid them crashing into the bounds. Another benefit of diffuse priors is the control of parameters that are given unnaturally wide bounds. When a parameter is given too broad of a bound, then early in a model run it could drift into this tail and potentially get into a situation where the gradient with respect to that parameter approaches zero even though it is not at its global best value. Here the diffuse prior helps move the parameter back towards the middle of its range where it presumably will be more influential and estimable.

The options for parameter priors are as follows., described as a function of  $Pval$ , the value of the parameter for which a prior is being calculated, as well as the parameter bounds ( $Pmax$  and  $Pmin$ ), and the input values for  $Prior$  and  $Pr\_SD$ , which in some cases are the mean and standard deviation, but interpretation depends on the prior type. Finally,  $Pconst$  is a small constant, currently hardwired at 0.0001. The Prior Likelihoods below represent the negative log-likelihood in all cases.

### Prior Types

Note that the numbering in SS v.3.30 is different from that used in SS v.3.24 (where confusingly -1 indicated no prior and 0 indicated a normal prior). The calculation of the negative log-likelihood is provided below for each prior types, as a function of the following inputs:

$p$	The value of the parameter for which a prior is being calculated
$P_{min}$	The lower bound of the parameter (1st column in control file)
$P_{max}$	The upper bound of the parameter (2nd column in control file)
$Prior$	The input value for the PRIOR input (4th column in control file)
$Pr\_SD$	The input value for the PR_SD input (5th column in control file)

- **Prior Type = 0 = No prior applied**

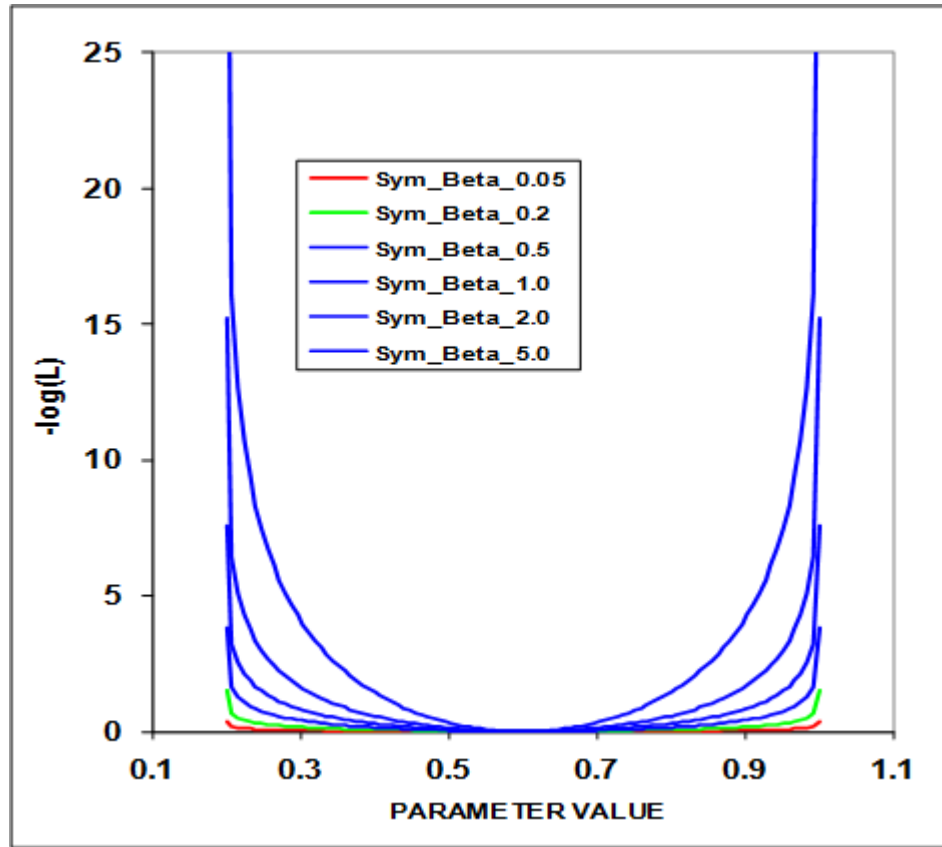
In a Bayesian context this is equivalent to a uniform prior between the parameter bounds.

- **Prior Type = 1 = Symmetric beta prior**

The symmetric beta is scaled between parameter bounds, imposing a larger penalty near the bounds. Prior standard deviation of 0.05 is very diffuse and a value of 5.0 provides a smooth U-shaped prior. The PRIOR input is ignored for this prior type.

$$\mu = -Pr\_SD \cdot \log\left(\frac{P_{max} + P_{min}}{2} - P_{min}\right) - Pr\_SD \cdot \log(0.5) \quad (42)$$

$$\begin{aligned} \text{Prior Likelihood} = & -\mu - Pr\_SD \cdot \log(p - P_{min} + 0.0001) \\ & - Pr\_SD \cdot \log\left(1 - \frac{p - P_{min} - 0.0001}{P_{max} - P_{min}}\right) \end{aligned} \quad (43)$$



Prior distributions for the symmetric beta distribution.

- **Prior Type = 2 = Beta prior**

The definition of  $\mu$  is consistent with CASAL's formulation with the *Bprior* and *Aprior* corresponding to the *m* and *n* parameters.

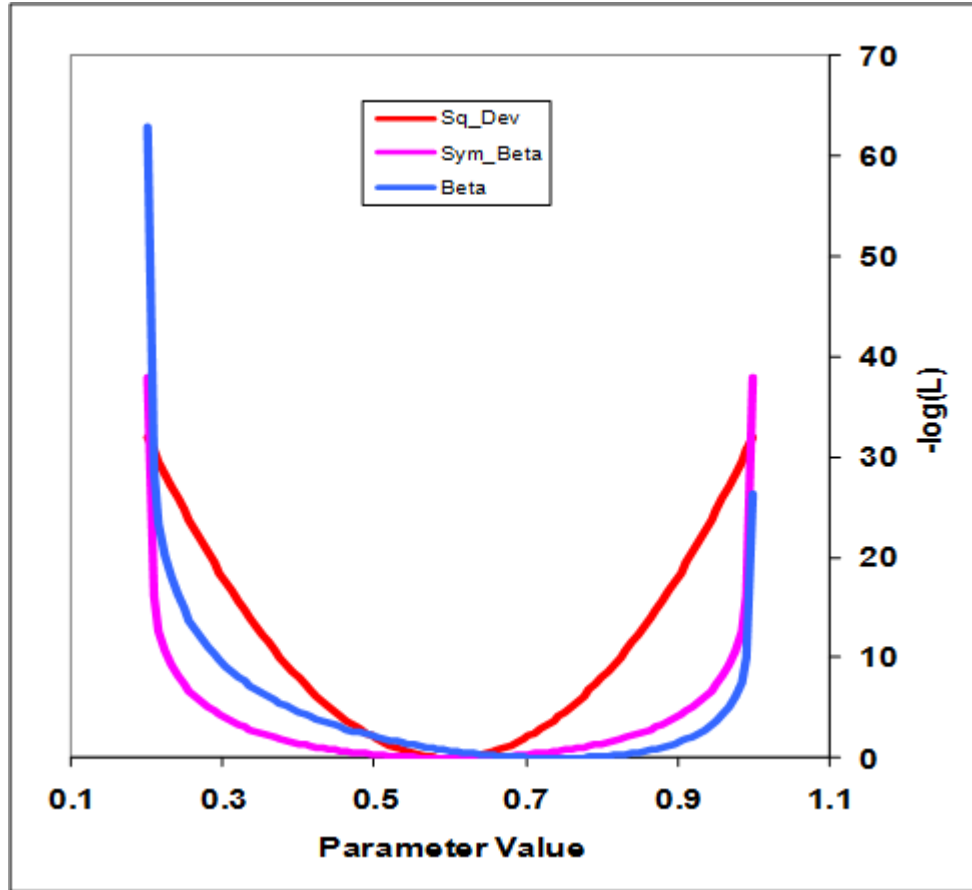
$$\mu = \frac{Prior - P_{min}}{P_{max} - P_{min}} \quad (44)$$

$$\tau = \frac{(Prior - P_{min})(P_{max} - Prior)}{Pr\_SD^2} - 1 \quad (45)$$

$$Bprior = \tau \cdot \mu \quad (46)$$

$$Aprior = \tau(1 - \mu) \quad (47)$$

$$\begin{aligned} \text{Prior Likelihood} = & (1 - Bprior) \cdot \log(0.0001 + p - P_{min}) \\ & + (1 - Aprior) \cdot \log(0.0001 + P_{max} - p) \\ & - (1 - Bprior) \cdot \log(0.0001 + Prior - P_{min}) \\ & - (1 - Aprior) \cdot \log(0.0001 + P_{max} - Prior) \end{aligned} \quad (48)$$



Comparison of the symmetric beta and the beta prior functions

- **Prior Type 3 = Lognormal prior**

Note that this is undefined for  $p \leq 0$  so the lower bound on the parameter must be  $> 0$ . The prior value is input into the parameter line in log space while the initial parameter value is defined in normal space (e.g. INIT = 0.20, PRIOR = -1.609438).

$$\text{Prior Likelihood} = \frac{1}{2} \left( \frac{\log(p) - \text{Prior}}{\text{Pr\_SD}} \right)^2 \quad (49)$$

- **Prior Type 4 = Lognormal prior with bias correction**

This option is thanks to Larry Jacobson. Note that this is undefined for  $p \leq 0$  so the lower bound on the parameter must be  $> 0$ .

$$\text{Prior Likelihood} = \frac{1}{2} \left( \frac{\log(p) - \text{Prior} + \frac{1}{2}\text{Pr\_SD}^2}{\text{Pr\_SD}} \right)^2 \quad (50)$$

- **Prior Type 5 = Gamma prior**

This option is thanks to Larry Jacobson. The lower bound should be 0 or greater.

$$\text{scale} = \frac{\text{Pr\_SD}^2}{\text{Prior}} \quad (51)$$

$$\text{shape} = \frac{\text{Prior}}{\text{scale}} \quad (52)$$

$$\text{Prior Likelihood} = -\text{shape} \cdot \log(\text{scale}) - \log(\Gamma(\text{shape})) + (\text{shape} - 1) \cdot \log(p) - \frac{p}{\text{scale}} \quad (53)$$

- **Prior Type 6 = Normal prior**

Note that this function is independent of the parameter bounds.

$$\text{Prior Likelihood} = \frac{1}{2} \left( \frac{p - \text{Prior}}{\text{Pr\_SD}} \right)^2 \quad (54)$$

## Optional Inputs

### Empirical Weight-at-Age (wtatage.ss)

SS has the capability to read empirical body weight at age for the population and each fleet, in lieu of generating these weights internally from the growth parameters, weight-at-length, and size-selectivity. Selection of this option is done by setting an explicit switch near the top of the

control file. The values are read from a separate file named, wtatage.ss. This file is only required to exist if this option is selected.

The first value read is a single integer for the maxage used in reading this file. So if the maximum age is 40, there will be 41 columns of weight-at-age entries to read, with the first column being for age 0.

If N ages in this table is greater than maximum age in the model, the extra weight-at-age values are ignored.

If N ages in this table is less than maximum age in the model, the weight-at-age for N ages in the file is filled in for all unread ages out to maximum age.

The format of this input file is:

Year	Season	Gender	Growth		Birth		Age-0	Age-1	...
			Pattern	Season	Fleet				
1971	1	1	1	1	-2	0	0	0.1003	
1971	1	1	1	1	-1	0.0169	0.0864	0.2495	
1971	1	1	1	1	0	...	...	...	
1971	1	1	1	1	1	...	...	...	
1971	1	1	1	1	2	...	...	...	
-9999	1	1	1	1	0	...	...	...	

where:

- Fleet = -2 is age-specific fecundity\*maturity, so time-varying fecundity is possible to implement.
- Fleet = -1 is population wt-at-age at middle of the season.
- Fleet = 0 is population wt-at-age at the beginning of the season.
- There must be an entry for fecundity\*maturity, population wt-at-age at the middle of the season, population wt-at-age at the beginning of the season, and wt-at-age for each fleet (even if these vectors are identical in some cases)
- Fleets that do not use biomass do not need to have wt-at-age assigned.
- GP and birth season probably will never be used, but are included for completeness.
- A negative value for year will fill the table from that year through the ending year of the



forecast, overwriting anything that has already been read for those years.

- Judicious use of negative years in the right order will allow user to enter blocks without having to enter a row of info for each year
- There is no internal error checking to verify that weight-at-age has been read for every fleet and every year.
- In the future, there could be an option to use another value of the control file switch to turn off all aspects of growth parameters and size selectivity.
- The values entered for  $\text{endyr}+1$  will be used for the benchmark calculations and for the forecast; this aspect needs a bit more checking.

## Caveats

- SS will still calculate growth curves from the input parameters and can still calculate size-selectivity and can still examine size composition data.
- However, there is no calculation of wt-at-age from the growth input, so no way to compare the input wt-at-age from the wt-at-age derived from the growth parameters.
- If wt-at-age is read and size-selectivity is used, a warning is generated.
- If wt-at-age is read and discard/retention is invoked, then a BEWARE warning is generated because of untested consequences for the body wt of discarded fish.
- Warning: age 0 fish seem to need to have weight=0 for spawning biomass calculation (code -2).

## Testing

- A model was setup with age-maturity (option 2) and only age selectivity.
- The output calculation of wt-at-age and fecundity-at-age was taken from report.sso and put into wtatage.ss (as shown above).
- Re-running SS with this input wt-at-age (Maturity\_Option 5) produced identical results to the run that had generated the weight-at-age from the growth parameters.

## runnumbers.ss

This file contains a single integer value. It is read when the program starts, incremented by 1, used when processing the profile value inputs (see below), used as an identifier in the batch output, then saved with the incremented value. Note that this incrementation may not occur if a run crashes.

## profilevalues.ss

This file contains information for changing the value of selected parameters for each run in a batch. In the ctl file, each parameter that will be subject to modification by profilevalues.ss is designated by setting its phase to -9999 .

The first value in profilevalues.ss is the number of parameters to be batched. This value MUST match the number of parameters with phase set equal to -9999 in the ctl file. The program performs no checks for this equality. If the value is zero in the first field, then nothing else will be read. Otherwise, the model will read runnumber \* Nparameters values and use the last Nparameters of these to replace the initial values of parameters designated with phase = -9999 in the ctl file.

Usage Note: If one of the batch runs crashes before saving the updated value of runnumber.ss, then the processing of the profilevalue.ss will not proceed as expected. Check the output carefully until a more robust procedure is developed. Usage Note: This options was created before use of R became widespread. You probably can create a more flexible approach using R today.

## Likelihood components

The objective function  $L$  is the weighted sum of the individual components indexed by kind of data  $i$ , and fishery/survey  $f$  as appropriate:

$$L = \sum_{i=1}^I \sum_{f=1}^{A_f} \omega_{i,f} L_{i,f} + \omega_R L_R + \sum_{\theta} \omega_{\theta} L_{\theta} + \sum_P \omega_P L_P \quad (55)$$

where  $L$  is the total objective function,  $i$  is the index of the objective function component,  $L_{i,f}$  is the objective function for data kind  $i$  for the fishery/survey  $f$ , and  $\omega_{i,f}$  is a weighting factor for each objective function component.

The components of the objective function based on the model set-up and data are:

Index	Source	Kind	Error structure
$i$	fishery/survey $f$	CPUE or Abundance index	user choice
$i$	fishery $f$	Discard biomass	user choice
$i$	fishery/survey $f$	Mean body weight	normal
$i$	fishery/survey $f$	Length composition	multinomial or log-gamma
$i$	fishery/survey $f$	Age composition	multinomial or log-gamma
$i$	fishery/survey $f$	Mean size-at-age	normal
$i$	fishery/survey $f$	Tag-recapture 1	multinomial
$i$	fishery/survey $f$	Tag-recapture 2	negative binomial
$i$	fishery $f$	Initial equilibrium catch	normal
$R$		Recruitment deviations	lognormal
$P$		Random parameter devs	normal
$\theta$		Parameter priors	user choice
$F_B$		F ballpark penalty	
$C_P$		Crash penalty	

Full description of likelihood distributions by source will be added in the future.

## Running SS

### Command Line Interface

The name of the SS executable files often contains the phrase "safe" or "opt" (for optimized). The safe version includes checking for out of bounds values and should always be used whenever there is a change to the data file. The optimized version runs slightly faster but can result in data not being included in the model as intended if the safe version has not been run first. A file named "ss.exe" is typically the safe version unless the result of renaming by the user. In some situations, users may wish to rename the file they are using to ss.exe, but the longer file name can be used.

On Mac and Linux computers, the executable does not include an extension (like .exe on Windows).

