Stock Synthesis Completes the Cycle: Assessment - Management Quantities – Projections – MSE

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Outline

- SS history
- SS overview
- SS example – focus on recruitment bias adjustment
- Reference points
- Forecast method
- Forecast example
- MSE
- Wrap-up

SS History – 1984 - LaJolla

- Why "Synthesis"?
  - Whole is greater than sum of parts
- Specific model for California anchovy
  - Low F, diverse data
  - Absolute and relative abundance surveys
  - Fleets-as-areas for US and Mexican fisheries
  - Temperature effects on maturation and selectivity
  - M = f(predator abundance)
- Coded in FORTRAN, numerical derivatives with IMSL library

SS used to be concise

A deterministic description of a homogeneous, fished population with annual recruitment is as follows:

y is time (years, measured quarterly);
a is age (years, measured quarterly);
t is type (here, U.S. or Mexican fishery);
$P(y,a)$ is the age-specific abundance;
$P(y+1,a+1) = P(y,a)e_{-Z(y,a)}$
is survivorship; (1)

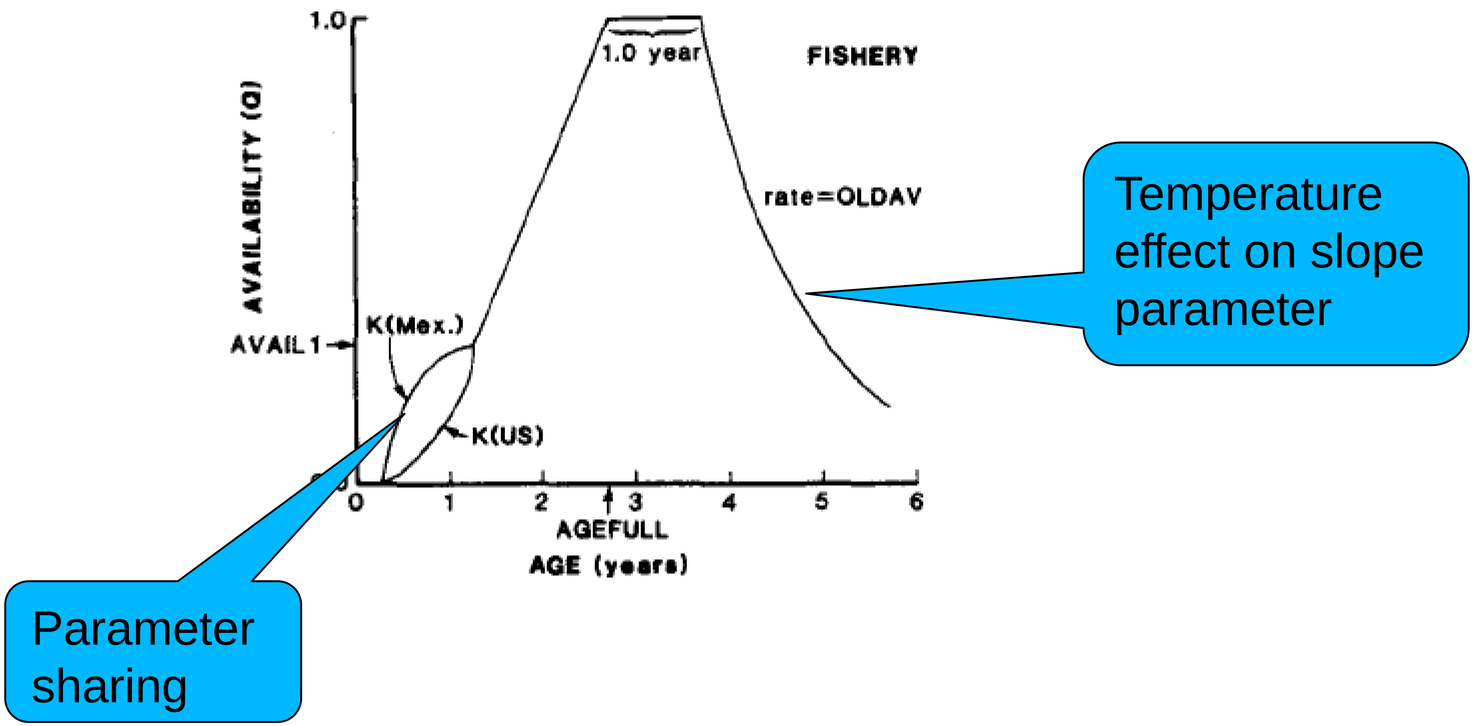
$P(y,0) = R(y)$ is the recruitment in year y; (2)

$$C(y,a,t) = P(y,a)\frac{F(y,a,t)}{Z(y,a)}[1\text{-}e^{-Z(y,a)}]$$
is catch at age; (3)

$$Z(y,a) = M + \sum_{t=1}^{2} F(y,a,t)$$ is total mortality; (4)

M is natural mortality;
$F(y,a,t) = E(y,t)\,Q(a,t)$ is fishing mortality; (5)
$E(y,t)$ is nominal fishing effort;
$Q(a,t)$ is age-specific availability.

