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

Sean C. Anderson[1*] Athol Whitten[2]
Curry Cunningham[2] Felipe Hurtado Ferro[2]
Kelli Johnson[2] Carey McGilliard[3] Cole Monnahan[2]
Kotaro Ono[2] Juan Valero[2,4] Roberto Licandeo[5]
Melissa Muradian[2] Cody Szuwalksi[2] Katyana Vertpre[6]
(authorship and order to be discussed)

[1]Department of Biological Sciences, Simon Fraser University, Burnaby BC, V5A 1S6, Canada
[2]School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020, USA
[3]NOAA
[4]
[5]UBC?
[6]?

1 Introduction

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

- stock assessment simulation is…
- stock-assessment simulation is a critical component to evaluating stock assessment methods and understanding their strengths and weaknesses. …
- 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) truths and assessments
- refs: Hilborn and Walters (1992) among others; recent papers on stock-assessment simulation

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

- Stock synthesis is a modelling framework… Integrated analysis — models population dynamics using a wide range of data (Maunder and Punt, 2012)
- SS3 is the 3rd version of the software using this framework
- SS software ref: Methot and Wetzel (2012)
- ADMB software ref: Fournier et al. (2012)
- Importance of integrated analysis with SS as an example: Maunder and Punt (2012)
- most widely used now world wide (?) and especially on West Coast of United States
- facilitates rapid, reproducible analyses… focus on peer-review of the science 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 simulation models to ask specific questions, and how to translate models and questions across stocks and species. [Maybe delete this or go into how most solutions are GUI right now]Further, while the statistical software R has become the standard for data analysis and visualization, and the stock-assessment framework Stock Synthesis is increasingly the standard for fisheries

stock assessment, we lack a generalized framework to link the two in a simulation context.

In this paper we introduce ss3sim, a software package for the popular statistical programming language R that facilitates large-scale, rapid, and reproducible stock-assessment simulation with the widely-used SS framework. We begin by outlining the general philosophy of ss3sim, and describing its functions. Then, to demonstrate 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 and interpretation of the output. Our example includes considerations for setting up operating and estimation models, choosing a folder structure, model testing, and output manipulation and plotting. We conclude by discussing how ss3sim complements other stock assessment simulation software and outlining research questions our accessible and general SS simulation framework could address.

2 The ss3sim framework

2.1 Terminology

Throughout this paper we refer to a number of terms which we defined here. We use 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 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 *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 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 *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 all scenarios and iterations.

2.2 General philosophy

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. 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 easier to understand and less error-prone. ss3sim than keeps all SS3 output files as well as generating its own log files along the way for documentation.

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 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 provided functions or their own tools.

To be rapid, ss3sim relies on SS3, which uses ADMB as a backend optimization platform — the most rapid and robust optimization software available today. Further, we built ss3sim so that it is easy to deploy across multiple computers or multiple 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 therefore more likely to detect errors quickly and understand their models. Finally, ss3sim minimizes the amount of bookkeeping simulation code that researchers have to write so that they can concentrate on the science itself.

2.3 General structure

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 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). ss3sim works, in general, by converting simulation arguments (e.g. a given natural mortality trajectory) into manipulations of SS3 configuration files at the appropriate stage along with running the OM and EM as needed.

2.4 Low-level generic ss3sim functions

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:

1. Functions that manipulate SS configuration files. These manipulations generate an underlying "truth" (OM) and control our assessment of those models (EM).
2. Functions that conduct simulations. These functions generate a folder structure, call manipulation functions, run `SS3` as needed, and save the output.
3. Functions for analyzing and plotting simulation output.

2.5 High-level tailored ss3sim functions

- an example framework
- because it relies on manipulation of these configuration files, it's important the config files match a specific format

- general framework, because you start with your own OM and EM, and a wide variety of questions are then available through manipulations of …, …

3 An example simulation with ss3sim

3.1 Setting up the SS models

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

3.2 File and folder setup

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

3.3 Translating research questions into configuration files

- E.g. time-varying M

3.4 Deterministic model testing

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

3.5 Output analysis and visualization

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

4 Discussion

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

4.1 How ss3sim complements other generic stock-assessment simulation software

- focus on "generic" software, e.g. not software the just works for salmon simulation

4.1.1 r4ss

- Taylor et al. (2013)
- r4ss has functions to facilitate aspects of simulations, mostly focused on reading and plotting output for stock assessment
- ss3sim uses r4ss functions for some reading, writing, and bias adjustment

4.1.2 FLR

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

4.1.3 "Hooilator"

- http://fisherysimulation.codeplex.com, Windows only, GUI…, works on bootstrapped data only, therefore isn't as flexible as ss3sim. Used in:
  1. Lee et al. (2012)
  2. Piner et al. (2011)
  3. Lee et al. (2011)

4.1.4 Others?

4.2 The need for balance between generalizing and tailoring in simulation software

- maybe?
- why we developed generic low-level functions and higher level functions
- 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 functions as needed

4.3 Maybe lessons learned? From Athol's work

- importance of version control
- benefits to developing analysis within an R package

- importance of model testing
- importance of rapid visualization of output, example `shiny` or `manipulator`

4.4 Research opportunities with ss3sim

5 Acknowledgements

- funding: Fulbright Canada, NSERC, Simon Fraser University, …
- discussions and advice: André Punt, Richard Methot, Ian Taylor, James Thorson, …

6 Figure captions

Figure 1: Flow diagram of ss3sim

Figure 2: Panels with output from the example

7 Tables

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

Function name	Description
`change_f`	Changes the fishing mortality
`change_m`	Adds time-varying natural mortality features
`change_growth`	Adds time-varying growth features
`change_sel`	Adds time-varying selectivity
`change_e`	Controls what and how parameters are estimated
`change_lcomp`	Controls how length composition data are sampled
`change_agecomp`	Controls how age composition data are sampled
`change_index`	Controls how the fishery and survey indices operate
`change_rec_devs`	Substitutes recruitment deviations

`change_retro`	Controls the number of years to discard for a retrospective analysis
`run_ss3sim`	Master function that runs an ss3sim simulation
`run_fish600`	Wrapper function that facilitates one particular simulation setup
`get_results_all`	Extract results from a series of scenarios
`get_results_scenario`	Extract the results for a single scenario
`plotting functions!!`	Plot the output…

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

8 References

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 statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software, 27: 233–249.

Hilborn, R. W., and Walters, C. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty. Chapman and Hall, London.

Hillary, R. 2009. An introduction to FLR fisheries simulation tools. Aquatic Living Resources, 22: 225–232.

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 development of management strategies. ICES Journal of Marine Science, 64: 640–646.

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 simulation analysis based on twelve stock assessments. Fisheries Research, 109: 89–94.

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?. Fisheries Research, 125–126: 254–261.

Maunder, M. N., and Punt, A. E. 2012. A review of integrated analysis in fisheries stock assessment. Fisheries Research, 142: 61–74.

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

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

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

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/.