Running the executable on from the DOS command line in Windows simply require typing the executable name (without the .exe extension):

```
> ss
```

On Mac and Linux computers, the executable name must be preceded by a period and slash (unless it's location has been added to the user's PATH):

```
> ./ss
```

Additional ADMB commands can follow the executable name, such as "-nohess" to avoid calculating the Hessian matrix. To see a full list of options, add "-?" after the executable name (with a space in between).

On all operating systems, a copy of the SS executable can either be located in the same directory as the model input files or in a central location and referenced either by adding it to the PATH or by a script files. Further discussion on script files for Windows is below. Editing the PATH is not covered here.

## Example of DOS batch input file

One file management approach is to put ss.exe in its own folder (example: C:\SS\_model) and to put your input files in separate folder (example: C:\My Documents \SS\_runs). Then a DOS batch file in the SS\_runs folder can be run at the command line to start ss.exe. All output will appear in SS\_runs folder.

A DOS batch file (e.g. SS.bat) might contain some explicit ADMB commands, some implicit commands, and some DOS commands:

```
c:\SS_model\ss.exe -cbs 5000000000 -gbs 50000000000 %1 %2 %3 %4
del ss.r0*
del ss.p0*
del ss.b0*
```

In this batch file, the -cbs and -gbs arguments allocate a large amount of memory for SS to use (you may need to edit these for your computer and SS configuration), and the %1, %2 etc. allows passing of command line arguments such as -nox or -nohess. You add more items to the list of % arguments as needed.

An easy way to start a command line in your current directory (SS\_runs) is to create a shortcut to the DOS command line prompt. The shortcut's target would be:

```
> %SystemRoot%\system32\cmd.exe
```

And it would start in:

```
> %CURRDIR%
```

## Simple Batch

This first example relies upon having a set of prototype files that can be renamed to starter.ss and then used to direct the running of SS. The example also copies one of the output files to save it from being overwritten. This sequence is repeated 3 times here and can be repeated an unlimited number of times. The batch file can have any name with the .bat extension, and there is no particular limit to the DOS commands invoked. Note that brief output from each run will be appended to cumreport.sso (see below).

```
del ss.cor
del ss.std
copy starter.r01 starter.ss
c:\admodel\ss\ss.exe -sdonly
copy ss.std ss-std01.txt
copy starter.r01 starter.ss
c:\admodel\ss\ss.exe -sdonly
copy ss.std ss-std02.txt
```

## Complicated Batch

This second example processes 25 dat files from a different directory, each time using the same ctl and nam file. The loop index is used in the file names, and the output is searched for particular keywords to accumulate a few key results into the file SUMMARY.TXT. Comparable batch processing can be accomplished by using R or other script processing programs.

```
del summary.txt
del ss-report.txt
copy /Y runnumber.zero runnumber.ss
FOR /L %%i IN (1,1,25) DO (
copy /Y ..\MakeData\A1-D1-%%i.dat Ase1.dat
del ss.std
del ss.cor
del ss.par
c:\admodel\ss\ss.exe
copy /Y ss.par A1-D1-A1-%%i.par
copy /Y ss.std A1-D1-A1-%%i.std
```

```
find "Number" A1-D1-A1-%%i.par >> Summary.txt
find "hessian" ss.cor >> Summary.txt)
```

## Batch Using PROFILEVALUES.SS

This example will run a profile on natural mortality and spawner-recruitment steepness, of course. Edit the control file so that the natural mortality parameter and steepness parameter lines have the phase set to -9999. Edit STARTER.SS to refer to this control file and the appropriate data file.

Create a PROFILEVALUES.SS file

```
2 # number of parameters using profile feature
0.16 # value for first selected parameter when runnumber equals 1
0.35 # value for second selected parameter when runnumber equals 1
0.16 # value for first selected parameter when runnumber equals 2
0.40 # value for second selected parameter when runnumber equals 2
0.18 # value for first selected parameter when runnumber equals 3
0.40 # value for second selected parameter when runnumber equals 3
etc.; make it as long as you like.
```

Create a batch file that looks something like this. Or make it more complicated as in the example above.

```
del cumreport.sso
copy /Y runnumber.zero runnumber.ss % so you will start with runnumber=0
C:\SS330\ss.exe
C:\SS330\ss.exe
C:\SS330\ss.exe
```

Repeat as many times as you have set up conditions in the PROFILEVALUES.SS file. The summary results will all be collected in the cumreport.sso file. Each step of the profile will have a unique run number and its output will include the values of the natural mortality and steepness parameters for that run.

## Re-Starting a Run

SS model runs can be restarted from a previously estimated set of parameter values. In the starter.ss file, enter a value of 1 on the first numeric input line. This will cause SS to read the file ss.par and use these parameter values in place of the initial values in the control file. This option only works if the number of parameters to be estimated in the new run is the same as the number of parameters in the

previous run because only actively estimated parameters are saved to the file ss.par. The file ss.par can be edited with a text editor, so values can be changed and rows can be added or deleted. However, if the resulting number of elements does not match the setup in the control file, then unpredictable results will occur. Because ss.par is a text file, the values stored in it will not give exactly the same initial results as the run just completed. To achieve greater numerical accuracy, SS can also restart from ss.bar which is the binary version of ss.par. In order to do this, the user must make the change described above to the starter.ss file and must also enter `-binp ss.bar` as one of the command line options.

## Debugging Tips

When SS input files are causing the program to crash or fail to produce sensible results, there are a few steps that can be taken to diagnose the problem. Before trying the steps below, examine the ECHOINPUT.SSO file. It is highly annotated, so you should be able to see if SS is interpreting your input files as you intended.

1. Set the `turn_off_phase` switch to 0 in the STARTER.SS file. This will cause the mode to not attempt to adjust any parameters and simply converges a dummy parameter. It will still produce a REPORT.SSO file, which can be examined to see what has been calculated from the initial parameter values.
2. Turn the verbosity level to 2 in the STARTER.SS file. This will cause the program to display the value of each likelihood component to the screen on each iteration. So if the program is creating an illegal computation (e.g. divide by zero), it may show you which likelihood component contains the problematic calculation. If the program is producing a REPORT.SSO file, you may then see which observation is causing the illegal calculation.
3. Run the program with the command `ss »SSpipe.txt`. This will cause all screen display to go to the specified text file (note, delete this file before running because it will be appended to). Examination of this file will show detailed statements produced during the reading and preprocessing of input files.
4. CHECKUP.SSO: This file can be written during the first iteration of the program. It contains details of selectivity and other calculations as an aid to debugging model problems.
5. If SS fails to achieve a proper Hessian it exits without writing the detailed outputs in the FINAL\_SECTION. If this happens, you can do a run with the `-nohess` option so you can view the report.sso to attempt to diagnose the problem.

## Keyboard Tips

Typing "N" during a run will cause ADMB to immediately advance to the next phase of estimation.

Typing "Q" during a run will cause ADMB to immediately go to the final phase. This bypasses estimation of the Hessian and will produce all of the SS outputs, which are coded in the FINAL\_SECTION.

## Running MCMC

Run SS v3.30

- This gives maximum posterior density estimates, report file, Hessian matrix and the .cor file
- (Recommended) Look for parameters stuck on bounds which will degrade efficiency of MCMC implementation
- (Recommended) Look for very high correlations that may degrade the efficiency of MCMC implementation

Run SS v.3.30 with arguments -mcmc xxxx -mcsave yyyy

- Where: xxxx is the number of iterations for the chain, and yyyy is the thinning interval (1000 is a good place to start)
- MCMC chain starts at the MPD values
- (Recommended) Remove existing .psv files in run directory to generate a new chain.
- (Recommended) Set DOS run detail switch in starter file to 0; reporting to screen will dramatically slow MCMC progress
- (Optional) Add -nohess to use the existing Hessian file without re-estimating
- (Optional) To start the MCMC chain from specific values change the par file; run the model with estimation, adjust the par file to the values that the chain should start from, change within the starter file for the model to begin from the par file, and call the MCMC function using ss -mcmc xxxx - mcsave yyyy -nohess -noest.
- (Optional) Add -noest -nohess and modify starter file so that run will now start from the converged (or modified) parameter estimates in "ss.par"



Run SS v3.30 with argument -mceval

- This generates the posterior output files.
- (Optional) Modify starter file entries to add a burn-in and thinning interval above and beyond the ADMB thinning interval applied at run time.
- (Recommended) MCMC always begins with the maximum posterior density values and so a burn-in >0 should always be used.
- This step can be repeated for alternate forecast options (e.g. catch levels) without repeating step 2.

(Optional) Run SS v3.30 with arguments -mcr -mcmc xxxx -mcsave yyyy ...

- This restarts and extends an uninterrupted chain previously completed (note that any intermediate runs without the -mcr command in the same directory will break this option).

#### NOTES:

When SS switches to MCMC or MCEVAL mode, it sets all the bias adjustment factors to 1.0 for any years with recruitment deviations defined. SS does not create a report file after completing MCMC because it would show values based on the last MCMC step.

## Output Files

### Standard ADMB output files

Standard ADMB files are created by SS. These are:

SS.PAR – This file has the final parameter values. They are listed in the order they are declared in SS. This file can be read back into SS to restart a run with these values (see running SS on page 150).

SS.STD – This file has the parameter values and their estimated standard deviation for those parameters that were active during the model run. It also contains the derived quantities declared as sdreport variables. All of this information is also report in the covar.sso. Also, the parameter section of report.sso lists all the parameters with their SS generated names, denotes which were active in the reported run, displays the parameter standard deviations, then displays the derived quantities with their standard deviations.

SS.REP – This report file is created between phases so, unlike report.sso, will be created even if the Hessian fails. It does not contain as much output as shown in report.sso.

SS.COR – This is the standard ADMB report for parameter and sdreport correlations. It is in matrix form and challenging to interpret. This same information is reported in covar.sso.

## SS Summary

The `ss_summary.sso` file (available for versions 3.30.08.03 and later) is designed to put key model outputs all in one concise place. It is organized as a list. At the top of the file are some descriptors, followed by the likelihoods for each component, then the parameters and their standard errors, then the derived quantities and their standard errors. The total biomass, summary biomass, and catch were added to the quantities reported in this file in version 3.30.11 and later. This output was created to make it easy to compare the results between different versions of the executable, however, this file could be useful for numerous other uses.

## SIS table

The `SIS_table.sso` file contains model output formatted for reading into the NMFS Species Information System (SIS). This file includes an assessment summary for categories of information (abundance, recruitment, spawners, catch estimates) that are input into the SIS database. A time-series of estimated quantities which aggregates estimates across multiple areas and seasons are provided to summarize model results. Access to the SIS database is granted to all NOAA employees and can be accessed as: <https://www.st.nmfs.noaa.gov/sis/>.

## Derived Quantities

Before listing the derived quantities reported to the `sdreport`, there are a couple of topics that deserve further explanation.

### Virgin Spawning Biomass (B0) vs Unfished Spawning Biomass

Unfished is the condition for which reference points (benchmark) are calculated. Virgin Spawning Biomass (B0) is the initial condition on which the start of the time-series depends. If biology or SR parameters are time-varying, then the benchmark year input in the forecast file tells SS which years to average in order to calculate "unfished". In this case, virgin recruitment and/or the virgin spawning biomass will differ from their unfished counterparts. Virgin recruitment and spawning biomass are reported in the `mgmt_quant` portion of the `sd_report` and are now labeled as "unfished" for clarity. Note that if  $\ln(R0)$  is time-varying, then this will cause unfished to differ from virgin. However, if regime shift parameter is time-varying, then unfished will remain the same as virgin because the regime shift is treated as a temporary offset from virgin. Virgin spawning biomass is denoted as `SPB_virgin` and spawning biomass unfished is denoted as `SPB_unf` in the report file.

Virgin Spawning Biomass ( $B_0$ ) is used in four ways within SS:

1. Anchor for the spawner-recruitment relationship as virgin spawning biomass.
2. Basis for the initial equilibrium abundance.
3. Basis against which annual depletion is calculated.
4. Benchmark calculations.

However, if there is time-varying biology, then the 4th usage can have a different  $B_0$  calculation compared to the other usages.

## Metric for Fishing Mortality

A generic single metric of annual fishing mortality is difficult to define in a generalized model that admits multiple areas, multiple biological cohorts, dome-shaped selectivity in size and age for each of many fleets. Several separate indices are provided and others could be calculated by a user from the detailed information in report.sso.

## Equilibrium SPR

This index focuses on the effect of fishing on the spawning potential of the stock. It is calculated as the ratio of the equilibrium reproductive output per recruit that would occur with the current year's  $F$  intensities and biology, to the equilibrium reproductive output per recruit that would occur with the current year's biology and no fishing. Thus it internalizes all seasonality, movement, weird selectivity patterns, and other factors. Because this index moves in the opposite direction than  $F$  intensity itself, it is usually reported as  $1 - \text{SPR}$ . A benefit of this index is that it is a direct measure of common proxies used for  $F_{\text{MSY}}$ , such as  $F_{40\%}$ . A shortcoming of this index is that it does not directly demonstrate the fraction of the stock that is caught each year. The SPR value is also calculated in the benchmarks (see below). The derived quantities report shows an annual SPR statistic. The options, as specified in the starter.ss file, are:

- 0 = skip
- 1 =  $(1 - \text{SPR}) / (1 - \text{SPR}_{\text{TGT}})$
- 2 =  $(1 - \text{SPR}) / (1 - \text{SPR}_{\text{MSY}})$
- 3 =  $(1 - \text{SPR}) / (1 - \text{SPR}_{\text{Btarget}})$

- 4 = raw SPR

## F std

This index provides a direct measure of fishing mortality. The options are:

- 0 = skip
- 1 = exploitation(Bio)
- 2 = exploitation(Num)
- 3 = sum(Frates)

The exploitation rates are calculated as the ratio of the total annual catch (in either biomass or numbers as specified) to the summary biomass or summary numbers on January 1. The sum of the F rates is simply the sum of all the apical Fs. This makes sense if the F method is in terms of instantaneous F (not Pope's approximation) and if there are not fleets with widely different size/age at peak selectivity, and if there is no seasonality, and especially if there is only one area. In the derived quantities, there is an annual statistic that is the ratio of the can be annual F\_std value to the corresponding benchmark statistic. The available options for the denominator are:

- 0 = raw
- 1 =  $F/F_{SPR}$
- 2 =  $F/F_{MSY}$
- 3 =  $F/F_{Btarget}$

## F-at-Age

Because the annual F is so difficult to interpret as a sum of individual F components, an indirect calculation of F-at-age is reported at the end of the report.sso file. This section of the report calculates Z-at-age simply as  $\ln(N_{a+1,t+1}/N_{a,t})$ . This is done on an annual basis and summed over all areas. It is done once using the fishing intensities as estimated (to get Z), and once with the F intensities set to 0.0 to get M-at-age. This latter sequence also provides a measure of dynamic Bzero. The user can then subtract the table of M-at-age/year from the table of Z-at-age/year to get a table of F-at-age/year. From this apical F, average F over a range of ages, or other user-desired statistics could be calculated. Further work within SS with this table of values is anticipated.

## MSY and other Benchmark Items

The following quantities are included in the `sdreport` vector `mgmt_quantities`, so obtain estimates of variance. Some additional quantities can be found in the benchmarks section of the `forecast_report.sso`.

Benchmark Item	Description
SSB_Unfished	Unfished reproductive potential (SSB is commonly female mature spawning biomass).
TotBio_Unfished	Total age 0+ biomass on January 1.
SmryBio_Unfished	Biomass for ages at or above the summary age on January 1.
Recr_Unfished	Unfished recruitment.
SSB_Btgt	SSB at user specified SSB target.
SPR_Btgt	Spawner potential ratio (SPR) at F intensity that produces user specified SSB target.
Fstd_Btgt	F statistic at F intensity that produces user specified SSB target.
TotYield_Btgt	Total yield at F intensity that produces user specified SSB target.
SSB_SPRtgt	SSB at user specified SPR target (but taking into account the spawner-recruitment relationship).
Fstd_SPRtgt	F intensity that produces user specified SPR target.
TotYield_SPRtgt	Total yield at F intensity that produces user specified SPR target.
SSB_MSY	SSB at F intensity that is associated with MSY; this F intensity may be directly calculated to produce MSY, or can be mapped to F_SPR or F_Btgt.
SPR_MSY	Spawner potential ratio (SPR) at F intensity associated with MSY.
Fstd_MSY	F statistic at F intensity associated with MSY.
TotYield_MSY	Total yield (biomass) at MSY.
RetYield_MSY	Retained yield (biomass) at MSY.