Dome-Shaped Selectivity



Ageing Error

Age-Determination Variability

Variance in age determination cannot be avoided and has the effect of smearing the sampled age composition as it becomes the observed age composition. A small misaging percentage, say 10%, has little effect on a good year class, but could double the apparent abundance of an adjacent small year class. In the SS model, the per-

Likelihood & Data-Weighting

Relative Emphasis on Data Types

The overall log-likelihood function, L, is a weighted sum of the log-likelihoods for each type of data (four age-composition types, three abundance types):

$$L = \sum_{t=1}^{7} \mathrm{EMPHASIS}(t) l(t).$$

EMPHASIS(t) is specified by the user.

And with a whole paragraph on shortcomings of multinomial as approach for log likelihood of composition data

Estimation

The search for the best parameter values was based on quadratic hill climbing (Goldfeld and Quandt 1972), which is a modification of Newton's method, and included a Hessian matrix scaling described by Conway et al. 1970. The vectors of first (dX) and second (d^2X) derivatives of L with respect to each value of the parameter X were numerically evaluated in the region around the current estimates of the parameters ($\pm 5\%$ of X). The Hessian matrix, H, of mixed partial derivatives, which includes the d^2X on its main diagonal, also was calculated. The vectors of

approach. Each evaluation of the overall log-likelihood function, L, takes about 3 s on an IBM PC/AT computer. Convergence of the complete model takes about 4 h, even if the numerous mixed partial derivatives are recalculated only when the absolute value of the previous estimate of CORR (i,j) was greater than a uniform random value (0–0.3). Second derivatives and large mixed

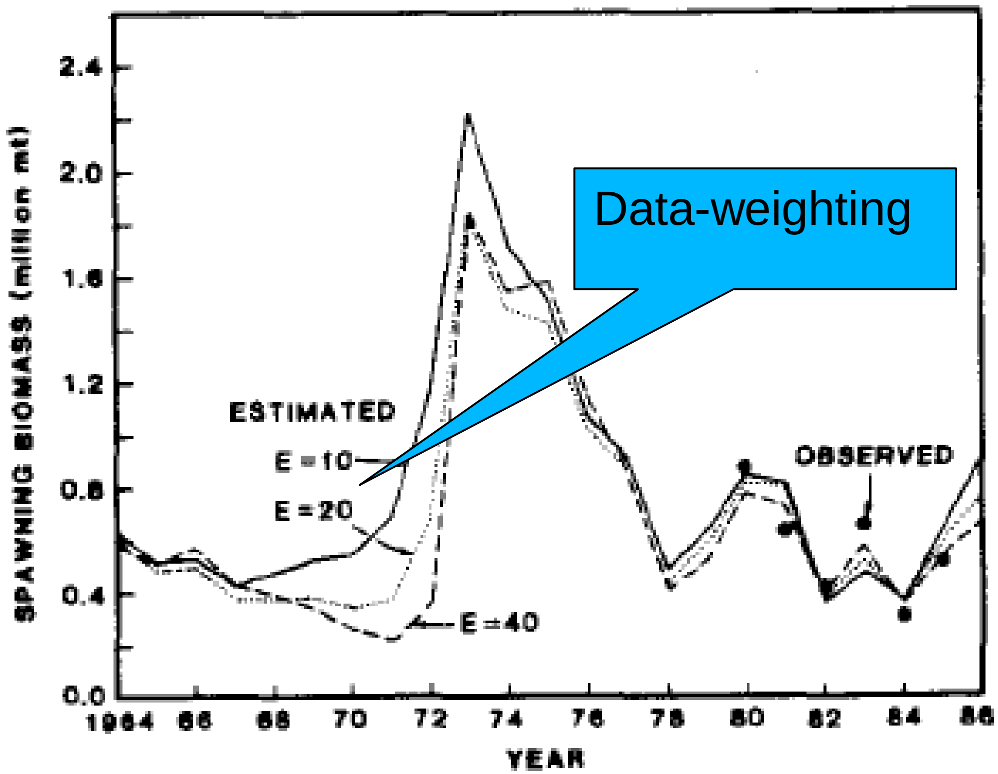
ADMB does not use the Hessian during estimation, so creeps along ridges

Model complexity has increased and "tolerable" runtimes remain about the same

Built by hand in a workshop at LaJolla

Sparse matrix approach

Anchovy SS Results



SS History – 1988 - Seattle

- **Two generalized models coded in FORTRAN**
  - SYNL: Size-age structured, allows size and age selectivity, estimates growth parameters
  - SYNA: Age-area structured, empirical body weight input, age selectivity, allows multiple areas with estimable movement rates
- **Target species: west coast groundfish**
- **Long-lived, some 50+ yr old fish still in data**
- **Weak historical data, except catch, but discarding significant**
- **More size data than age data; ageing imprecise and biased**

