

ss3sim: An R package for generalized stock-assessment simulation with Stock Synthesis

Sean C. Anderson^{1*}, Athol Whitten², Curry Cunningham², Felipe Hurtado Ferro²,
Kelli Johnson², Carey McGilliard³, Cole Monnahan², Kotaro Ono², Juan Valero^{2,4},
Roberto Licandeo⁵, Melissa Muradian², Cody Szuwalski², Katyana Vertpre⁶, (au-
thorship and order to be discussed)

¹Department of Biological Sciences, Simon Fraser University, Burnaby BC, V5A 1S6,
Canada

²School of Aquatic and Fishery Sciences, University of Washington, Box 355020,
Seattle, WA 98195-5020, USA

³NOAA

⁴

⁵UBC?

⁶?

Introduction

16 Paragraph 1: What is stock assessment simulation? Why is it increasingly critical?

- stock assessment simulation is...
- 18 • stock-assessment simulation is a critical component to evaluating stock assessment methods and understanding their strengths and weaknesses. ...
- 20 • important because it lets us test our assessments on known truths
- further, it lets us explore truths we are interested in and match (or mismatch)
- 22 truths and assessments
- refs: Hilborn and Walters (1992) among others; recent papers on stock-assessment
- 24 simulation

Paragraph 2: What is SS3, why is it important, why simulate with it?

- 26 • Stock synthesis is a modelling framework... Integrated analysis — models population dynamics using a wide range of data (Maunder and Punt, 2012)
- 28 • SS3 is the 3rd version of the software using this framework
- SS software ref: Methot and Wetzel (2012)
- 30 • ADMB software ref: Fournier et al. (2012)
- Importance of integrated analysis with SS as an example: Maunder and Punt
- 32 (2012)
- most widely used now world wide (?) and especially on West Coast of United
- 34 States
- facilitates rapid, reproducible analyses... focus on peer-review of the science
- 36 not the modelling code

- allows a separation of research from stock assessment that informs management
(Methot and Wetzel, 2012)
- been instrumental to investigating new stock assessment concepts: e.g. Piner
et al. (2011), Methot and Taylor (2011)
- been used in XX stock assessments world wide (~60 as of 2012 - ask Rick) and
involved in many more currently
- Piner et al. (2011) example of stock-assessment simulation research with SS3
- Methot and Taylor (2011) example of stock-assessment research with SS

Methot and Wetzel (2012):

A comprehensive modeling framework such as SS enhances communication, efficiency, and education in the fishery assessment community (Methot, 2009). Communication is enhanced by creating a familiarity among users, reviewers, and clients regarding terminology and approach. Reviewers who are already familiar with SS can quickly focus on key issues for the assessment being reviewed, rather than spend time learning the features of a novel assessment model.

Therefore there are two benefits to simulating with SS: (1) much of the model has already been built (research can then progress rapidly and with less chance of errors) and checked and (2) the results are directly applicable to the tools used by stock assessment scientists — in fact, used by all Western US assessments.

There are, however, many complications to conducting large-scale, rapid, and reproducible stock-assessment simulations. Complications include how to manage data and file structure, how to avoiding coding errors, how to repeatedly manipulate

60 simulation models to ask specific questions, and how to translate models and ques-
tions across stocks and species. [Maybe delete this or go into how most solutions are
62 GUI right now]Further, while the statistical software R has become the standard for
data analysis and visualization, and the stock-assessment framework Stock Synthe-
64 sis is increasingly the standard for fisheries stock assessment, we lack a generalized
framework to link the two in a simulation context.

66 In this paper we introduce ss3sim, a software package for the popular statistical
programming language R that facilitates large-scale, rapid, and reproducible stock-
68 assessment simulation with the widely-used SS framework. We begin by outlining
the general philosophy of ss3sim, and describing its functions. Then, to demon-
70 strate how a researcher might conduct a stock-assessment simulation with ss3sim,
we work through an example starting at a research question and ending with plots
72 and interpretation of the output. Our example includes considerations for setting
up operating and estimation models, choosing a folder structure, model testing, and
74 output manipulation and plotting. We conclude by discussing how ss3sim comple-
ments other stock assessment simulation software and outlining research questions
76 our accessible and general SS simulation framework could address.