## Brief cumulative output

Cum\_Report.sso: contains a brief version of the run output, which is appended to current content of file so results of several runs can be collected together. This is especially useful when a batch of runs is being processed. Unless this file is deleted, it will contain a cumulative record of all runs done in that subdirectory. The first column contains the run number.

## Output for Rebuilder Package

Output filename is REBUILD.DAT

#Title # various run summary outputs

SS#\_default\_rebuild.dat

# Number of sexes

2

# Age range to consider (minimum age; maximum age)

0 40

# Number of fleets

3

# First year of projection (Yinit)

2002

# First Year of rebuilding period (Ydecl)

1999

# Number of simulations

1000

# Maximum number of years

500

# Conduct projections with multiple starting values (0 = No, 1 = Yes)

0

# Number of parameter vectors

1000

# Is the maximum age a plus-group (1 = Yes; 2 = No)

1

#Generate future recruitments using historical recruitments (1) historical recruits/spawner (2) or a stock-recruitment (3)

3

# Constant fishing mortality (1) or constant Catch (2) projections

1

# Fishing mortality based on SPR (1) or actual rate (2)

1v # Pre-specify the year of recovery (or -1) to ignore

-1

```

# Fecundity-at-age
# 0 1 2 3 4 5 6 7 8 9 10 <deleted values>
0 0.000450117 0.00436298 0.0271371 <deleted values>
# Age specific selectivity and weight adjusted for discard and discard mortality
#wt and selex for gender, fleet: 1 1
0.146708 0.320119 0.555587 0.830467 <deleted values>
0.0122887 0.0351722 0.0838682 0.165479 <deleted values>
#wt and selex for gender ,fleet: 2 1
0.150944 0.33768 0.588317 0.874376 <deleted values>
0.0127241 0.0380999 0.0922667 <deleted values>
# M and current age-structure in year Yinit: 2002
# gender = 1
0.1 0.1 0.1 0.1 0.1 <deleted values>
1425.96 797.624 1234.77 428.207 <deleted values>
# gender = 2
0.1 0.1 0.1 0.1 0.1 <deleted values>
1425.96 797.531 1233.66 <deleted values>
# Age-structure at Ydeclare= 1999
598.671 652.739 2925.76 2227.69 <deleted values>
598.671 652.666 2923.27 2221.05 <deleted values>
# Year for Tmin Age-structure (set to Ydecl by SS) 1999
1999
# recruitment and biomass
# Number of historical assessment years
33
# Historical data
# year recruitment spawner in B0 in R project in R/S project
1970 1971 1972 1973 1974 1975 1976 <deleted values> 2001 2002
#years (with first value representing R0)
8853.43 8658.22 8651.96 8645.41 8638.43 8630.75 <deleted values> 1594.53 2075.34 #recruits; first
value is R0 (virgin)
63679.5 63679.5 63679.3 63678.3 63673.9 63661.6 <deleted values> 8614.18 7313.2 #spbio; first
value is S0 (virgin)
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 <deleted values> 0 0 # in Bzero
0 1 1 1 1 1 1 <deleted values> 1 1 0 0 0 # in R project
0 1 1 1 1 1 1 <deleted values> 1 1 0 0 0 # in R/S project
# Number of years with pre-specified catches
0
# catches for years with pre-specified catches go next
# Number of future recruitments to override
3
# Process for overriding (-1 for average otherwise index in data list)

```

```

2000 1 2000
2001 1 2001
2002 1 2002
# Which probability to product detailed results for (1=0.5; 2=0.6; etc.)
3
# Steepness sigma-R Auto-correlation
0.610789 0.6 0
# Target SPR rate (FMSY Proxy); manually change to SPR_MSY if not using SPR_target
0.5
# Target SPR information: Use (1=Yes) and power
0 20
# Discount rate (for cumulative catch)
0.1
# Truncate the series when 0.4B0 is reached (1=Yes)
0
# Set F to FMSY once 0.4B0 is reached (1=Yes)
0
# Maximum possible F for projection (-1 to set to FMSY)
-1
# Defintion of recovery (1=now only; 2=now or before)
2
# Projection type
4
# Definition of the 40-10 rule
10 40
# Produce the risk-reward plots (1=Yes)
0
# Calculate coefficients of variation (1=Yes)
0
# Number of replicates to use
10
# Random number seed
-99004
# File with multiple parameter vectors
rebuild.SS0
# User-specific projection (1=Yes); Output replaced (1->9)
0 5
# Catches and Fs (Year; 1/2/3 (F or C or SPR); value); Final row is -1v 2002 1 1
-1 -1 -1
# Split of Fs
2002 1
-1 1 1 1

```



```

# Yrs to define TTARGET for projection type 4 (aka 5 pre-specified inputs)
2011 2012 2013 2014 2015 2016 2017 2018
# Time varying weight-at-age (1=Yes;0=No)
0
# File with time series of weight-at-age data
none
# Use bisection (0) or linear interpolation (1)
1
# Target Depletion
0.4
# CV of implementation error
0

```

## Bootstrap Data Files

Data.ss\_new: contains a user-specified number of data files, generated through a parametric bootstrap procedure, and written sequentially to this file. These can be parsed into individual data files and re-run with the model. The first output provides the unaltered input data file (with annotations added). The second provides the expected values for only the data elements used in the model run. The third and subsequent outputs provide parametric bootstraps around the expected values.

## Forecast and Reference Points

FORECAST-REPORT.sso: This file contains output of fishery reference points and forecasts. It is designed to meet the needs of the Pacific Fishery Management Council's Groundfish Fishery Management Plan, but it should be quite feasible to develop other regionally specific variants of this output.

The vector of forecast recruitment deviations is estimated during an additional model estimation phase. This vector includes any years after the end of the recruitment deviation time series and before or at the end year. When this vector starts before the ending year of the time series, then the estimates of these recruitments will be influenced by the data in these final years. This is problematic, because the original reason for not estimating these recruitments at the end of the time series was the poor signal/noise ratio in the available data. It is not that these data are worse than data from earlier in the time series, but the low amount of data accumulated for each cohort allows an individual datum to dominate the model's fit. Thus, an additional control is provided so that forecast recruitment deviations during these years can receive an extra weighting in order to counter-balance the influence of noisy data at the end of the time series.

An additional control is provided for the fraction of the log-bias adjustment to apply to the forecast recruitments. Recall that  $R$  is the expected mean level of recruitment for a particular year as specified by the spawner-recruitment curve and  $R'$  is the geometric mean recruitment level calculated by discounting  $R$  with the log-bias correction factor  $e^{-0.5s^2}$ . Thus a lognormal distribution of recruitment deviations centered on  $R'$  will produce a mean level of recruitment equal to  $R$ . During the modeled time series, the virgin recruitment level and any recruitments prior to the first year of recruitment deviations are set at the level of  $R$ , and the lognormal recruitment deviations are centered on the  $R'$  level. For the forecast recruitments, the fraction control can be set to 1.0 so that 100% of the log-bias correction is applied and the forecast recruitment deviations will be based on the  $R'$  level. This is certainly the configuration to use when the model is in MCMC mode. Setting the fraction to 0.0 during maximum likelihood forecasts would center the recruitment deviations, which all have a value of 0.0 in ML mode, on  $R$ . Thus would provide a mean forecast that would be more comparable to the mean of the ensemble of forecasts produced in MCMC mode. Further work on this topic is underway.

Note:

- Cohorts continue growing according to their specific growth parameters in the forecast period rather than staying static at the endyr values.
- Environmental data entered for future years can be used to adjust expected recruitment levels. However, environmental data will not affect growth or selectivity parameters in the forecast.

The top of this file shows the search for  $F_{SPR}$  and the search for  $F_{MSY}$  so the user can verify convergence. Note: if the STD file shows aberrant results, such as all the standard deviations being the same value for all recruitments, then check the  $F_{MSY}$  search for convergence.

The  $F_{MSY}$  can be calculated, or set equal to one of the other  $F$  reference points per the selection made in STARTER.SS.

The reference point output is shown in the table below:

<b>Management_report</b>						
Steepness_R0_S0	0.371	8853	63680			
+	(B_in_mT; N_in_thousands)					
Element	Value	B_per_Recr	B_per_R0	B_Total	N_per_Recr	N_total
Recr_unfis hed(R0)	--	1.000	1.000	8853		
SPB_unfis hed(S0)	--	7.193	7.193	63680		
BIO_Smry_unfis hed	--	18.493	18.493	163727		
+	+	+	+	+		
SPR_target	0.500					
SPR_calc	0.500					
Fmult	0.261					
Exploit(Y/Bs mry)	0.052					
Recruit	--	--	0.265	2343		
SPBio	--	3.596	--	8426		
YPR_encountered	--	0.550	--	1289		
YPR_dead	--	0.550	--	1289	0.257	602
YPR_retain	--	0.550	--	1289		
Biomass_Smry	--	10.517	--	24641		
+	+	+	+	+		
Btarget_rel_to_S0	0.500					
Btgt_calc	0.500					
SPR	0.712					
Fmult	0.116					
Exploit(Y/Bs mry)	0.024					
Recruit	--	--	0.702	6218		
SPBio	--	5.120	--	31840		
YPR_encountered	--	0.335	--	2085		
YPR_dead	--	0.335	--	2085	0.141	880
YPR_retain	--	0.335	--	2085		
Biomass_Smry	--	13.947	--	86730		
+	+	+	+	+		
calculate_FMSY						
SPR	0.660					
Fmult	0.144					
Exploit(Y/Bs mry)	0.030					
Recruits	--	--	0.622	5506		
SPBio	--	4.750	--	26157		
SPBmsy/SPBzero(using_S0)	--	0.411	--			
SPBmsy/SPBzero(using_endyear_LifeHistory)	--	0.411	--			
MSY_for_optimize	--	0.391	--	2151		
MSY_encountered	--	0.391	--	2151		
MSY_dead	--	0.391	--	2151	0.168	927
MSY_retain	--	0.391	--	2151		
Biomass_Smry	--	13.124	--	72263		

The forecast is done once using the Target SPR and once using the adjustments specified in the 40:10 section of forecast.ss input. Each section contains a time series of seasonal biomass and catch, followed by a time series of population numbers-at-age for each platoon.

Forecast_using_Fspr																															
Allocation_Pattern_as_in_endyear																															
Harvest_Rates_by_Season&Fleet_(equals_selected_forecast_Fmult*_Allocation_pattern																															
Season		feet:1																													
1		0.0802																													
+																															
Forecast_recruitments_use_this_fra																															
tion_of_logbias_adj_before_endyr+1:		1																													
and_this_value_after_endyr:		0																													
Extra_emphasis_on_forecast_recrdev																															
s_before_endyr+1:		1																													
N_forecast_yrs_and_with_stddev		6		6																											
OY_Control:		Top:		Bottom:		Scale																									
+		0.4		0.1		1																									
+																															
FORECAST:_Without_40:10																															
pop		year		season		4010		bio-all		bio-Smry		SpawnBio		Depletion		recruit-0		dead_cat_B-1		retain_B-1		dead_cat_N-1		retain_N-1		Hrate-1		opt		ABC	
1		2002		1		1		22361		21634		7313		0.115		2075		1116		1116		533		533		0.0802		R		1116	
1		2003		1		1		22472		21613		7341		0.115		2082		1123		1123		534		534		0.0802		R		1123	
+																															
Forecast-NUMBERS_AT_AGE		<not shown here>																													
FORECAST: __with_40:10_Adjustmen		0.4		0.1		1																									
pop		year		season		4010		bio-all		bio-Smry		SpawnBio		Depletion		recruit-0		dead_cat_B-1		retain_B-1		dead_cat_N-1		retain_N-1		Hrate-1		opt		ABC	
1		2002		1		0.17242		22361		21634		7313		0.115		2075		192		192		92		92		0.0138		R		1116	
1		2003		1		0.226996		23357		22481		7674		0.121		2163		266		266		125		125		0.0182		R		1171	
+																															
Annual_all_area_values_stored_in_sdreport_vector 'depletion' beginning_in_element_6																															
Year		Spbio		Recruits		Depletion		Catch_or		Exploitation																					
2002		7313		2075		0.115		192.4		0.0089																					
2003		7674		2163		0.121		265.8		0.0118																					

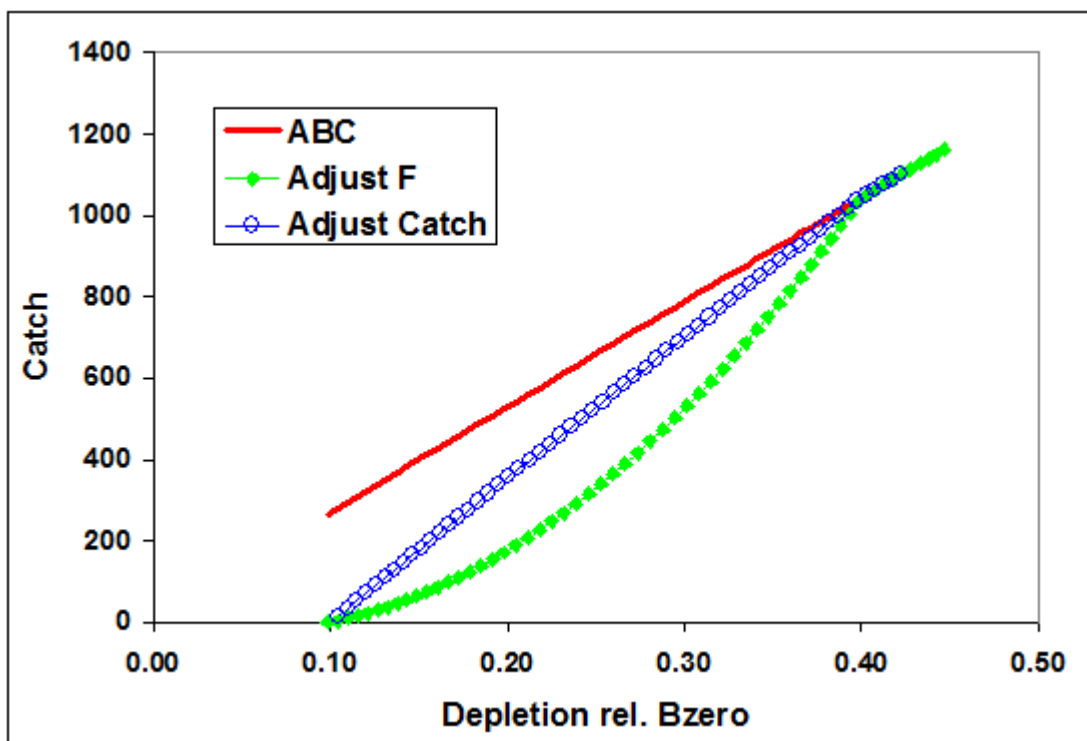
where:

- 40:10 is the magnitude of the adjustment of harvest multiplier to implement the OY policy
- bio-all is the biomass of all ages
- bio-smry is the biomass for ages at or above the summary age
- Spawnbio - is the female spawning output
- Depletion is the spawnbio divided by the unfished spawnbio
- Recruit-0 is the recruitment of age-0 fish in this year
- Dead\_cat\_B-1 is the total dead (retained plus dead discard) catch in MT for fleet 1
- Retain\_B-1 is fleet 1's retained catch in MT
- Equivalent catch in numbers is then reported.
- Hrate-1 is the harvest rate, as adjusted by the 40:10 policy. The units will depend on the F method selected (Pope's method giving mid-year harvest rate or the continuous F.
- Opt=C means that the rate was calculated from an input catch level (and crashed means that this caused an excessive harvest rate.
- Opt=R means that the catch was calculated from the target harvest rate.
- ABC is equal to the Total-Catch when the 40:10 option is not used (upper portion of table). When the 40:10 is on (lower table), the ABC is the catch level corresponding to no 40:10 adjustment after accounting for catch in previous year's from the 40:10.

The time series output described above is detailed by season, area, platoon and fishery. It is usually more convenient to have annual values summed across areas, platoons and fisheries. This is done for the 40:10 output and a subset of these values are replicated in the depletion vector in the sd\_report so that variance estimates can be obtained. The elements of the depletion vector in the sd\_report are:

- depletion level in end year
- depletion level in end year+1
- MSY (if calculated, else spbio in endyr-1)
- $B_{MSY}$  (if calculated, else spbio in endyr)

- $SPR_{MSY}$  (if calculated, else  $spbio$  in  $endyr+1$ ) then the time series of:
  - Spawning biomass
  - Recruitment
  - Depletion level
  - Total catch (if forecast calculated catch from rates) or sum of fishery-specific harvest rates (if forecast is based on fixed input catch level in this year)
  - Total exploitation rate (total dead catch divided by the summary biomass at the beginning of the year).



Two examples of harvest forecast adjustment: one adjusts catch and the other adjusts F.