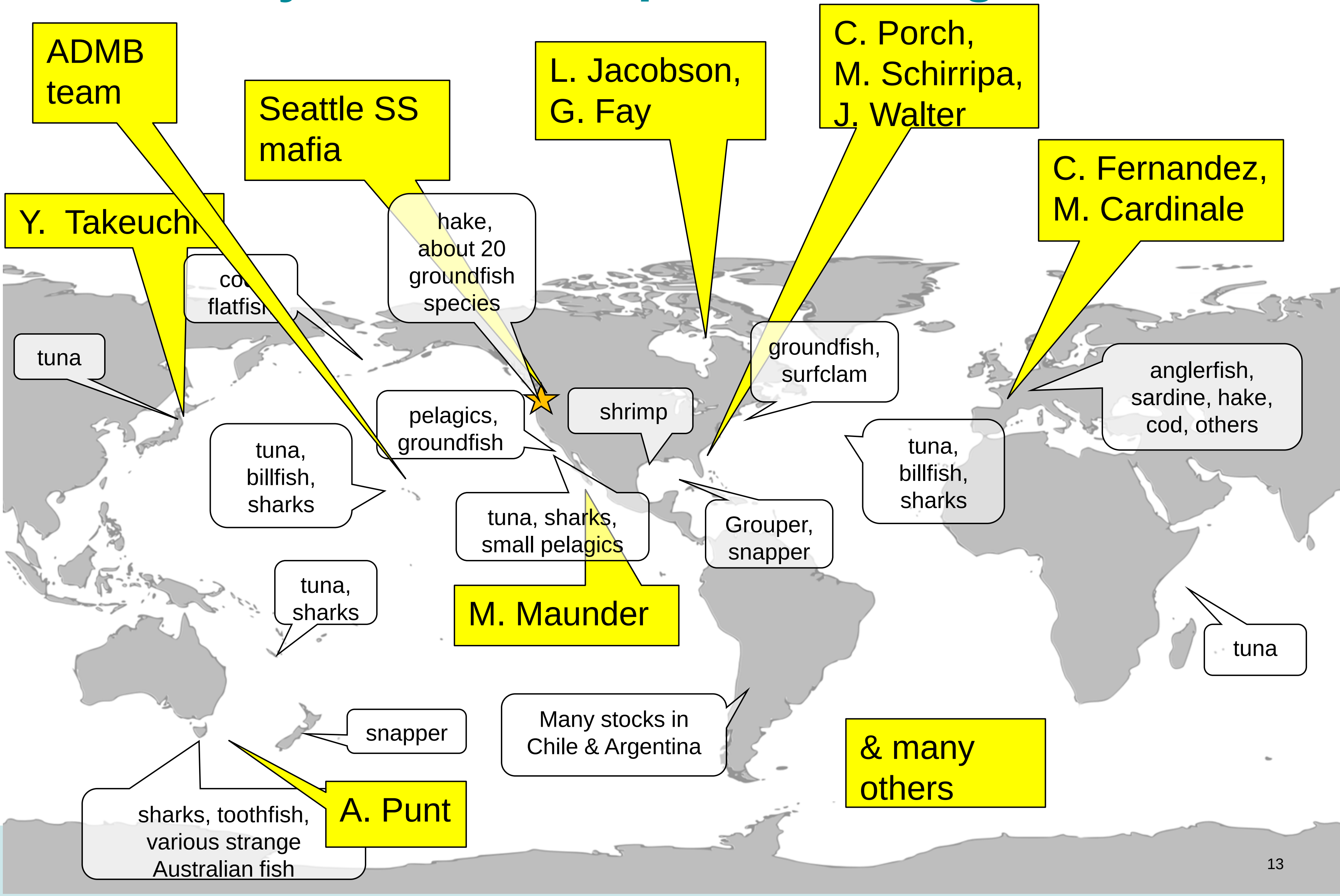
SS History - The 1990's

- Expansion to most U.S. Pacific coast groundfish by mid-1990s – rockfishes, flatfish, hake, sablefish
- ADMB custom models begin to show up
- I became supervisor, so development stalled

SS History – 2003+

- **No longer a supervisor**
- **Generalized model coded in C++ with ADMB**
  - codename: Isabel
  - Based on Cope et al Cabezon model
- **Merged and expanded features for age/size/area**
- **R4ss created**
- **IATTC-Maunder, CSIRO-Punt, SEFSC-Porch teams achieve self-sufficiency**
- **High SS usage in Univ. Washington graduate education**

Stock Synthesis Diaspora & Evangelicals



SS Today

- Continued expansion in use, probably >100 stocks
- SS Team: 1.5 contractors plus high contribution from several NWFSC staff
- Two development grants (postdoc and contractor)
- 2-3 workshops per year; webinars
- NOAA VLAB is a repository for code development and for community communication
- GUI and R tools
- Continued augmentation with 2-3 releases per year

What's in SS Today?