The ss3sim framework

78 Terminology

Throughout this paper we refer to a number of terms which we defined here. We use
80 the term *operating model* (OM) to refer to the model that represents the underlying
true dynamics of the system. We use the term *estimation model* (EM) refer to
82 the model used to estimate quantities of interest. Whereasa the OM refers to the

underlying truth, the EM generates our perception of that truth. We use the term
84 *scenario* to refer to a combination of operating and estimation model *cases*. An OM
case might be natural mortality that follows a random walk, an EM case might be
86 estimating a fixed parameter for natural mortality, and the combination of these
two cases along with all other specified conditions creates a scenario. We refer to
88 *iterations* as replicates of a scenario with potentially new process and observation
error added with each replicate. A simulation therefore refers to the combination of
90 all scenarios and iterations.

General philosophy

92 We designed ss3sim to be reproducible, flexible, and rapid. To be reproducible,
ss3sim allows for the simulation to be documented in code and plaintext control files.
94 Further, the plaintext control files refer to individual cases, which allows researchers
to reuse control files as much as possible across scenarios to make some relation code
96 easier to understand and less error-prone. ss3sim then keeps all SS3 output files as
well as generating its own log files along the way for documentation.

98 To be flexible, ss3sim allows the user to specify their own OM and EM using
all the possibilities of SS3. ss3sim can take input in a number of forms (in R list
100 format or through control files), and return output in a standard, separated value
(CSV) format allowing researchers to work with the output either using the package
102 provided functions or their own tools.

To be rapid, ss3sim relies on SS3, which uses ADMB as a backend optimization
104 platform — the most rapid and robust optimization software available today. Fur-
ther, we built ss3sim so that it is easy to deploy across multiple computers or multiple
106 researchers and re-combine the output. The package provides a number of functions

to make visualization easy so that users are more likely to visualize their models and
108 therefore more likely to detect errors quickly and understand their models. Finally,
ss3sim minimizes the amount of bookkeeping simulation code that researchers have
110 to write so that they can concentrate on the science itself.

General structure

112 An ss3sim simulation requires three types of input: (1) a base model of the underlying
truth (an SS3 OM), (2) a base model of how you will assess that truth (an SS3
114 EM), (3) and a set of cases that deviate from these base models that you want
to compare (configuration arguments either as R lists or plaintext control files).
116 ss3sim works, in general, by converting simulation arguments (e.g. a given natural
mortality trajectory) into manipulations of SS3 configuration files at the appropriate
118 stage along with running the OM and EM as needed.

Low-level generic ss3sim functions

120 See Table 1 for description of functions. See Figure 1 for the functions fit into the
general structure. ss3sim functions are divided into three types of functions:

- 122 1. Functions that manipulate SS configuration files. These manipulations gener-
ate an underlying “truth” (OM) and control our assessment of those models
124 (EM).
2. Functions that conduct simulations. These functions generate a folder struc-
126 ture, call manipulation functions, run SS3 as needed, and save the output.
3. Functions for analyzing and plotting simulation output.

128 **High-level tailored ss3sim functions**

- an example framework
- 130 • because it relies on manipulation of these configuration files, it's important the config files match a specific format
- 132 • general framework, because you start with your own OM and EM, and a wide variety of questions are then available through manipulations of ..., ...

134 **An example simulation with ss3sim**

Setting up the SS models

- 136 • the (simple) research question
- setting up the OM and EM SS models
- 138 • things to keep in mind
- running through SS to format as `.ss_new` files and renaming

140 **File and folder setup**

- required files
- 142 • Why we chose a flat-file structure
- see vignette

144 **Translating research questions into configuration files**

- E.g. time-varying M

146 **Deterministic model testing**

- reduce recdevs, reduce sigma R, bias correction
- 148 • what to plot, what to look for, how good is OK?

Output analysis and visualization

- 150 • examples using the included functions
- brief take home of what we'd conclude

152 **Discussion**

Other sections? how we validated it; benefit of using one well tested and well-
154 understood model (but disadvantages too) — benefit to playing with all the switches
and understanding one framework (SS) well versus having many tools that we su-
156 perfcially understand

158 **How ss3sim complements other generic stock-assessment sim- ulation software**

- focus on “generic” software, e.g. not software the just works for salmon simu-
160 lation

r4ss

- 162 • Taylor et al. (2013)
- r4ss has functions to facilitate aspects of simulations, mostly focused on reading
164 and plotting output for stock assessment

- ss3sim uses r4ss functions for some reading, writing, and bias adjustment

166 **FLR**

- Kell et al. (2007) for FLR and Hillary (2009) for simulation in FLR
- 168 • statistical catch-at-age only?
- not integrated analysis, not SS
- 170 • but particularly relevant to Europe

“Hooilator”

- 172 • <http://fisherysimulation.codeplex.com>, Windows only, GUI... , works on bootstrapped data only, therefore isn’t as flexible as ss3sim. Used in:
- 174 1. Lee et al. (2012)
- 2. Piner et al. (2011)
- 176 3. Lee et al. (2011)

Others?