## Main Output File, report.sso

This is the primary output file. Its major sections are listed below.

The sections of the output file are:

- SS version number with date compiled. Time and date of model run. This info appears at the top of all output files.
- Comments
  - Input file lines starting with #C are echoed here
- Keywords
  - List of keywords used in searching for output sections.
- Fleet Names
  - List of fishing fleet and survey names assigned in the data file
- Likelihood
  - Final values of the negative log(likelihood) are presented.
- Input Variance Adjustments
  - The matrix of input variance adjustments is output here because these values affect the logL calculations
- Parameters
  - The parameters are listed here. For the estimated parameters, the display shows: Num (count of parameters), Label (as internally generated by SS), Value, Active\_Cnt, Phase, Min, Max, Init, Prior, Prior\_type, Prior\_SD, Prior\_Like, Parm\_StD (standard deviation of parameter as calculated from inverse Hessian), Status (e.g. near bound), Pr\_atMin (value of prior penalty if parameter was near bound), and Pr\_atMin. The Active\_Cnt entry is a count of the parameters in the same order they appear in the ss.cor file.
- Derived Quantities
  - This section starts by showing the options selected from the starter.ss and forecast.ss input files:
    - \* SPR ratio basis
    - \* F report basis
    - \* B ratio denominator

Then the time series of output, with standard deviation of estimates, are produced with internally generated labels. Note that these time series extend through the forecast era. The order of the output

is: spawning biomass, recruitment, SPRratio, Fratio, Bratio, management quantities, forecast catch (as a target level), forecast catch as a limit level (OFL), Selex\_std, Grow\_std, NatAge\_std. For the three "ratio" quantities, there is an additional column of output showing a Z-score calculation of the probability that the ratio differs from 1.0. The "management quantities" section is designed to meet the terms of reference for west coast groundfish assessments; other formats could be made available upon request. The std quantities at the end are set up according to specifications at the end of the control input file. In some cases, a user may specify that no derived quantity output of a certain type be produced. In those cases, SS substitutes a repeat output of the virgin spawning biomass so that vectors of null length are not created.

ADMB NOTE: while vectors of null length are very useful for controlling optional model inputs, they cannot be used with current version of ADMB for sdreport quantities.

- MGparm by year after adjustments
  - This block shows the time series of mortality-growth parameters by year after adjustment by environmental links, blocks and deviations.
- SELparm (size) by year after adjustments
  - This block shows the size selectivity parameters, after adjustment, for each year in which a change occurs.
- SELparm (age) by year after adjustments
  - This block shows the age selectivity parameters, after adjustment, for each year in which a change occurs.
- Recruitment Distribution
  - This block shows the distribution of recruitment across growth patterns, genders, birth seasons, and areas in the endyr of the model.
- Platoon Indexing
  - This block shows the internal index values for various quantities. It can be a useful reference for complex model setups. The vocabulary is: Bio\_Pattern refers to a collection of cohorts with the same defined growth and natural mortality parameters; sex is the next main index. If recruitment occurs in multiple seasons, then birth season is the index for that factor. The index labeled "Platoon" is used as a continuous index across all the other factor-specific indices. If sub-platoons are used, they are nested within the Bio\_Pattern x Sex x Birth Season platoon. However, some of the output tables use the column label "platoon" as a continuous index across platoons and sub-platoons. Note that there is no index here for area. Each of the cohorts is distributed across areas and they



retain their biological characteristics as they move among areas.

- Size Freq Translation
  - If the generalize size frequency approach is used, this block shows the translation probabilities between population length bins and the units of the defined size frequency method. If the method uses body weight as the accumulator, then output is in corresponding units.
- Movement
  - This block shows movement rate between areas in a multi-area model.
- Exploitation
  - This block shows the time series of the selected  $F_{std}$  unit and the  $F$  multiplier for each fleet in terms of harvest rate (if Pope's approximation is used) or fully selected  $F$ .
- Index 2
  - This section reports the observed and expected values for each index. All are reported in one list with index number included as a selection field. At the bottom of this section, the root mean squared error of the fit to each index is compared to the mean input error level to assist the user in gaging the goodness-of-fit and potentially adjusting the input level of imprecision.
- Index 3
  - This section shows the parameter number assigned to each parameter used in this section.
- Discard
  - This is the list of observed and expected values for the amount (or fraction) discard.
- Mean Body Wt
  - This is the list of observed and expected values for the mean body weight.
- Fit Len Comps
  - This is the list of the goodness of fit to the length compositions. The input and output levels of effective sample size are shown as a guide to adjusting the input levels to better match the model's ability to replicate these observations.
- Fit Age Comps

- This has the same format as the length composition section.
- Fit Size Comps
  - This has the same format as the length composition section and is used for the generalized size composition summary.
- Len Selex
  - Here is the length selectivity and other length specific quantities for each fishery and survey.
- Age Selex
  - Here is reported the time series of age selectivity and other age-related quantities for each fishery and survey. Some are directly computed in terms of age, and others are derived from the combination of a length-based factor and the distribution of size-at-age.
- Environmental Data
  - The input values of environmental data are echoed here. In the future, the summary biomass in the previous year will be mirrored into environmental column –2 and that the age zero recruitment deviation into environmental column –1. Once so mirrored, they may enable density-dependent effects on model parameters.
- Numbers at Age
  - The output (in thousands of fish) is shown for each cohort tracked in the model.
- Numbers at Length
  - The output is shown for each cohort tracked in the model.
- Catch at Age
  - The output is shown for each fleet. It is not necessary to show by area because each fleet operates in only one area.
- Biology
  - The first biology section shows the length-specific quantities in the ending year of the time series only. The derived quantity spawn is the product of female body weight, maturity and fecundity per weight. The second section shows natural mortality.
- Growth Parameters

- This section shows the growth parameters, and associated derived quantities, for each year in which a change is estimated.
- Biology at Age
  - This section shows derived size-at-age and other quantities. It is the basis for the Bio report page of the Excel output processor.
- Mean Body Wt (begin)
  - This section reports the time series of mean body weight for each platoon. Values shown are for the beginning of each season of each year.
- Mean Size Time series
  - This section shows the time series of mean length-at-age for each platoon. At the bottom is the average mean size as the weighted average across all platoons for each gender.
- Age Length Key
  - This is reported for the midpoint of each season in the ending year.
- Age Age Key
  - This is the calculated distribution of observed ages for each true age for each of the defined ageing keys.
- Selectivity Database
  - This section contains the selectivities organized as a database, rather than as a set of vectors.
- Spawning Biomass Report 2, etc.
  - The section shows annual total spawning biomass, then numbers-at-age at the beginning of each year for each Bio\_Pattern and Sex as summed over sub-platoons and areas. Then Z-at-age is reported simply as  $\ln(N_{t+1,a+1}N_{t,a})$ . Then the Report\_1 section loops back through the time series with all F values set to zero so that a dynamic Bzero, N-at-age, and M-at-age can be reported. The difference between Report\_1 and Report\_2 can be used to create an aggregate F-at-age.
- Composition Database
  - This section is reported to a separate file, compreport.sso, and contains the length composition, age composition, and mean size-at-age observed and expected values. It is

arranged in a database format, rather than an array of vectors. Software to filter the output allows display of subsets of the database.

## Using R To View Model Output (r4ss)

A collection of functions developed as a package, `r4ss`, for the statistical software R has been created to explore SS model output. The functions include tools for summarizing and plotting results, manipulating files, visualizing model parameterizations, and various other tasks. Currently, information on the code, including installation instructions, can be found at [github.com/r4ss/r4ss](https://github.com/r4ss/r4ss). The software package is under constant development to maintain compatibility with new versions of SS and to improve functionality.

Two of the most commonly used functions for model diagnostics are `SS_output` and `SS_plots`. After running a model using SS, the report can be read into R by the `SS_output` function which stores quantities in a list with named objects. This list can then be passed to the `SS_plots` function which creates a series of over 100 plots that are useful to visualize output such as model fit to the data and time series of quantities of interest.

The latest `r4ss` version on CRAN can be installed using a command like:

```
> install.packages("r4ss")
```

However, more frequent enhancements and bug fixes are posted to the GitHub project. The latest version of `r4ss` can be installed directly from GitHub at any time via the `devtools` package in R with the following commands:

```
> install.packages("devtools")
> devtools::install_github("r4ss/r4ss")
```

Note: `devtools` will give this message: *"WARNING: Rtools is required to build R packages, but is not currently installed."* However, `Rtools` is NOT required for installing `r4ss` via `devtools`, so ignore this warning.

Once you have installed the `r4ss` package, it can be loaded in the regular manner:

```
> library(r4ss)
```

The results from a model run can be read in and plots created using the following commands:

```
> setwd("C:\\directory where model was run")
> base.model = SS_output(getwd())
> SS_plots(base.model)
```

Example of the data displayed used by the SS\_output function:

```

RGui - [R Console]
File Edit View Misc Packages Windows Help

[1] "SS-V3.23b-safe; 11/05/2011; Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_10"

$SS_versionshort
[1] "SS-V3.23"

$Run_time
[1] "StartTime: Wed Aug 01 09:25:26 2012"

$Files_used
[1] "Data_File: simple.dat Control_File: simple.ct1"

$Nwarnings
[1] 0

$warnings
[1] "SS-V3.23b-safe; 11/05/2011; Stock_Synthesis_by_Richard_Methot_(NOAA)_using_ADMB_10"
[2] "Wed Aug 01 09:25:26 2012"
[3] ""
[4] " N warnings: 0"
[5] "Number_of_active_parameters_on_or_near_bounds: 0"

$likelihoods_used
              values lambdas
TOTAL          1306.5199999999999818
Catch           0.0000000000431523
Equil_catch      0.0000000000000000    1
Survey          -3.9812099999999999
Length_comp     651.0109999999999673
Age_comp        586.6159999999999854
Size_at_age     79.22079999999999970
Recruitment     -7.3997500000000000    1
Forecast_Recruitment 0.0000000000000000    1
Parm_priors     1.0557700000000000    1
Parm_softbounds 0.0012052100000000    NA
Parm_devs       0.0000000000000000    1
Crash_Pen       0.0000000000000000    1

$likelihoods_raw_by_fleet
      Fleet:      ALL      1      2      3
99  Catch_lambda:      -      1      1      1
100 Catch_like: 4.31523e-011 4.31523e-011 0      0
101 Surv_lambda:      -      0      1      1
102 Surv_like:  -3.98121      0 -6.17026 2.18904
103 Length_lambda:      -      1      1      0
104 Length_like:  651.011    512.842 138.169 0
105 Age_lambda:      -      1      1      0
106 Age_like:  586.616    456.089 130.527 0
107 Sizeatage_lambda:      -      1      1      0
108 sizeatage_like:  79.2208    37.9909 41.2298 0

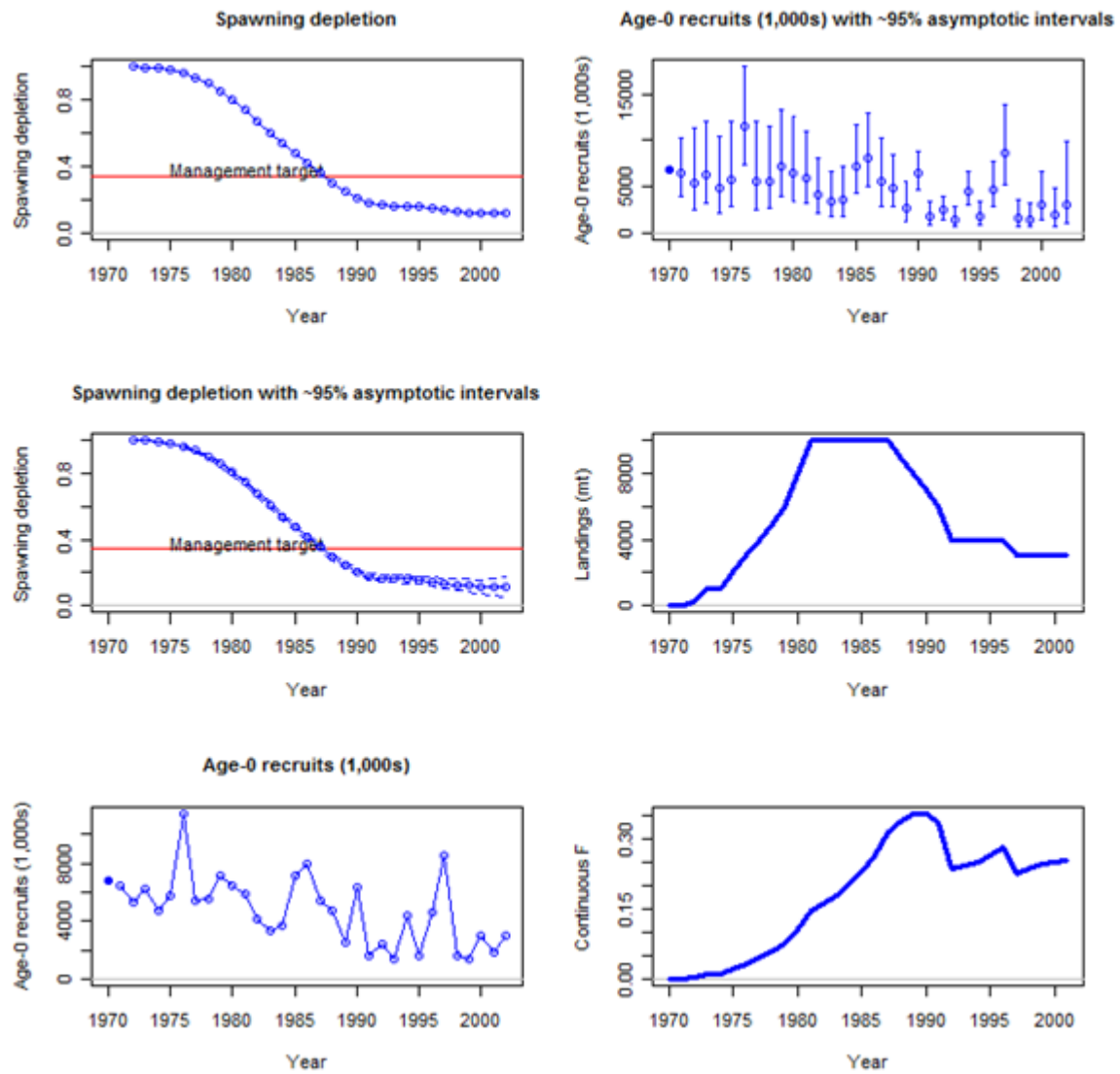
$N_estimated_parameters
[1] 54

$stable_of_phases
-99 -4 -3 -1 1 2 3 4
 1 7 16 7 3 3 2 5

$estimated_non_rec_devparameters
      Label      Value Phase  Min  Max      Init Status
121 L_at_Amin_Fem_GP_1 21.655200 2 -10.00 45.00 21.655200 OK
122 L_at_Amax_Fem_GP_1 71.649200 4 40.00 90.00 71.649200 OK
123 VonBert_K_Fem_GP_1 0.147282 4 0.05 0.25 0.147282 OK
128 L_at_Amax_Mal_GP_1 69.536100 4 40.00 90.00 69.536100 OK
129 VonBert_K_Mal_GP_1 0.163516 4 0.05 0.25 0.163516 OK

```

Example of the plots created using the SS\_plots function:



The functions included in r4ss ranging from general use to functions developed for specific model applications:

Core Functions	
SS_output	A function to create a list object for the output from Stock Synthesis
SS_plots	Plot many quantities related to output from Stock Synthesis
Plot functions called by SS_plots:	
SSplotBiology	Plot biology related quantities from Stock Synthesis model output, including mean weight, maturity, fecundity, and spawning output.
SSplotCatch	Plot catch related quantities
SSplotCohorts	Plot cumulative catch by cohort
SSplotComps	Plot composition data and fits
SSplotData	Timeline of presence/absence data by type, year, and fleet
SSplotDiscard	Plot fit to discard fraction
SSplotIndices	Plot indices of abundance and associated quantities
SSplotMnwt	Plot mean weight data and fits
SSplotMovementMap	Show movement rates on a map
SSplotMovementRates	Show movement rates on a map
SSplotNumbers	Plot numbers-at-age related data and fits
SSplotRecdevs	Plot recruitment deviations
SSplotRecdist	Plot of recruitment distribution among areas and seasons
SSplotSelex	Plot selectivity
SSplotSexRatio	Plot sex ratios
SSplotSummaryF	Plot time series summary of F (or harvest rate)
SSplotSpawnrecruit	Plot spawner-recruit curve
SSplotSPR	Plot SPR quantities
SSplotTags	Plot tagging data and fits
SSplotTimeseries	Plot time series data