Stock Synthesis

Navigation Menu

- Home
- SS Document Library
- Useful Links
- Announcements

Search

Web Content Display

Welcome

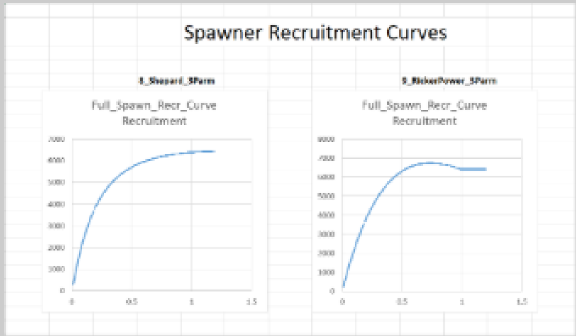
Greetings from the Stock Synthesis (SS) Development Team:

Stock Synthesis (SS) is an age-structured population dynamics model that is used to assess the impact of fisheries on fish and shellfish stocks while taking into account the influence of environmental factors.

The SS executables and most associated resources are **publicly available;** no registration is required. Below are links to the publicly available resources in the Document Library.

1. BEGIN HERE – Introduction to Stock Synthesis: This has many resources to introduce new users to SS.
2. Latest SS Executables: Includes the latest SS release executables, a folder containing post-release fixes, and the latest version of SSI (i.e., Stock Synthesis Interface or the SS GUI). SSI is a useful tool for modifying SS input files and running SS models.
3. SS Examples: Example SS models for users.
4. Documentation: SS user manuals (including older versions) are available here.

Media Gallery



Stock Synthesis – VLAB Link:

https://vlab.ncep.noaa.gov/web/stock-synthesis/home

Sub-Models of SS

- **Population Model**
  - Recruitment, mortality, growth
  - Age or age-size structured
- **Observation Model**
  - Derive expected values for data
- **Likelihood-based Statistical Model**
  - Quantify goodness-of-fit
- **Algorithm to search for parameter set that maximizes the likelihood**
  - Auto-Differentiation Model Builder (ADMB)
- **Cast results in terms of management quantities**
  - Reference points and projections
- **Parameter uncertainty cast onto results and management quantities**
- **Parametric bootstrap**

Stock Synthesis Population Model

NUMBERS-AT-AGE

Bio_type: gender x settlement time x growth pattern;

"platoons" can be nested within to achieve size-survivorship

RECRUITMENT

E(recruitment) = fxn(global female reproductive output);

Environ. effects & regime shift;

apportioned among bio_types, areas, and platoons;

Forecast recruitments are estimated, so get variance

AREA

Recruits are distributed among areas;

Age-specific movement between areas;

Natal bio_type conserved

FLEET / SURVEY

Length-, age-, sex selectivity

CATCH

F to match observed catch;

Catch partitioned into retained and discarded, with discard mortality

PARAMETERS

Can have prior/penalty;

Time-vary as time blocks, penalized annual deviations, or a function of input environmental data