178 **The need for balance between generalizing and tailoring in simulation software**

- 180 • maybe?
- why we developed generic low-level functions and higher level functions
- 182 • but researchers are free to develop their own higher level functions
- because in an open-source MIT(?) licensed R package, users are free to modify
- 184 functions as needed

Maybe lessons learned? From Athol's work

- 186 • importance of version control
- benefits to developing analysis within an R package
- 188 • importance of model testing
- importance of rapid visualization of output, example `shiny` or `manipulator`

190 Research opportunities with `ss3sim`

Acknowledgements

- 192 • funding: Fulbright Canada, NSERC, Simon Fraser University, . . .
- discussions and advice: Andre Punt, Richard Methot, Ian Taylor, James Thor-
- 194 son, . . .

Figure captions

196 Figure 1: Flow diagram of ss3sim

Figure 2: Panels with output from the example

Tables

Table 1: User-facing ss3sim functions and a description of their purpose.

Function name	Description
<code>change_f</code>	Changes the fishing mortality
<code>change_m</code>	Adds time-varying natural mortality features
<code>change_growth</code>	Adds time-varying growth features
<code>change_sel</code>	Adds time-varying selectivity
<code>change_e</code>	Controls what and how parameters are estimated
<code>change_lcomp</code>	Controls how length composition data are sampled
<code>change_agecomp</code>	Controls how age composition data are sampled
<code>change_index</code>	Controls how the fishery and survey indices operate
<code>change_rec_devs</code>	Substitutes recruitment deviations
<code>change_retro</code>	Controls the number of years to discard for a retrospective analysis
<code>run_ss3sim</code>	Master function that runs an ss3sim simulation
<code>run_fish600</code>	Wrapper function that facilitates one particular simulation setup
<code>get_results_all</code>	Extract results from a series of scenarios
<code>get_results_scenario</code>	Extract the results for a single scenario

plotting functions!! Plot the output...

200 Table X: Comparison with related software? - maybe a table with the possible
columns: software, reference, platform (e.g. R, GUI...), Short description/comparison,
202 examples of papers using it

References

- 204 Fournier, D. A., Skaug, H. J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.
N., and Nielsen, A. *et al.* 2012. AD Model Builder: using automatic differentiation for
206 statistical inference of highly parameterized complex nonlinear models. *Optimization
Methods and Software*, 27: 233–249.
- 208 Hilborn, R. W., and Walters, C. 1992. *Quantitative Fisheries Stock Assessment:
Choice, Dynamics, and Uncertainty*. Chapman and Hall, London.
- 210 Hillary, R. 2009. An introduction to FLR fisheries simulation tools. *Aquatic Living
Resources*, 22: 225–232.
- 212 Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J.-M., Garcia, D., Hillary, R.,
and Jardim, E. *et al.* 2007. FLR: an open-source framework for the evaluation and
214 development of management strategies. *ICES Journal of Marine Science*, 64: 640–
646.
- 216 Lee, H.-H., Maunder, M. N., Piner, K. R., and Methot, R. D. 2011. Estimating
natural mortality within a fisheries stock assessment model: An evaluation using
218 simulation analysis based on twelve stock assessments. *Fisheries Research*, 109: 89–
94.
- 220 Lee, H.-H., Maunder, M. N., Piner, K. R., and Methot, R. D. 2012. Can steepness of
the stock-recruitment relationship be estimated in fishery stock assessment models?
222 *Fisheries Research*, 125–126: 254–261.
- Maunder, M. N., and Punt, A. E. 2012. A review of integrated analysis in fisheries

224 stock assessment. Fisheries Research, 142: 61–74.

Methot, R. D., and Taylor, I. G. 2011. Adjusting for bias due to variability of
226 estimated recruitments in fishery assessment models. Canadian Journal of Fisheries
and Aquatic Sciences, 68: 1744–1760.

228 Methot, R. D., and Wetzel, C. R. 2012. Stock Synthesis: A biological and statistical
framework for fish stock assessment and fishery management. Fisheries Research,
230 142: 86–99.

Piner, K. R., Lee, H.-H., Maunder, M. N., and Methot, R. D. 2011. A simulation-
232 based method to determine model misspecification: examples using natural mortality
and population dynamics models. Marine and Coastal Fisheries, 3: 336–343.

234 Taylor, I., Stewart, I., Hicks, A., Garrison, T., Punt, A., Wallace, J., and Wetzel, C.
2013. r4ss: R code for Stock Synthesis. <http://code.google.com/p/r4ss/>.