SSplotYield	Plot yield and surplus production
SS_html	Create HTML files to view figures in browser
SS_fitbiasramp	Estimate bias adjustment for recruitment deviates
Model Comparisons and other diagnostics:	
SSplotPars	Plot distributions of priors, posteriors, and estimates
SSplotProfile	Plot likelihood profile results
PinerPlot	Plot fleet-specific contributions to likelihood profile
SSplotRetroRecruits	Make retrospective pattern of recruitment estimates (a.k.a. squid plot) as seen in Pacific hake assessments
Functions related to MCMC diagnostics:	
mcmc_nuisance	Summarize nuisance MCMC output
mcmc_out	Summarize, analyze, and plot key MCMC output
SSgetMCMC	Read MCMC output
SSplotMCMC_ExtraSelex	Plot uncertainty around chosen selectivity ogive from MCMC
Interactive tools for exploring functional forms:	
movepars	Explore movement parameterization
selfit	A function to visualize parameterization of double normal and double logistic selectivity in SS
selfit_spline	Visualize parameterization of cubic spline selectivity in SS
sel_line	A function for drawing selectivity curves
File manipulation for inputs:	
SS_readdat	Read data file
SS_readforecast	Read forecast file
SS_readstarter	Read starter file
SS_writedat	Write data file
SS_writeforecast	Write forecast file
SS_writestarter	Write starter file



SS_makedatlist	Make a list for SS data
SS_parlines	Get parameter lines from SS control file
SS_changepars	Change parameters in the control file
SSmakeMmatrix	Create inputs for entering a matrix of natural mortality by age and year
SS_profile	Run a likelihood profile in SS (incomplete)
NegLogInt_Fn	Calculated variances of time-varying parameters using SS implementation of the Laplace Approximation
<hr/> File manipulations for outputs:	
SS_recdevs	Insert a vector of recruitment deviations into the control file
SS_splitdat	Split apart bootstrap data to make input file
<hr/> Minor plotting functions:	
bubble3	Create a bubble plot
make_multifig	Create multi-figure plots
Make_multifig_sexratio	Create multi-figure plots of sex ratios
plotCI	Plot points with confidence intervals
rich_colors_short	Make a vector of colors
stackpoly	Plot stacked polygons
mountains	Make shaded polygons with a mountain-like appearance
<hr/> Really specialized functions:	
DoProjectPlots	Make plots from Rebuilder program
IOTCmove	Make a map of movement for a 5-area Indian Ocean model
SSFishGraph	A function for converting SS output to the format used by FishGraph
TSCplot	Create a plot for the TSC report

# Special Set-ups

## Continuous seasonal recruitment

It is awkward in SS to set up a seasonal model such that recruitment can occur with similar and independent probability in any season of any year. Consequently, some users have attempted to setup SS so that each quarter appears as a year. They have set up all the data and parameters to treat quarters as if they were years (i.e. each still has a duration of 1.0 time step). This can work, but requires that all rate parameters be re-scaled to be correct for the quarters being treated as years.

Another option is available. If there is one season per year and the season duration is set to 3 (rather than the normal 12), then the season duration is calculated to be  $3/12$  or 0.25. This means that the rate parameters can stay in their normal per year scaling and this shorter season duration makes the necessary adjustments internally. Some other adjustments to make when doing quarters as years include:

- re-index all "year seas" inputs to be in terms of quarter-year because all are now season 1; increase endyr value in sync with this
- increase max age because age is now in quarters
- in the age error definitions, increase the number of entries in accord with new max age
- in the age error definitions, recode so that each quarter-age gets assigned to the correct agebin; This is because the age data are still in terms of agebins; i.e. the first 4 entries for quarter-ages 1 through 4 will all be assigned to agebin 1.5; the next four to agebin 2.5; you cannot accomplish the same result by editing the age bin values because the stddev of ageing error is in terms of agebin
- in the control file, multiple the natM age breakpoints and growth AFIX values by 1/seasdur
- decrease the R0 parameter starting value because it is now the average number of recruitments per quarter year
- edit the rec\_dev start and endyrs to be in terms of quarter year
- edit any age selectivity parameters that refer to age to now refer to quarter age
- if there needs to be some degree of seasonality to recruitment or some parameter, then you could create a cyclic pattern in the environmental input and make recruitment or some other parameter a function of this cyclic pattern

A good test showing comparability of the 3 approaches to setting up a quarterly model should be done.

## Change Log

This section has been removed from the user manual. Information on changes to SS is now recorded in the spreadsheet database, SS\_Changes.xlsx. Fields include date, version number, category (e.g. growth, selectivity), type (e.g. new, clarify, fix). Occasional model tips will be added with the type="Tip".

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## Appendix A: Recruitment Variability and Bias Correction

Recruitments in SS are defined as lognormal deviates around a log-bias adjusted spawner-recruitment curve. The magnitude of the log-bias adjustment is calculated from the level of  $\sigma_R$ , which is the standard deviation of the recruitment deviations (in log-space). There are 5 segments of the time series in which to consider the effect of the log-bias adjustment: virgin; initial equilibrium; early data-poor period; data-rich period; very-recent/forecast. The choice of break points between these segments need not correspond directly with the settings for the bias adjustment, although some alignment might be desired. Methot et al. (2011) provide more detailed discussion of the bias adjustment than what is provided below but do not address the separation of time periods into separate segments. The approach is illustrated with figures associated with a recent assessment for darkblotched rockfish (Gertseva and Thorson, James T, 2013).

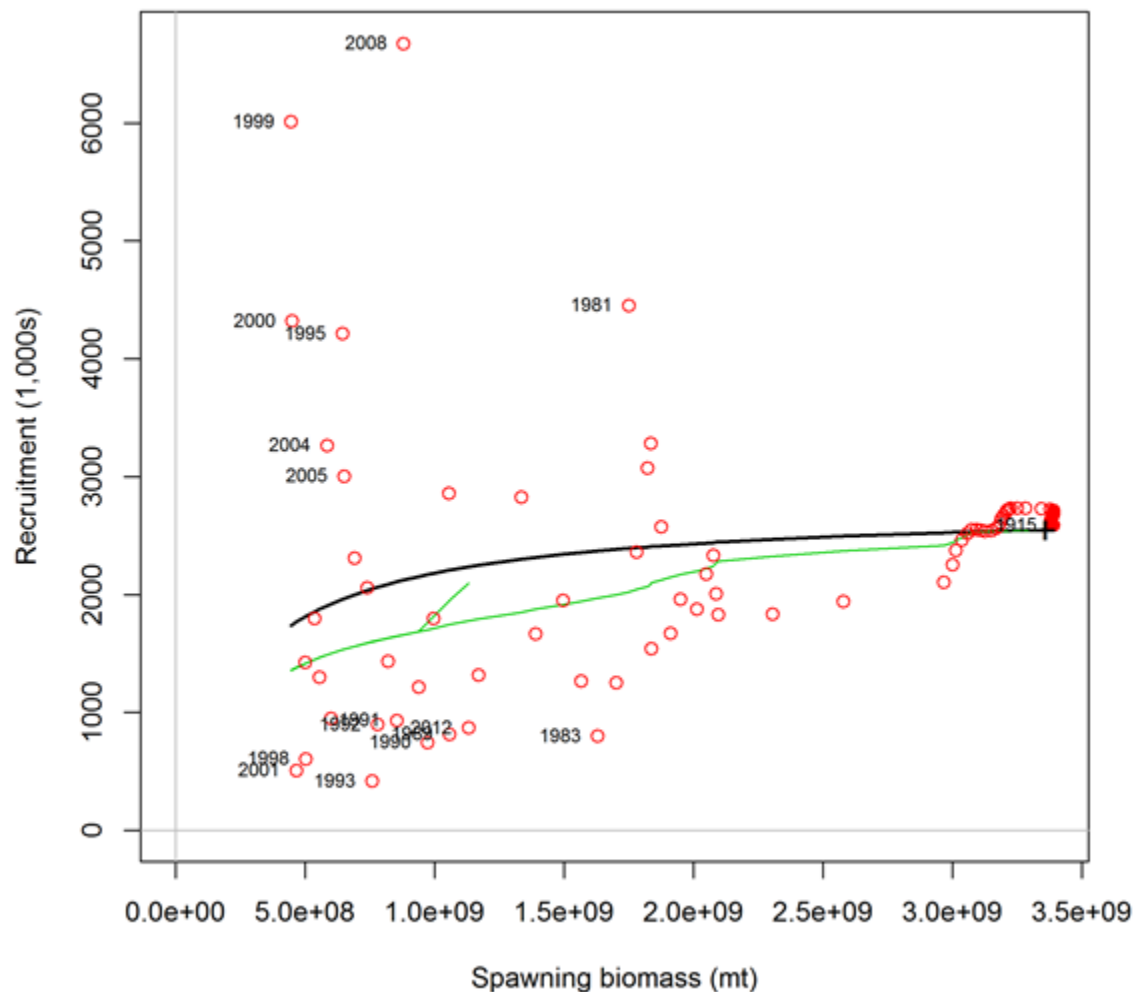


Figure A.1. Spawner-recruitment relationship for darkblotched rockfish (Gertseva and Thorson, James T, 2013). Red points represent estimated recruitments, the solid black line is the stock-recruit relationship and the green line represents the adjustment to this relationship after adjustment to account for the lognormal distribution associated with each year. The "+" symbol labeled 1915 near the right side represents both the virgin and initial equilibrium of the model. The numerous red points close to the initial conditions correspond to the early years of the model with low harvest rates.

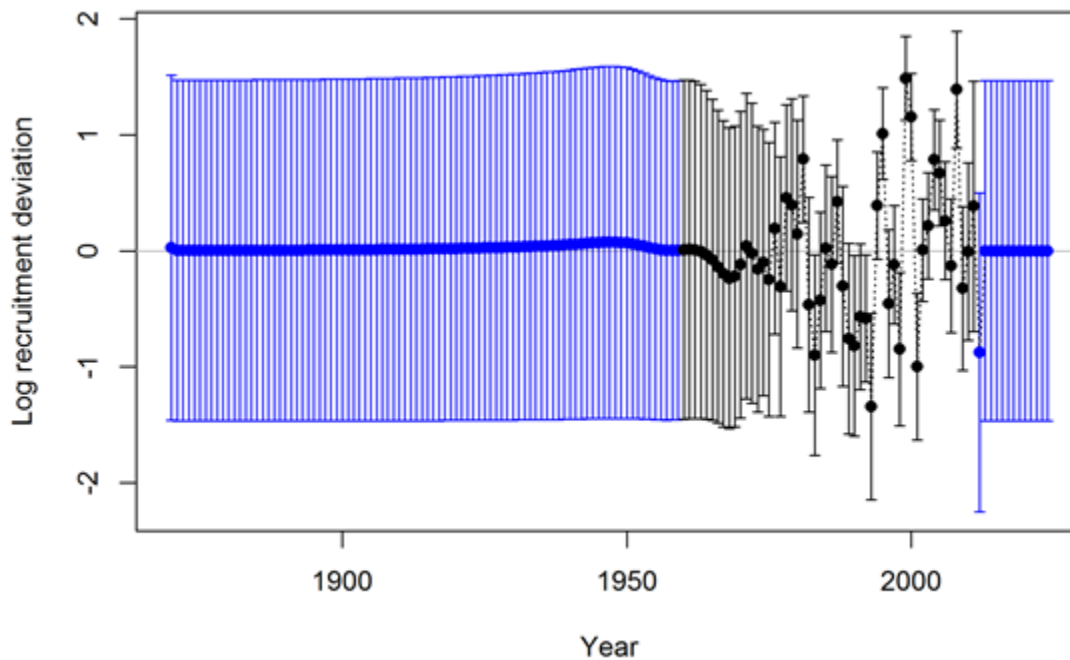


Figure A.2. Timeseries of log recruitment deviations for darkblotched rockfish with 95% uncertainty intervals. The start year of the model is 1915, but recruitment deviations are estimates starting in 1870. The 45 deviation estimates for 1870–1914 inform the age structure used in the start year. The black color for the years 1960–2011 indicates the "main" recruitment deviation vector, while the blue color for the years 1870–1959 and 2012–2024 indicates the "early" and "late/forecast" recruitment deviation vectors, respectively.

## Virgin Biomass

The  $R_0$  level of recruitment is a parameter of the spawner-recruitment curve. This recruitment and the corresponding spawning biomass expected to represent the long-term arithmetic mean.

## Initial Equilibrium

The level of recruitment is typically maintained at the  $R_0$  level even though the initial equilibrium catch will reduce the spawning biomass below the virgin level. If steepness is moderately low or the initial  $F$  is high, then the lack of response in recruitment level may appear paradoxical. The logic is

that building in the spawner-recruitment response to initial  $F$  would significantly complicate the calculations and would imply that the initial equilibrium catch level had been going on for multiple generations. If the lack of response is considered to be problematic in a particular application, then start the model at an earlier year and with a lower initial equilibrium catch so that the dynamics of the spawner-recruitment response get captured in the early period, rather than getting lost in the initial equilibrium.

## Early Data-Poor Period

This is the early part of the time series where the only data typically are landed catch. There are no data to inform the model about the specific year-to-year fluctuations in recruitment, although the ending years of this period will begin to be influenced by the data. The "early time period" is not a formal concept. It is up to the user to decide whether to start estimating recruitment deviations beginning with the first year of the model, or to delay such estimation until the data become more informative. Modeling recruitment deviations in this period may lead to a more realistic portrayal of the uncertainty in depletion, but can also lead to spurious patterns in estimated recruitments that may be driven by the fit to index data or other sources that would not be expected to have accurate information on recruitment.

- Option A: Do not estimate recruitment deviations during this early period. During years prior to the first year of recruitment deviations, the model will set the recruitment equal to the level of the spawner-recruitment curve. Thus, it is a mean-based level of recruitment. Because these annual parameters are fixed to the level of the spawner-recruitment curve, they have no additional uncertainty and make no contribution to the variance of the model. This approach may produce relatively large, or small, magnitude deviations at the very beginning of the subsequent period, as the model "catches up" to any slight signal that could not be captured through estimated deviations in the early data-poor period. There may be some effect on the estimate of  $R_0$  as a result of lack of model flexibility in balancing early period removals with signal in the early portion of the data-rich period.
- Option B: Estimate recruitment deviations for all the early years. Each of these recruitment deviations is now a deviation parameter so will have a variance that contributes to the total model variance. The estimated standard deviation of each of these deviation parameters should be similar to  $\sigma_R$  because  $\sigma_R$  is the only constraint on these parameters (however, the last few in the sequence will begin to feel the effect of the data so may have lower standard deviations).

## Data-Rich Period

Here the data inform the model on the year-to-year level of recruitment. These fluctuations in recruitment are assumed to have a lognormal distribution around the log-bias adjusted spawner-recruitment curve. The level of  $\sigma_R$  input to the model should match this level of fluctuation to a reasonable degree. Because the recruitments are lognormal, they produce a mean biomass level that is comparable to the virgin biomass and thus the depletion level can be calculated without bias.

However, if the early period has recruitment deviations estimated by maximum posterior density, then the depletion levels during the early part of the data-rich period may have some lingering effect of negative bias during the early time period. The level of  $\sigma_R$  should be at least as large as the level of variability in these estimated recruitments. If too high a level of  $\sigma_R$  is used, then a bias can occur in the estimate of spawner-recruitment steepness, which determines the trend in recruitment. This occurs when the early recruitments are taken directly from the spawner-recruitment curve, so are mean unbiased, then the later recruitments are estimated as deviations from the log-bias adjusted curve. If  $\sigma_R$  is too large, then the bias-adjustment is too large, and the model may compensate by increasing steepness to keep the mean level of recent recruitments at the correct level.

### Recent Years/Forecast

Here the situation is very similar to the early time period in that there are no data to inform the model about the year-to-year pattern in recruitment fluctuations so all deviations will be pulled to a zero level in the maximum posterior density. The structure of SS creates no sharp dividing line between the estimation period and the forecast period. In many cases one or more recruitments at the end of the time series will lack appreciable signal in the data and should therefore be treated as forecast recruit deviations. To the degree that some variability is observed in these recruitments, partial or full bias correction may be desirable for these deviations separate from the purely forecast deviations, there is therefore an additional control for the level of bias correction applied to forecast deviations occurring prior to end year + 1.