Stock Synthesis Observation Model

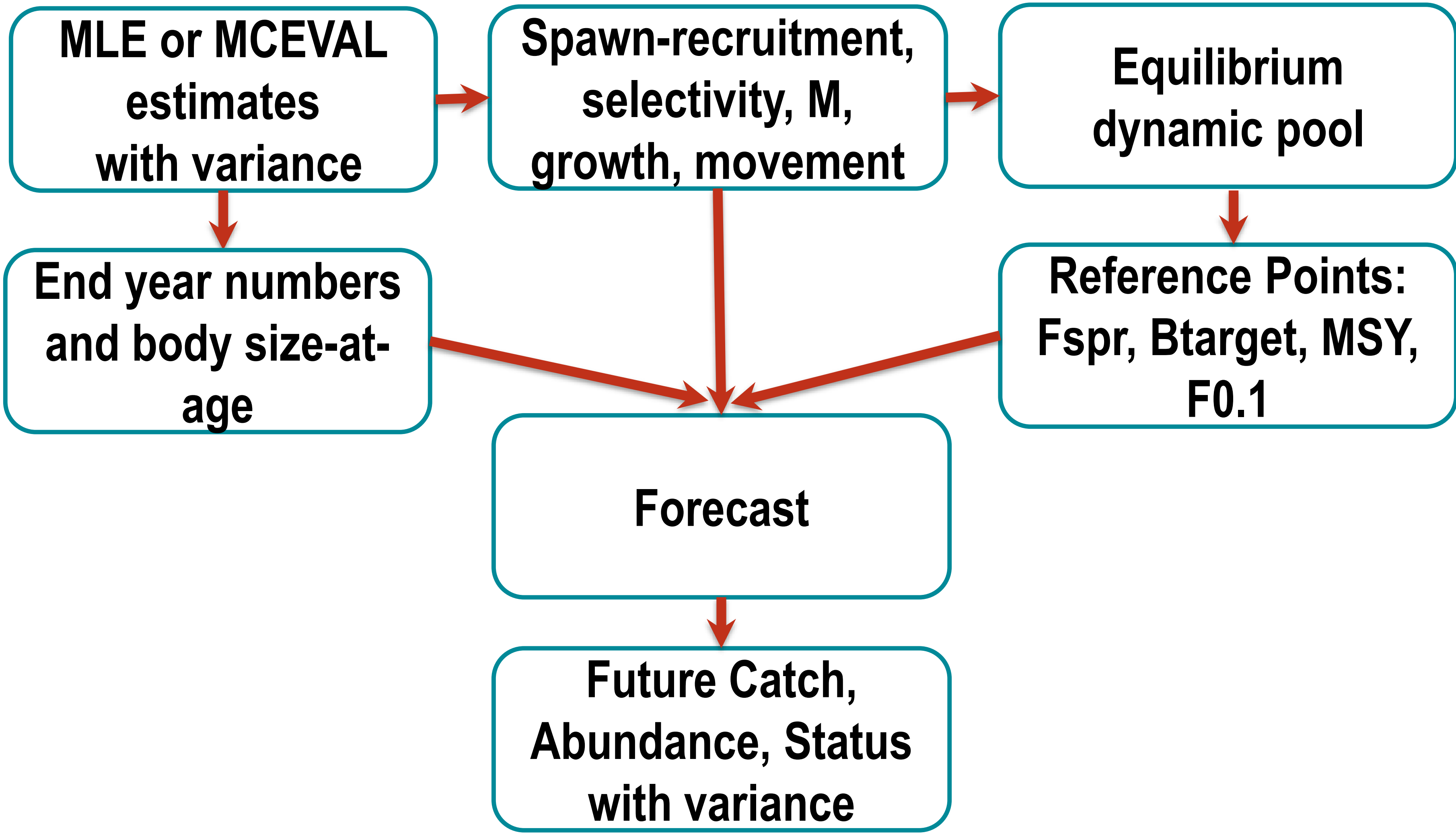
- Catches, with “q”
- Discards

- Absolute abundance
- Guesstimate on depletion

- Index of abundance
- Index of effort
- Index of random effect
- Average weight, average length
- Tagging

- Catch-at-age with ageing imprecision and bias
- Catch-at-length
- Generalized weight or length composition
- Age-conditional-on-length
- Average length-at-age, average weight-at-age