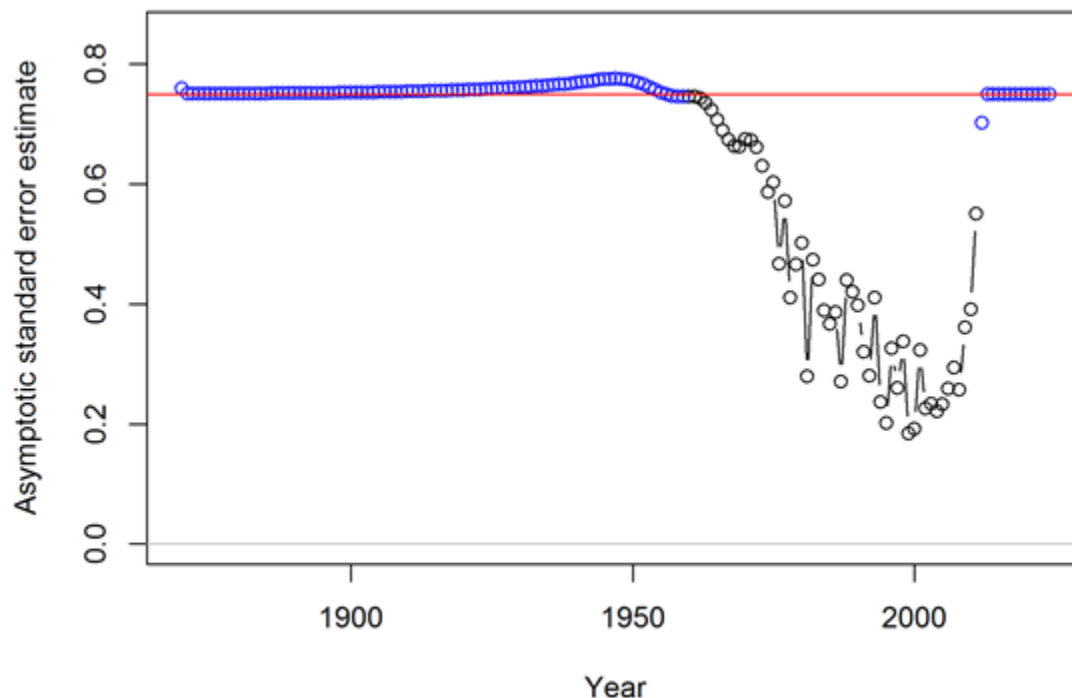


Figure A.3. Timeseries of standard error estimates for the log recruitment deviations for



darkblotched rockfish with 95% uncertainty intervals. As in Figure A.2, the black color indicates the main recruitment period. This period with lower standard error is associated with higher variability among deviations (Figure A.2). The red line at 0.75 indicates the  $\sigma_R$  value in this model.

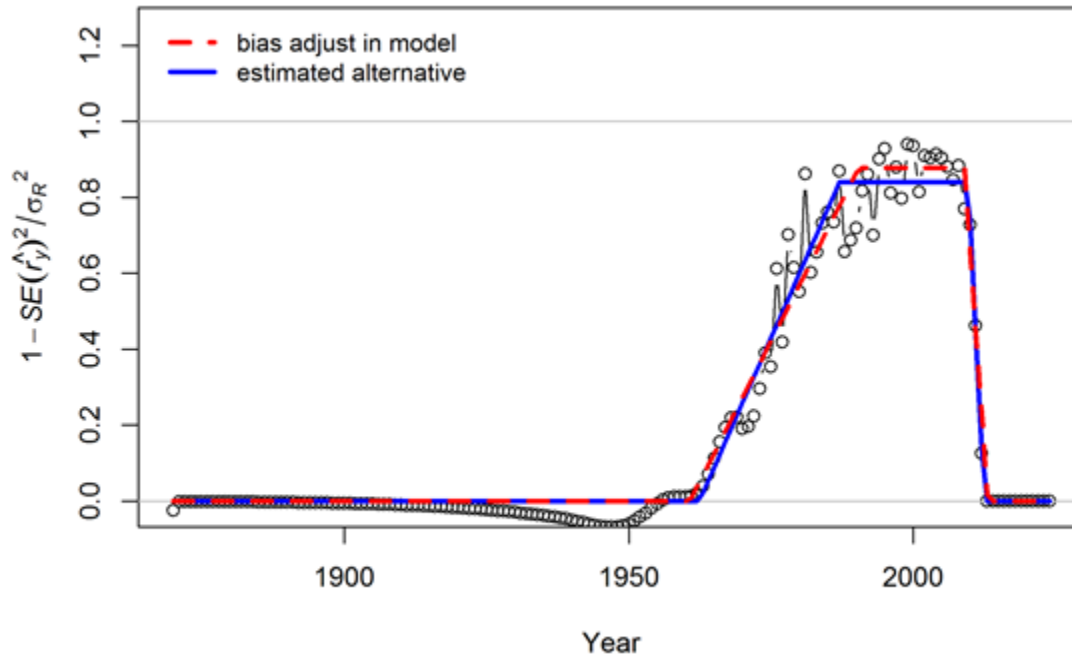


Figure A.4. Transformation of the standard error estimates (shown in Figure A.3) for darkblotched rockfish following the approach suggested by Methot et al. (2011). These values were used to set the 5 values controlling the degree of bias adjustment (as a fraction of  $\sigma_R/2$ ) to account for differences in the mean and median of the lognormal distribution from which the recruitment deviations are drawn. The red line indicates a bias adjustment of 0 up to the 1960.75, ramping up to a maximum adjustment level of 0.877 for the period 1990.4–2008.98, and reducing back to 0 starting in 2013.08. Note that these values controlling the bias adjustment need not be integer year values. Also the break points in the bias adjustment function need not match the break points between early, main, and late/forecast recruitment deviation vectors (indicated by blue and black colors in Figures A.2 and A.3). The blue line indicates a functional form that minimizes the sum of squared differences between the bias adjustment function and the transformed standard error values. The subtle differences between red and blue lines are unlikely to have any appreciable effect on the model results.

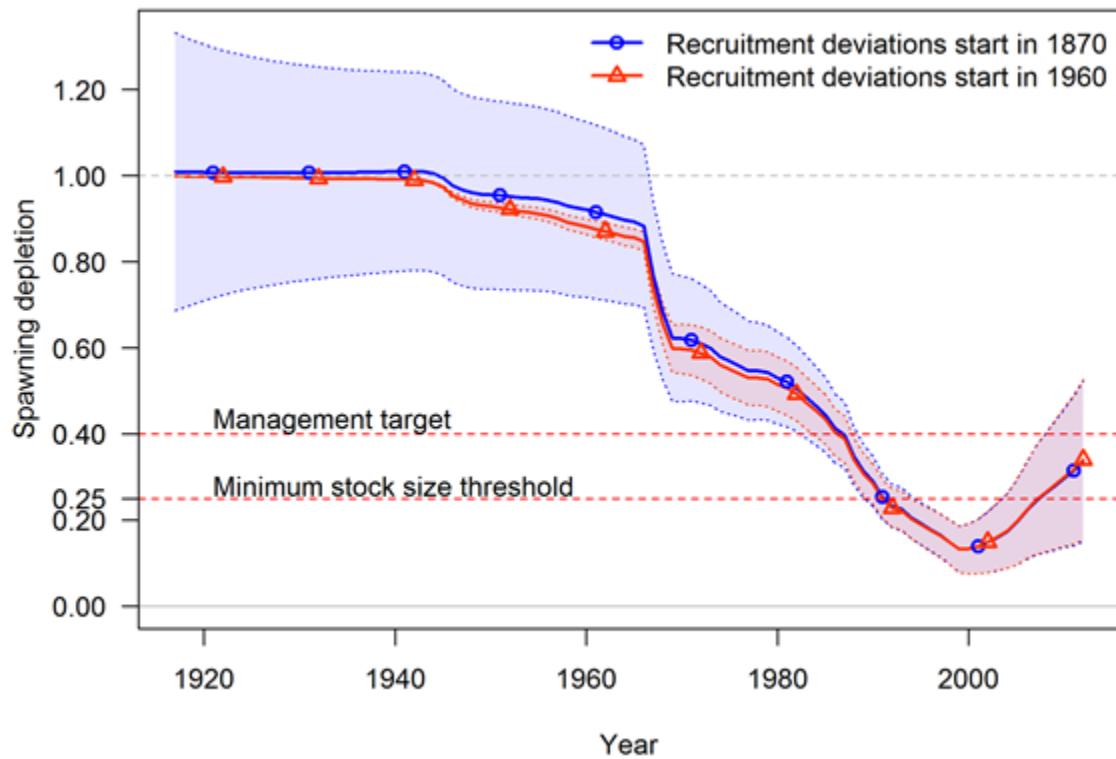


Figure A.5. Comparison of timeseries of spawning depletion for darkblotched rockfish models with early recruitment deviations (starting in 1870) and without early deviations (only main recruitment deviations starting in 1960). The point estimates are similar, but the 95% uncertainty intervals are substantially different. With no recruitment deviations for the early period, the estimates of spawning depletion in the early years are very precise and uncertainty increases as the stock moves into the data rich period. In contrast, the addition of the early recruitment deviations results in a large uncertainty in spawning depletion for the early years and an increase in precision as the stock moves into the data rich period. In this application, the uncertainty associated with the recent years is independent of the assumptions about early recruitments.

## Issues with Including Environmental Effects

The expected level of recruitment is a function of spawning biomass, an environmental time series, and a log-bias adjustment.

$$E(\text{Recruitment}) = f(\text{SpBio}) * \exp(\beta * \text{envdata}) * \exp(-0.5 * \sigma_R^2) \quad (56)$$

$\sigma_R$  is the variability of the deviations, so it is in addition to the variance "created" by the environmental effect. So, as more of the total recruitment variability is explained by the environmental effect, the residual  $\sigma_R$  should be decreased. The model does not do this automatically.

The environmental effect is inherently lognormal. So when an environmental effect is included in the model, the arithmetic mean recruitment level will be increased above the level predicted by  $f(\text{SpBio})$  alone. The consequences of this have not yet been thoroughly investigated, but there probably should be another bias correction based on the variability of the environmental data as scaled by the estimated linkage parameter,  $\beta$ . It is also problematic that the environmental effect time series used as input is assumed to be measured without error.

The preferred approach to including environmental effects on recruitment is not to use the environmental effect in the direct calculation of the expected level of recruitment. Instead, the environmental data would be used as if it was a survey observation of the recruitment deviation. This approach is similar to using the environmental index as if it was a survey of age 0 recruitment abundance because by focusing on the fit to the deviations it removes the effect of SpBio on recruitment. In this alternative, the  $\sigma_R$  would not be changed by the environmental data; instead the environmental data would be used to explain some of the total variability represented by  $\sigma_R$ . This approach may also allow greater uncertainty in forecasts, as the variability in projected recruitments would reflect both the uncertainty in the environmental observations themselves and the model fit to these observations.

## Initial Age Composition

If the first year with recruitment deviations is set less than the start year of the model, then these early deviations will modify the initial age composition. The amount of information on historical recruitment variability certainly will degrade as the model attempts to estimate deviations for older age groups in the initial equilibrium. So the degree of bias correction is reduced linearly in proportion to age so that the correction disappears when maximum age is reached. The initial age composition approach normally produces a result that is indistinguishable from a configuration that starts earlier in the time series and estimates a longer time series of recruitments. However, because the initial equilibrium is calculated from a recruitment level unaffected by spawner-recruitment steepness and initial age composition adjustments are applied after the initial equilibrium is calculated, it is possible that the initial age composition approach will produce a slightly different result than if the time series was started earlier and the deviations were being applied to the recruitment levels predicted from the spawner-recruitment curve.

## Appendix B: Data Weighting

In 2015 there was a CAPAM workshop dedicated to data-weighting. Description of the workshop can be found at [capamresearch.org/data-weighting/workshop](http://capamresearch.org/data-weighting/workshop). The presentations from the workshop are available through that website and many of them were included in a special issue of Fisheries Research a [sciencedirect.com/journal/fisheries-research/vol/192](http://sciencedirect.com/journal/fisheries-research/vol/192).

Currently, there are three main methods for weighting length and data applied for U.S. West Coast assessments using Stock Synthesis.

1. **McAllister - Ianelli:** Effective sample size is calculated from fit of observed to expected length or age compositions. Tuning algorithm is intended to make the arithmetic mean of the input sample size equal to the harmonic mean of the effective sample size (McAllister and Ianelli, 1997).
2. **Francis:** Based on variability in the observed mean length or age by year, where the sample sizes are adjusted such that the fit of the expected mean length or age should fit within the uncertainty intervals at a rate which is consistent with variability expected based on the adjusted sample sizes (Method "TA1.8") (Francis and Hilborn, 2011)
3. **Dirichlet-Multinomial:** A new likelihood (as opposed to the standard multinomial) which includes an estimable parameter (theta) which scales the input sample size. In this case, the term "Effective sample size" has a different interpretation than in the McAllister-Ianelli approach (Thorson et al., 2017).

## Applying the methods

### McAllister-Ianelli

The "Length\_Comp\_Fit\_Summary" and "Age\_Comp\_Fit\_Summary" sections in the Report file include information on the harmonic mean of the effective sample size and arithmetic mean of the input sample size used in this tuning method. In the r4ss package, these tables are returned by the SS\_output function as \$Length\_comp\_Eff\_N\_tuning\_check and \$Age\_comp\_Eff\_N\_tuning\_check.

A convenient way to process these values into the format required by the control file is to use the function:

```
SS_tune_comps(replist, option = "MI")
```

where the input "replist" is the object created by SS\_output. This function will return a table and also write a matching file called "suggested\_tuning.ss" to the directory where the model was run.

For models using SS version 3.30, the table created by SS\_tune\_comps can be pasted into the bottom of the control file in the section labeled "Input variance adjustments", followed by the terminator line which indicates the end of the section. Here's an example of the first few rows of the table followed by the terminator line (not added by the function):

```

#Factor Fleet New_Var_adj hash Old_Var_adj New_Francis New_MI Francis_mult Francis_lo Francis_hi MI_mult Type Name
1 4 1 0.118509 # 1 0.118509 0.416788 0.118509 0.074639 0.223240 0.416788 len Fishery
2 4 2 0.098549 # 1 0.098549 0.620938 0.098549 0.049584 0.450408 0.620938 len ASHOP
3 4 4 70.050597 # 1 70.050597 4.098752 70.050597 70.050597 Inf 4.098752 len POP
4 4 5 0.023763 # 1 0.023763 0.464394 0.023763 0.013256 0.145042 0.464394 len Triennial
5 4 6 0.082762 # 1 0.082762 0.696034 0.082762 0.047794 1.850003 0.696034 len AFSCSlope
6 4 7 0.579508 # 1 0.579508 0.463442 0.579508 0.579508 Inf 0.463442 len NWFSCSlope
7 4 8 0.061000 # 1 0.061000 0.548733 0.061000 0.042126 0.146227 0.548733 len NWFSCcombo
8 5 1 0.219201 # 1 0.219201 0.771078 0.219201 0.144972 0.444903 0.771078 age Fishery
9 5 2 0.032870 # 1 0.032870 0.140455 0.032870 0.021909 116.072298 0.140455 age ASHOP
10 5 4 1.173644 # 1 NA 1.173644 NA NA NA 1.173644 age POP
11 5 5 0.240507 # 1 0.240507 0.516917 0.240507 0.145298 1.299624 0.516917 age Triennial
12 5 7 0.319311 # 1 0.319311 1.084065 0.319311 0.319311 Inf 1.084065 age NWFSCSlope
13 5 8 0.347717 # 1 NA 0.347717 NA NA NA 0.347717 age NWFSCcombo

```

Also see the help page for the `r4ss` function `SS_varadj` just which can be used to automatically write a new control file if you want to streamline the process of applying multiple iterations of this tuning method.

If the tuning has been implemented, the green lines in the figure below would intersect at a point which is on the black 1-to-1 diagonal line in this figure created by the `r4ss` function `SS_plots`.