Pathway from Estimation to Forecast

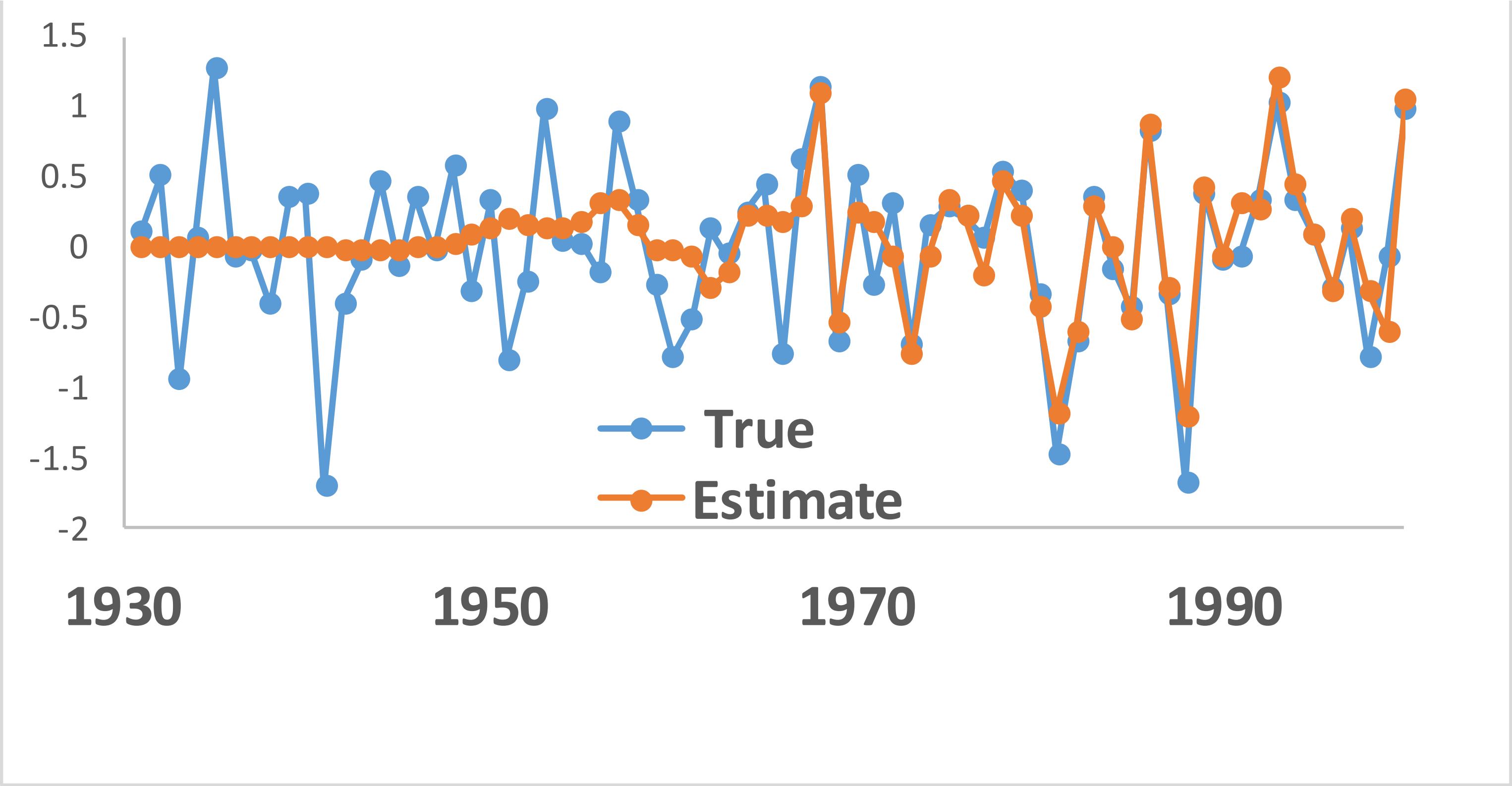


Generate a SS Example

- SS as OM simulates population beginning 1931 with known time series of recruitment deviations
- non-catch data generated by parametric bootstrap beginning in 1971
- SS as EM estimates spawn-recruitment curve, growth, selectivity and recr_devs
- Let’s focus on the estimates of recruitment

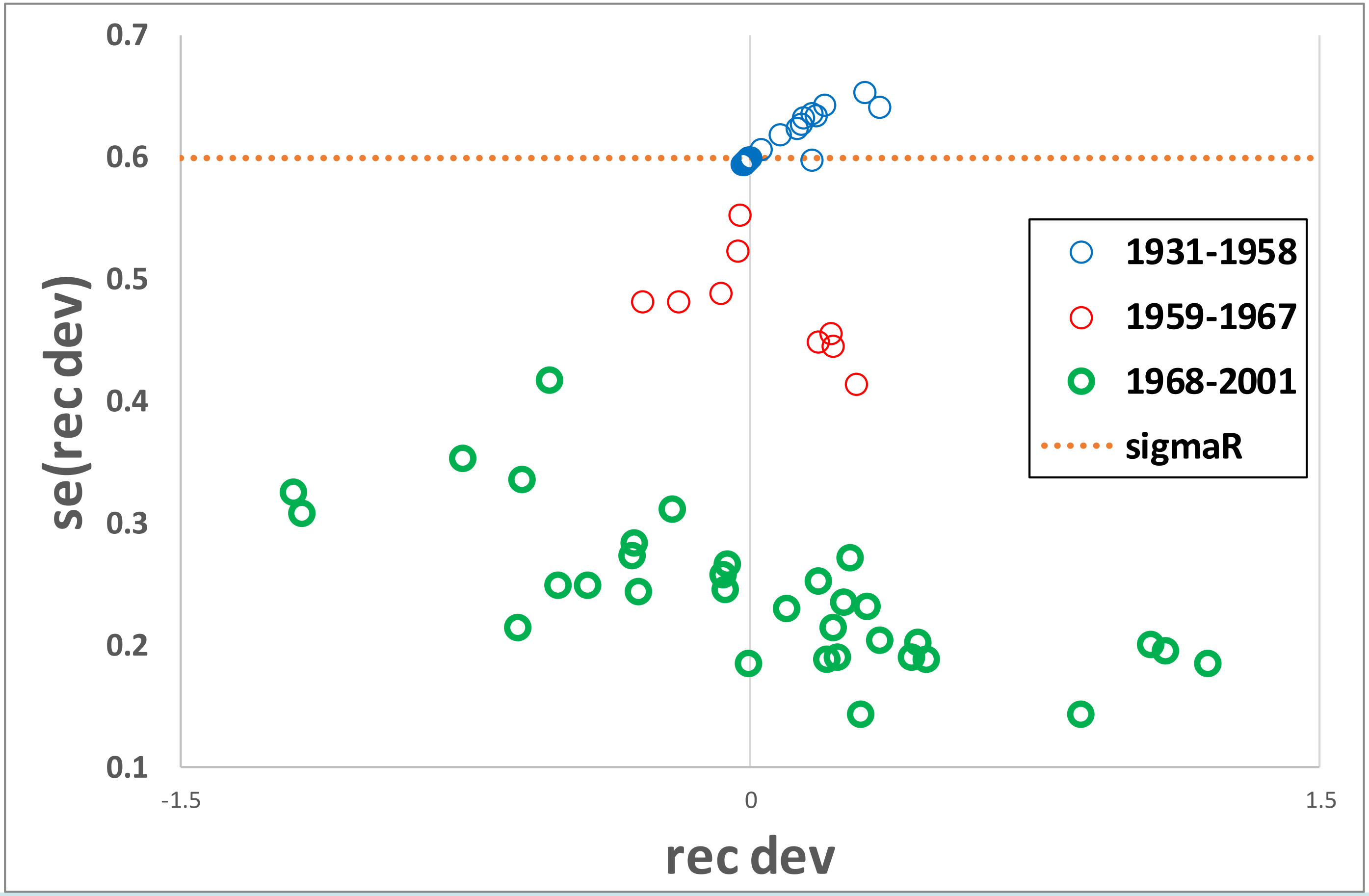
Recruitment Estimates

Estimated recr_devs are near zero until data become informative



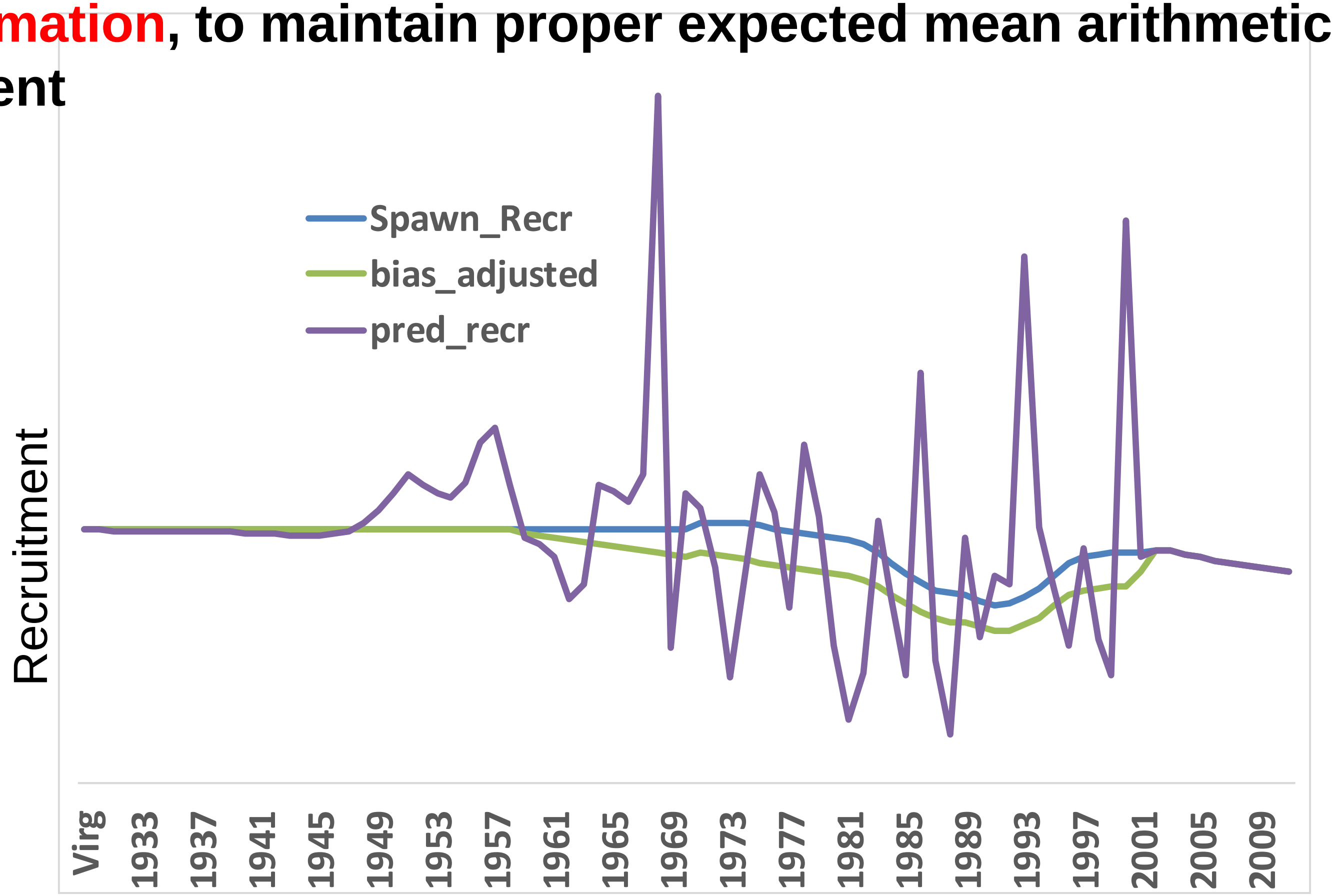
Estimated Variance of Recr_devs

- StdErr(recr_dev) depends on information in the data, so declines over time
- Aside: strong recruitment estimated more precisely (log-scale) than weak



Recruitment Bias Adjustment in SS

Early, uninformed deviations must have less bias adjustment, in MLE estimation, to maintain proper expected mean arithmetic recruitment