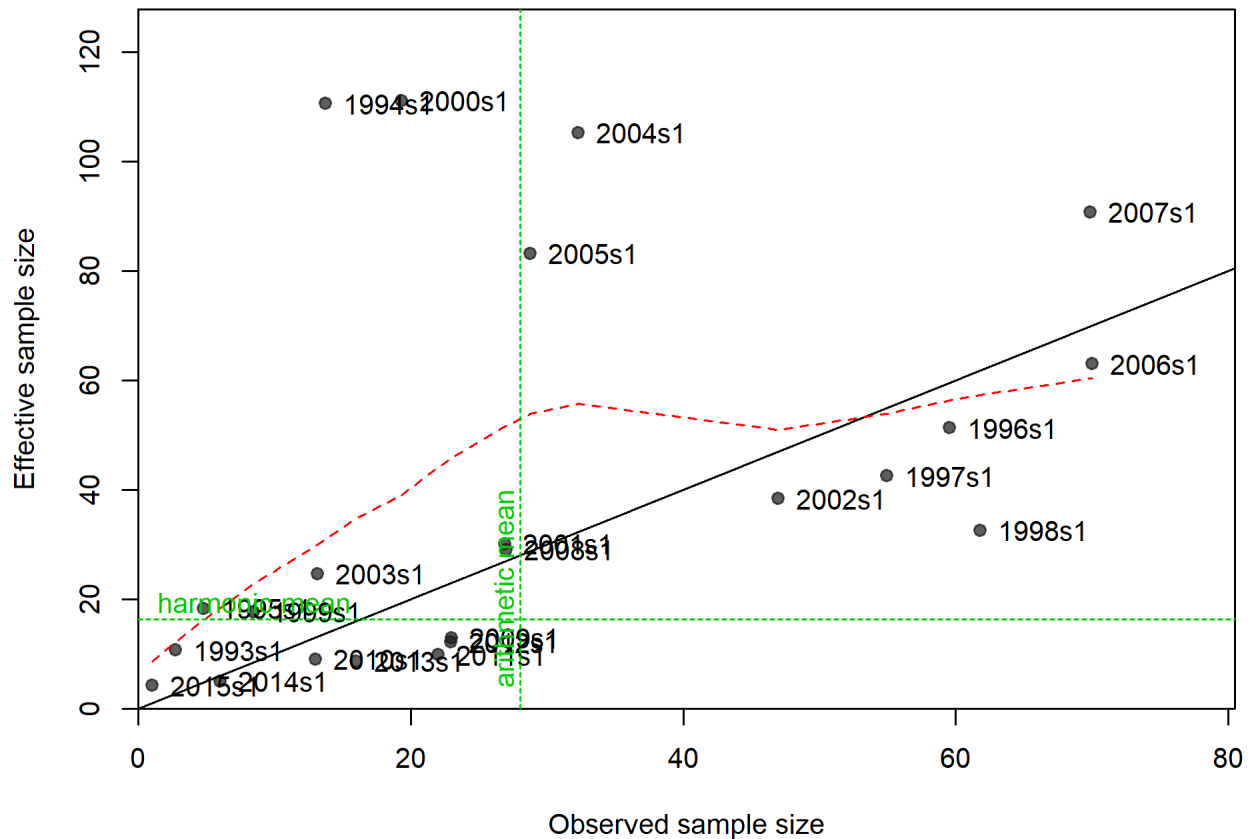


Figure B.1.N vs. EffN comparison, Length composition data as plotted by r4ss.

There are a couple of challenges posed by the McAllister-Ianelli data-weighting approach:

1. Subjective choice of how many iterations to take to achieve adequate convergence. Often just one iteration is applied.
2. Takes time to implement so tuning is rarely repeated during retrospective or sensitivity analyses.

## Francis

Implementation: recommended adjustments are calculated by the r4ss functions `SSMethod.TA1.8` and `SSMethod.Cond.TA1.8`. These functions are rarely used alone but are called by the `SS_plots` function when making plots like the one below. For SS 3.30 models, the simplest way to get the adjustments in the format required by the control file is to use the `SS_tune_comps` function (described above under the McAllister-Ianelli method), but with a different option specified:

```
SS_tune_comps(replist, option = "Francis")
```

The figure below shows the estimated 95% intervals around the observed mean length by year based on the input sample size (thick lines) and the increase in that uncertainty which would occur if the sample sizes were adjusted according to the proposed multiplier.

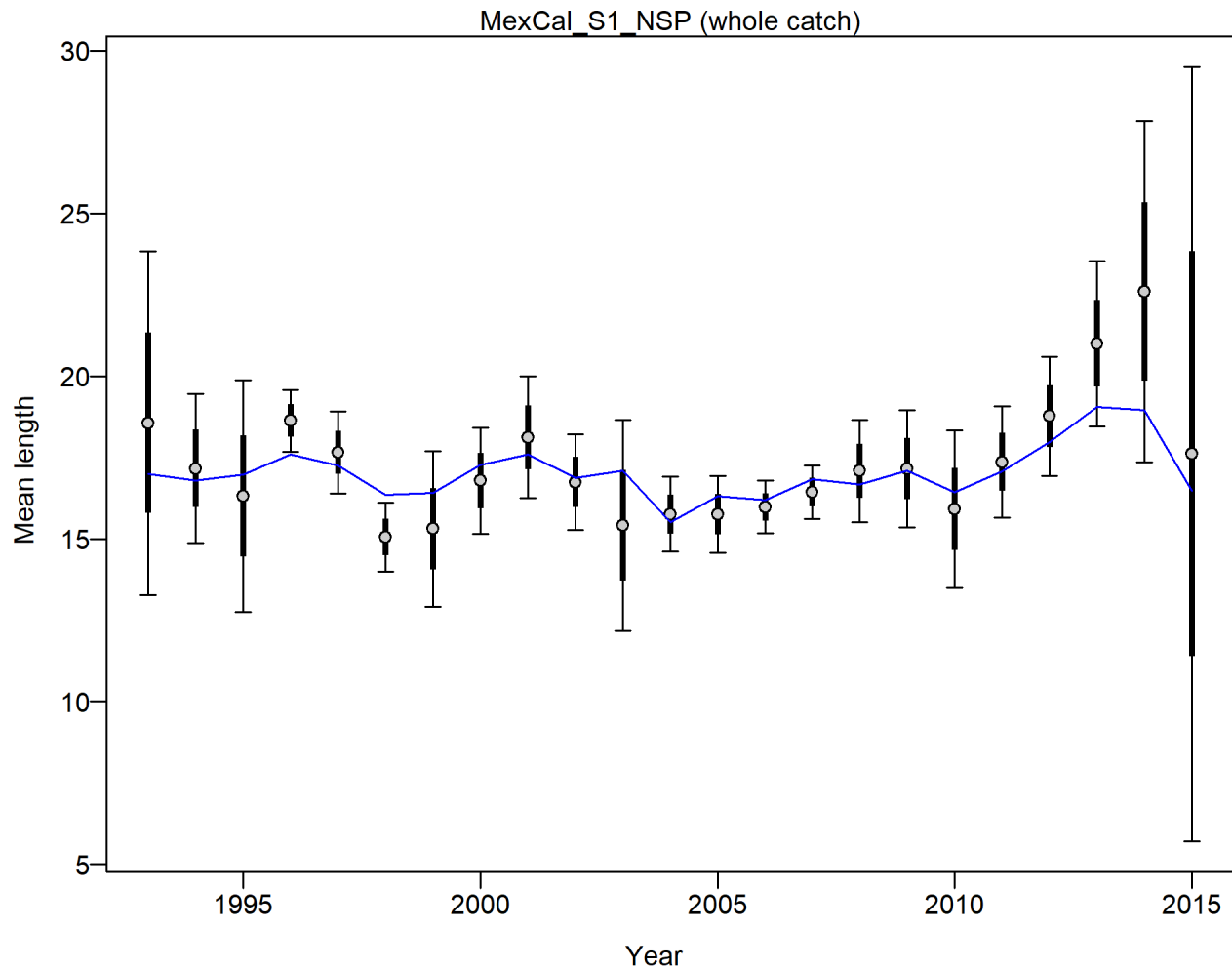


Figure B.2. Mean length for Fleet1 with 95% confidence intervals based on current samples sizes. Francis data weighting method TA1.8: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for len data from Fleet1: 0.2739 (0.1661-0.6305)

There are a several of challenges posed by the Francis data-weighting approach:

1. Subjective choice of how many iterations to take to achieve adequate convergence. Often just one iteration is applied.
2. Takes time to implement so tuning is rarely repeated during retrospective or sensitivity analyses.
3. Recommended adjustment can be sensitive to outliers (remove a few years of anomalous composition data can lead to large change in recommended adjustment).

## Dirichlet-Multinomial

Change the choice of likelihood and set parameter choices in the data file:

- In the specification of the length and/or age data, change "CompError" column in age and length comp specifications from 0 to 1 and "ParmSelect" from 0 to a sequence of numbers from 1 to N where N is the total number of combinations of fleet and age/length.
- Resulting input should look similar to:

```
#_mintailcomp addtocomp combM+F CompressBins CompError ParmSelect minsamplesize
-1 0.001 0 0 1 1 0.01 #_fleet:1_Fishery
-1 0.001 0 0 1 2 0.01 #_fleet:2_ASHOP
-1 0.001 0 0 0 0 0.01 #_fleet:3_Foreign
-1 0.001 0 0 1 3 0.01 #_fleet:4_POP
-1 0.001 0 0 1 4 0.01 #_fleet:5_Triennial
```

- The ParmSelect column can also have repeated values so that multiple fleets share the same log(theta) parameter.
- If you have both length and age data, the ParmSelect should have separate numbers for each, e.g. 1 and 2 for the length comps and 3 and 4 for the age comps for the same two fleets.

Add parameter lines to the control file:

- Add as many parameter lines as the maximum numbers in the ParmSelect column. The new parameter lines go after the main selectivity parameters but before any time-varying selectivity parameters
- Jim Thorson initially recommended bounds of -5 to 20, with a starting value of 0 (which corresponds to a weight of about 50% of the input sample size). However, parameter estimates above 5 are associated with 99-100% weight with little information in the likelihood about the parameter value. Therefore, an upper bound of 5 may help identify cases that otherwise would have convergence issues.
- Example parameter lines are below:

```
# Dirichlet parameters
#_LO HI INIT PRIOR PR_SD PR_type PHASE ... Blk_Fxn # Parm_name
-5 20 -0.2 0 50 0 2 ... 0 # ln(EffN_mult)_fishery - Dirichlet
-5 20 -0.2 0 50 0 2 ... 0 # ln(EffN_mult)_ashop - Dirichlet
-5 20 -0.2 0 50 0 2 ... 0 # ln(EffN_mult)_pop - Dirichlet
-5 20 -0.2 0 50 0 2 ... 0 # ln(EffN_mult)_tri - Dirichlet
-5 20 -0.2 0 50 0 2 ... 0 # ln(EffN_mult)_afsc - Dirichlet
```

- Reset any existing variance adjustments factors that might have been used for the McAllister-Ianelli or Francis tuning methods. In 3.24 this means setting the values to 1, in SS



version 3.30, you can simply delete or comment-out the rows with the adjustments.

The SS\_output function in r4ss returns table like the following:

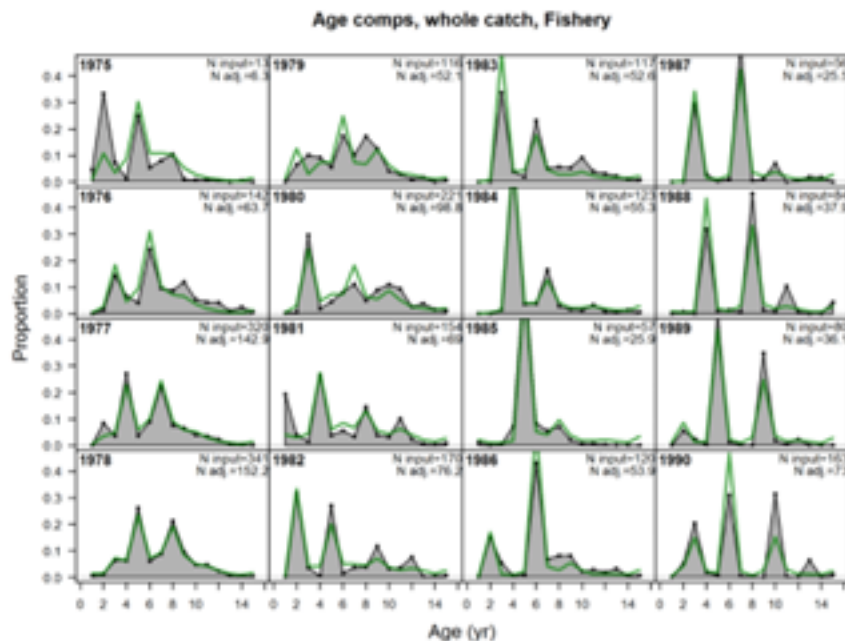
```
$Dirichlet_Multinomial_pars
      Value Phase Min Max      Theta Theta/(1+Theta)
ln(EffN_mult)_1 12.7638000      2  -5  15 3.493397e+05      0.9999971
ln(EffN_mult)_2  2.5263600      2  -5  15 1.250789e+01      0.9259692
ln(EffN_mult)_3 11.6519000      2  -5  15 1.149095e+05      0.9999913
ln(EffN_mult)_4  1.9373900      2  -5  15 6.940612e+00      0.8740651
ln(EffN_mult)_5 10.2865000      2  -5  15 2.933393e+04      0.9999659
ln(EffN_mult)_6 11.5556000      2  -5  15 1.043598e+05      0.9999904
```

The ratio shown in the final column is the estimated multiplier which can be compared to the sample size adjustment estimated in the other tuning methods above (the New\_Var\_adj column in the table produced by the SS\_tune\_comps function in r4ss).

If the reported  $\theta/(1 + \theta)$  ratio is close to 1.0, that indicates that the model is trying to tune the sample size as high as possible. In this case, the  $\ln(\theta)$  parameters should be fixed at a high value, like the upper bound of 20, which will result in 100% weight being applied to the input sample sizes. An alternative would be to manually change the input sample sizes to a higher value so that the estimated weighting will be less than 100

There is also information about this result produced in the plots created by the SS\_plots function:

## AgeComp



Age comps, whole catch, Fishery (plot 1 of 3).

'N input' is the input sample size. 'N adj.' is the sample size after adjustment by the Dirichlet-Multinomial  $\Theta$  parameter based on the formula  $N \text{ adj.} = 1 / (1 + \Theta) + N * \Theta / (1 + \Theta)$ .

For this fleet,  $\Theta = 0.801$  and the sample size adjustment is approximately  $\Theta / (1 + \Theta) = 0.445$

There are a several of challenges posed by the Dirichlet-Multinomial data-weighting approach:

1. Not yet widely used so little guidance is available.
2. Does not allow weights above 100% (by design) so it is not yet clear how best to deal with the situation when the estimated weight is close to 100%.
3. Parameterization has potential to cause convergence issues or inefficient MCMC sampling when weights are close to 100% (Jim Thorson has proposed a prior distribution that may help with this, but has not yet been tested).

# Appendix C: Forecast Module

## Introduction

SS version 3.20 introduced substantial upgrades to the benchmark and forecast module. The general intent was to make the forecast outputs more consistent with the requirement to set catch limits that have a known probability of exceeding the overfishing limit. In addition, this upgrade addressed several inadequacies with the previous module, including:

- The average selectivity and relative  $F$  was the same for the benchmark and the forecast calculations;
- The biology-at-age in  $\text{endyr}+1$  was used as the biology for the benchmark, but biology-at-age propagated forward in the forecast if there was time-varying growth;
- The forecast module had a kluge approach to calculation of overfishing limit (OFL) conditioned on previously catching ABC;
- The forecast module implementation of catch caps was incomplete and applied some caps on a seasonally, rather than the more logical annual basis;
- The  $F_{\text{mult}}$  scalar for fishing intensity presented a confusing concept for many users;
- No provision for specification of catch allocation among fleets;
- The forecast allowed for a blend of fixed input catches and catches calculated from target  $F$ ; this is not optimal for calculation of the variance of  $F$  conditioned on a catch policy that sets annual catch limits (ACLs).

The V3.20 module addressed these issues by:

- Providing for unique specification of a range of years from which to calculate average selectivity for benchmark, average selectivity for forecast, relative  $F$  for benchmark, and relative  $F$  for forecast;
- Create a new specification for the range of years over which to average size-at-age and fecundity-at-age for the benchmark calculation. In a setup with time-varying growth, it may make sense to do this over the entire range of years in the time series. Note that some additional quantities still use their  $\text{endyr}$  values, notably the migration rates and the allocation of recruitments among areas. This will be addressed shortly;
- Create a multiple pass approach that rectifies the OFL calculation;

- Improve the specification of catch caps and implement specification of catch allocations so that there can be an annual cap for each fleet, an annual cap for each area, and an annual allocation among groups of fleets (e.g. all recreational fleets vs. all commercial fleets);
- Introduce capability to have implementation error in the forecast catch (single value applied to all fleets in all seasons of the year).

## Multiple Pass Forecast

The most complicated aspect of the changes is with regard to the multiple pass aspect of the forecast. This multiple pass approach is needed to calculate both OFL and ABC in a single model run. More importantly, the multiple passes are needed in order to mimic the actual sequence of assessment-management action – catch over a multi-year period. The first pass calculates OFL based on catching OFL each year, so presents the absolute maximum upper limit to catches. The second pass forecasts a catch based on a harvest policy, then applies catch caps and allocations, then updates the  $F$ 's to match these catches. In the third pass, stochastic recruitment and catch implementation error are implemented and SS calculates the  $F$  that would be needed in order to catch the adjusted catch amount previously calculated in the second pass. With this approach, SS is able to produce improved estimates of the probability that  $F$  would exceed the overfishing  $F$ . In effect it is the complement of the  $P^*$  approach. Rather than the  $P^*$  approach that calculates the stream of annual catches that would have an annual probability of  $F > F_{limit}$ , SS calculates the expected time series of  $P^*$  that would result from a specified harvest policy implemented as a buffer between  $F_{target}$  and  $F_{limit}$ .

The sequence of multiple forecast passes is as follows:

1. Pass 1 (a.k.a. Fcast\_Loop1)
  - (a) Loop Years
    - i. SubLoop (a.k.a. ABC\_Loop) = 1
      - A.  $R = f(SSB)$  with no deviations
      - B.  $F = F_{limit}$
      - C. Fixed input catch amounts ignored
      - D. No catch adjustments (caps and allocations)
      - E. No implementation error
      - F. Result: OFL conditioned on catching OFL each year

## 2. Pass 2

### (a) Loop Years

#### i. SubLoop = 1

- A.  $R=f(SSB)$  with no deviations
- B.  $F=Flimit$
- C. Fixed input catch amounts ignored
- D. No catch adjustments (caps and allocations)
- E. No implementation error
- F. Result: OFL conditioned on catching ABC previous year. Stored in `std_vector`.

#### ii. SubLoop = 2

- A.  $R=f(SSB)$  with no deviations
- B.  $F=Ftarget$  to get catch for each fleet in each season
- C. Fixed input catch amounts replace catch from step 2
- D. Catch adjustments (caps and allocations) applied on annual basis (after looping through seasons and areas within this year). These adjustments utilize the logistic joiner approach common in SS so the overall results remain completely differentiable.
- E. No implementation error
- F. Result: ABC as adjusted for caps and allocations

#### iii. SubLoop = 3

- A.  $R=f(SSB)$  with no deviations
- B. Catches from Pass 2 multiplied by the random term for implementation error
- C.  $F=adjusted$  to match the  $catch*error$  while taking into account the random recruitments. This is most easily visualized in a MCMC context where the recruitment deviation and the implementation error deviations take on non-zero values in each instance. In MLE, because the forecast recruitments and implementation error are estimated parameters with variance, their

variance still propagates to the derived quantities in the forecast.

D. Result: Values for F, SSB, Recruitment, Catch are stored in std-vectors

- In addition, the ratios  $F/F_{limit}$  and  $SSB/SSB_{limit}$  or  $SSB/SSB_{target}$  are also stored in std\_vectors.
- Estimated variance in these ratios allows calculation of annual probability that  $F > F_{limit}$  or  $B < B_{limit}$ . This is essentially the realized  $P^*$  conditioned on the specified harvest policy.

## Example Effects on Correlations

An example that illustrates the above process was conducted. The situation was a low M, late-maturing species, so changes are not dramatic. The example conducted a 10 year forecast and examined correlations with derived quantities in the last year of the forecast. This was done once with the full set of 3 passes as described above, and again with only 2 passes and stochastic recruitment occurring in pass 2, rather than 3. This alternative setup is more similar to forecasts done using previous model versions.

2 Forecast Passes with F from ABC and random recruitment			2 Forecast Passes with catch from target F and equilibrium recruitment		
Factor X	Factor Y	Corr	Factor X	Factor Y	Corr
A1 F 2011	RecrDev 2002	-0.126	A2 F 2011	RecrDev 2002	0.090
B1 F 2011	Recr 2002	0.312	B2 F 2011	Recr 2002	0.518
C1 ForeCatch 2011	RecrDev 2002	0.000	C2 ForeCatch 2011	RecrDev 2002	0.129
D1 ForeCatch 2011	Recr 2002	0.455	D2 Forecatch 2011	Recr 2002	0.555

Correlation A2 shows a small positive correlation between the recruitment deviation in 2002 and the F in 2011. This is probably due to the fact that a positive deviation in recruitment in 2002 will reduce the chances that the biomass in 2011 will be below the inflection point in the control rule. This occurs because in calculating catch from F, the model effectively "knows" the future recruitments. I predict that this B1 correlation would be near zero if there was no inflection in the control rule.

Correlation A1 shows this turning into a negative correlation. This is because the future catches are first calculated from equilibrium recruitment, then when random recruitments are implemented, a positive recruitment deviation will cause a negative deviation in the F needed to catch that now

"fixed" amount of future catch.

Correlations B1 and B2 are in terms of absolute recruitment, not recruitment deviation. Now overall model conditions that cause a higher absolute recruitment level will also result in a higher forecast level. No surprise there, and the correlation is stronger when variance is based on catch is calculated from F (B2).

Correlation C2 shows a positive correlation between recruitment deviation in 2002 and forecast catch in 2011. However, correlation C1 is 0.0 because the forecast catch in 2011 is set based on equilibrium recruitment and is not influenced by the recruitment deviations.

## Future Work

- More testing with high M, rapid turnover conditions
- Testing without inflection in control rule
- Consider separating implementation error into a pass #4 so results will more clearly show effect of assessment uncertainty separate from implementation uncertainty
- Consider adding a random "assessment" error which essentially is a random variable that scales population abundance before passing into the forecast stage. Complication is figuring out how to link it to the correlated error in the benchmark quantities
- Because all of these calculations occur only in the sdphase or the mceval phase, it would be feasible for mceval calls to add an additional pass that is implemented many times and in which random forecast recruitment draws are made.
- Factors like selectivity and fleet relative F levels are calculated as an average of these values during the time series. This is internally consistent if these factors do not vary during the time series (although clearly this is a stiff model that will underestimate process variance). However, if these factors do vary over time, then the average used for the forecast will under-represent the variance. A better approach would be to set up the parameters of selectivity as a random process that extends throughout the forecast period, and to update estimated selectivity in each year of the forecast based upon the random realization of these parameters.

# Appendix D: Code Examples

## Ageing Error Estimation

```
/* SS_Label_FUNCTION 45 get_age_age */
FUNCTION void get_age_age(const int Keynum, const int AgeKey_StartAge, const int AgeKey_Linear1, const int AgeKey_Linear2)
{
  // FUTURE: calculate adjustment to oldest age based on continued ageing of old fish
  age_age(Keynum).initialize();
  dvariable age;
  dvar_vector age_err_parm(1,7);
  dvariable temp;

  if(Keynum==Use_AgeKeyZero)
  {
    // SS_Label_45.1 set age_err_parm to mgp_adj, so can be time-varying according to MGparm options
    for (a=1;a<=7;a++)
    {age_err_parm(a)=mgp_adj(AgeKeyParm-1+a);}
    age_err(Use_AgeKeyZero,1)(0, AgeKey_StartAge)=r_ages(0, AgeKey_StartAge)+0.5;
    age_err(Use_AgeKeyZero,2)(0, AgeKey_StartAge)=age_err_parm(5)*(r_ages(0, AgeKey_StartAge)+0.5)/
    (age_err_parm(1)+0.5);
    // SS_Label_45.3 calc ageing bias
    if(AgeKey_Linear1==0)
    {
      age_err(Use_AgeKeyZero,1)(AgeKey_StartAge,nages)=0.5 + r_ages(AgeKey_StartAge,nages) +
      age_err_parm(2)+(age_err_parm(3)-age_err_parm(2))*(1.0-mfexp(-age_err_parm(4)*
      (r_ages(AgeKey_StartAge,nages)-age_err_parm(1)))) / (1.0-mfexp(-age_err_parm(4)*
      (r_ages(nages)-age_err_parm(1))));
    }
    else
    {
      age_err(Use_AgeKeyZero,1)(AgeKey_StartAge,nages)=0.5 + r_ages(AgeKey_StartAge,nages) +
      age_err_parm(2)+(age_err_parm(3)-age_err_parm(2))*
      (r_ages(AgeKey_StartAge,nages)-age_err_parm(1))/(r_ages(nages)-age_err_parm(1));
    }
    // SS_Label_45.4 calc ageing variance
    if(AgeKey_Linear2==0)
    {
      age_err(Use_AgeKeyZero,2)(AgeKey_StartAge,nages)=age_err_parm(5)+(age_err_parm(6)-age_err_parm(5))*
      (1.0-mfexp(-age_err_parm(7)*(r_ages(AgeKey_StartAge,nages)-age_err_parm(1)))) /
      (1.0-mfexp(-age_err_parm(7)*(r_ages(nages)-age_err_parm(1))));
    }
    else
    {
      age_err(Use_AgeKeyZero,2)(AgeKey_StartAge,nages)=age_err_parm(5)+(age_err_parm(6)-age_err_parm(5))*
      (r_ages(AgeKey_StartAge,nages)-age_err_parm(1))/(r_ages(nages)-age_err_parm(1));
    }
  }
}
```

## Survival Based SRR Code

Code for the survival based recruitment is shown below:

```
// SS_Label_43.3.7 survival based
case 7: // survival based, so constrained such that recruits cannot exceed fecundity
{
```



```

SRZ_0=log(1.0/(SSB_virgin_adj/Recr_virgin_adj));
SRZ_max=SRZ_0+SR_parm_work(2)*(0.0-SRZ_0);
SRZ_surv=mfexp((1.-pow((SSB_curr_adj/SSB_virgin_adj),SR_parm_work(3)))*(SRZ_max-SRZ_0)+SRZ_0); // survival
NewRecruits=SSB_curr_adj*SRZ_surv;
exp_rec(y,1)=NewRecruits; // expected arithmetic mean recruitment

// SS_Label_43.3.7.1 Do variation in recruitment by adjusting survival
if(recdev_cycle>0)
{
gg=y - (styr+(int((y-styr)/recdev_cycle))*recdev_cycle)+1;
SRZ_surv*=mfexp(recdev_cycle_parm(gg));
}
exp_rec(y,2)=SSB_curr_adj*SRZ_surv;
SRZ_surv*=mfexp(-biasadj(y)*half_sigmaRsq); // bias adjustment
exp_rec(y,3)=SSB_curr_adj*SRZ_surv;
if(y <=recdev_end)
{
if(recdev_doit(y)>0) SRZ_surv*=mfexp(recdev(y)); // recruitment deviation
}
else if(Do_Forecast>0)
{
SRZ_surv *= mfexp(Fcast_recruitments(y));
}
join=1./(1.+mfexp(100*(SRZ_surv-1.)));
SRZ_surv=SRZ_surv*join + (1.-join)*1.0;
NewRecruits=SSB_curr_adj*SRZ_surv;
exp_rec(y,4) = NewRecruits;
break;
}

```

## Random Walk Selectivity: Pattern 17

Code for selectivity pattern 17, random walk shown below:

```
// SS_Label_Info_22.7.17 #age selectivity: each age has parameter as random walk
// #41 each age has parameter as random walk scaled by average of values at low age through high age
// transformation as selex=exp(parm); some special codes */
case 41:
scaling_offset = 2;
case 17:          //
{
lastsel=0.0; // value is the change in log(selex); this is the reference value for age 0
tempvec_a=-999.;
tempvec_a(0)=0.0; // so do not try to estimate the first value
int lastage;
if(seltype(f,4)==0)
{lastage=nages;}
else
{lastage=abs(seltype(f,4));}

for (a=1;a<=lastage;a++)
{
// with use of -999, lastsel stays constant until changed, so could create a linear change in ln(selex)
// use of (a+1) is because the first element, sp(1), is for age zero
if(sp(a+1+scaling_offset)>-999.) {lastsel=sp(a+1+scaling_offset);}
tempvec_a(a)=tempvec_a(a-1)+lastsel; // cumulative log(selex)
}
if (scaling_offset == 0)
{
temp=max(tempvec_a); // find max so at least one age will have selex=1.
}
else
{
int low_bin = int(value(sp(1)));
int high_bin = int(value(sp(2)));
if (low_bin < 0)
{
low_bin = 0;
N_warn++; warning<<" selex pattern 41; value for low bin is less than 0, so set to 0 "<<endl;
}
if (high_bin > nages)
{
high_bin = nages;
N_warn++; warning<<" selex pattern 41; value for high bin is greater than "<<nages<<" , so set to "<<nages<<" "<<endl;
}
if (high_bin < low_bin) high_bin = low_bin;
if (low_bin > high_bin) low_bin = high_bin;
sp(1) = low_bin;
sp(2) = high_bin;
temp=mean(tempvec_a(low_bin,high_bin));
}
sel_a(y,fs,1)=mfexp(tempvec_a-temp);
a=0;
while(sp(a+1+scaling_offset)==-1000) // reset range of young ages to selex=0.0
{
sel_a(y,fs,1,a)=0.0;
a++;
}
scaling_offset = 0; // reset scaling offset
if(lastage<nages)
{
for (a=lastage+1;a<=nages;a++)
```

```
{  
if(seltype(f,4)>0)  
{sel_a(y,fs,1,a)=sel_a(y,fs,1,a-1);}   
else  
{sel_a(y,fs,1,a)=0.0;}  
}  
}  
break;  
}
```

# Cubic Spline Selectivity

Code for cubic spline selectivity, option 42, shown below:

```
// SS_Label_Info_22.7.27 #age selectivity: cubic spline
// #42 cubic spline scaled by average of values at low age through high age
case 42:
scaling_offset = 2;
case 27:
{
k=seltype(f,4); // n points to include in cubic spline
for (i=1;i<=k;i++)
{
splineX(i)=value(sp(i+3+scaling_offset)); // "value" required to avoid error, but values should be always fixed anyway
splineY(i)=sp(i+3+k+scaling_offset);
}
z=nages;
while(r_ages(z)>splineX(k)) {z--;}
j2=z+1; // first age beyond last node
vcubic_spline_function splinefn=vcubic_spline_function(splineX(1,k),splineY(1,k),sp(2+scaling_offset),sp(3+scaling_offset));
tempvec_a= splinefn(r_ages); // interpolate selectivity at each age
if (scaling_offset == 0)
{
temp=max(tempvec_a(0,j2));
}
else
{
int low_bin = int(value(sp(1)));
int high_bin = int(value(sp(2)));
if (low_bin < 0)
{
low_bin = 0;
N_warn++; warning<<" selex pattern 42; value for low bin is less than 0, so set to 0 "<<endl;
}
if (high_bin > nages)
{
high_bin = nages;
N_warn++; warning<<" selex pattern 42; value for high bin is greater than "<<nages<<" , so set to "<<nages<<" "<<endl;
}
if (high_bin < low_bin) high_bin = low_bin;
if (low_bin > high_bin) low_bin = high_bin;
sp(1) = low_bin;
sp(2) = high_bin;
temp=mean(tempvec_a(low_bin,high_bin));
scaling_offset = 0; // reset scaling offset
}
tempvec_a-=temp; // rescale to get max of 0.0
tempvec_a(j2+1,nages) = tempvec_a(j2); // set constant above last node
sel_a(y,fs,1)=mfexp(tempvec_a);
break;
}
```

# Deviation Link

Code for alternative deviation links shown below:

```
case 1 (multiplicative):
{
  for (j=timevary_setup(10);j<=timevary_setup(11);j++)
  {
    parm_timevary(tvary,j)*=mfexp(parm_dev(k,j)*parm_dev_stddev(k));
  }
  break;
}

case 2 (additive):
{
  for (j=timevary_setup(10);j<=timevary_setup(11);j++)
  {
    parm_timevary(tvary,j)+=parm_dev(k,j)*parm_dev_stddev(k);
  }
  break;
}

case 3 (random walk):
{
  parm_dev_rwalk(k,timevary_setup(10))=parm_dev(k,timevary_setup(10))*parm_dev_stddev(k);
  parm_timevary(tvary,timevary_setup(10))+=parm_dev_rwalk(k,timevary_setup(10));
  for (j=timevary_setup(10)+1;j<=timevary_setup(11);j++)
  {
    parm_dev_rwalk(k,j)=parm_dev_rwalk(k,j-1)+parm_dev(k,j)*parm_dev_stddev(k);
    parm_timevary(tvary,j)+=parm_dev_rwalk(k,j);
  }
  break;
}

case 4 (mean reverting random walk)
{
  parm_dev_rwalk(k,timevary_setup(10))=parm_dev(k,timevary_setup(10))*parm_dev_stddev(k);
  parm_timevary(tvary,timevary_setup(10))+=parm_dev_rwalk(k,timevary_setup(10));
  for (j=timevary_setup(10)+1;j<=timevary_setup(11);j++)
  {
    //      =(1-rho)*mean + rho*prevval + dev    //   where mean = 0.0
    parm_dev_rwalk(k,j)=parm_dev_rho(k)*parm_dev_rwalk(k,j-1)+parm_dev(k,j)*parm_dev_stddev(k);
    parm_timevary(tvary,j)+=parm_dev_rwalk(k,j);
  }
  break;
}
```