Shift Gears to Equilibrium Calculations and Reference Points

SS' Equilibrium Calculator

- Operates per recruit with recruits allocated among partitions for area, sex, bio_patterns, platoons, settlement times
- Selectivity, movement, other processes applied identically as in the time series
- Do calculations out to 3*maxage, then accumulates back to maxage
- Limitation – cannot implement area-specific spawner-recruitment if fish move between areas*

*Relative recruitment between areas cannot depend on relative spawning biomass per area

Find Reference Point F's

- Calculations does YPR and SPR and dynamic pool using same per-recruit routine as is used for initial equilibrium
- User control on relative F among fleets
- User control on range of years to average for biology, spawn-recruit parameters, selectivity, etc.
- Iterative search over fixed number of iterations to find:
  - F_{SPR}, $F_{BTARGET}$, $F_{0.1}$, F_{MSY}
  - Results stored with variance
- Do Kobe plot and Dynamic Bzero
- Also do global MSY search for each age of knife-edge selectivity

Reference Point Calculations

	B31%		SPR_42%		MSY	
	value	se	value	se	value	se
SSB	15642	1914	15476	4377	16336	5144
SPR	0.423	0.095			0.435	0.150
F	0.245	0.091	0.248	0.005	0.235	0.137
Catch	6907	1827	6904	1955	6913	1773
Catch_retained					6913	1773
B_MSY/SSB_unfished					0.326	0.069

Three Stages of Forecast

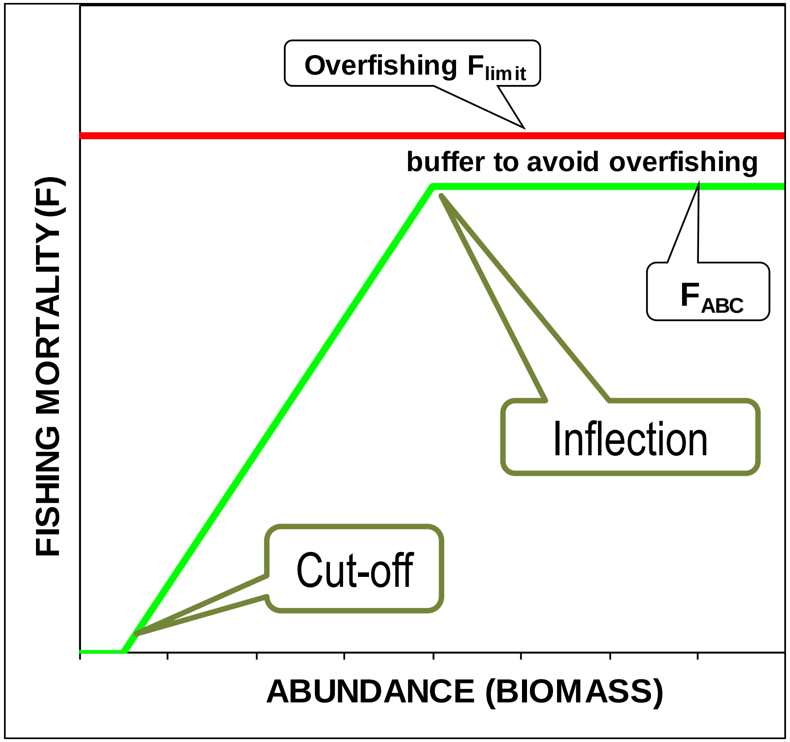
- Stage 1 – calculate annual catch limits
- Stage 2 – calculate annual catch targets
- Stage 3 – calculate effect on stock of catching the catch target

Stage 1 of Forecast

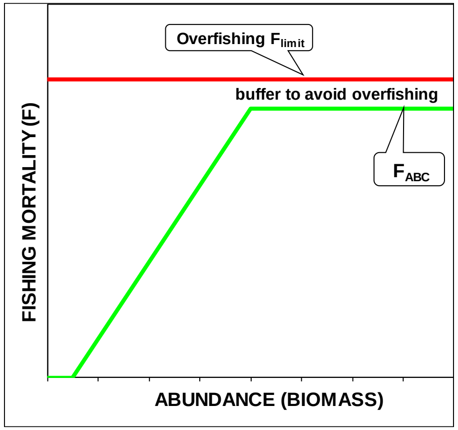
- Find annual catch limits
  - F = Flimit (based on user choice of Flimit basis)
  - No recruitment deviations (usually)
  - Cohort length-at-age continues to propagate into future according to annual growth parameters

Harvest Control Rule

- Buffer is specified as fraction of Flimit
- Buffer can be time-varying
- Inflection and cut-off
- Various options for how ramp is applied
- Easy to create more regional variants



Stage 2 of Forecast



- Find annual catch targets
  - Harvest control rule applied
  - As modified by:
    - fixed input catches or F's, allocations constraints; rich feature set here
  - Various options for expected recruitment
  - No recruitment deviations applied because you do not know future deviations
  - Store fleet-specific catches as a time series of future quotas

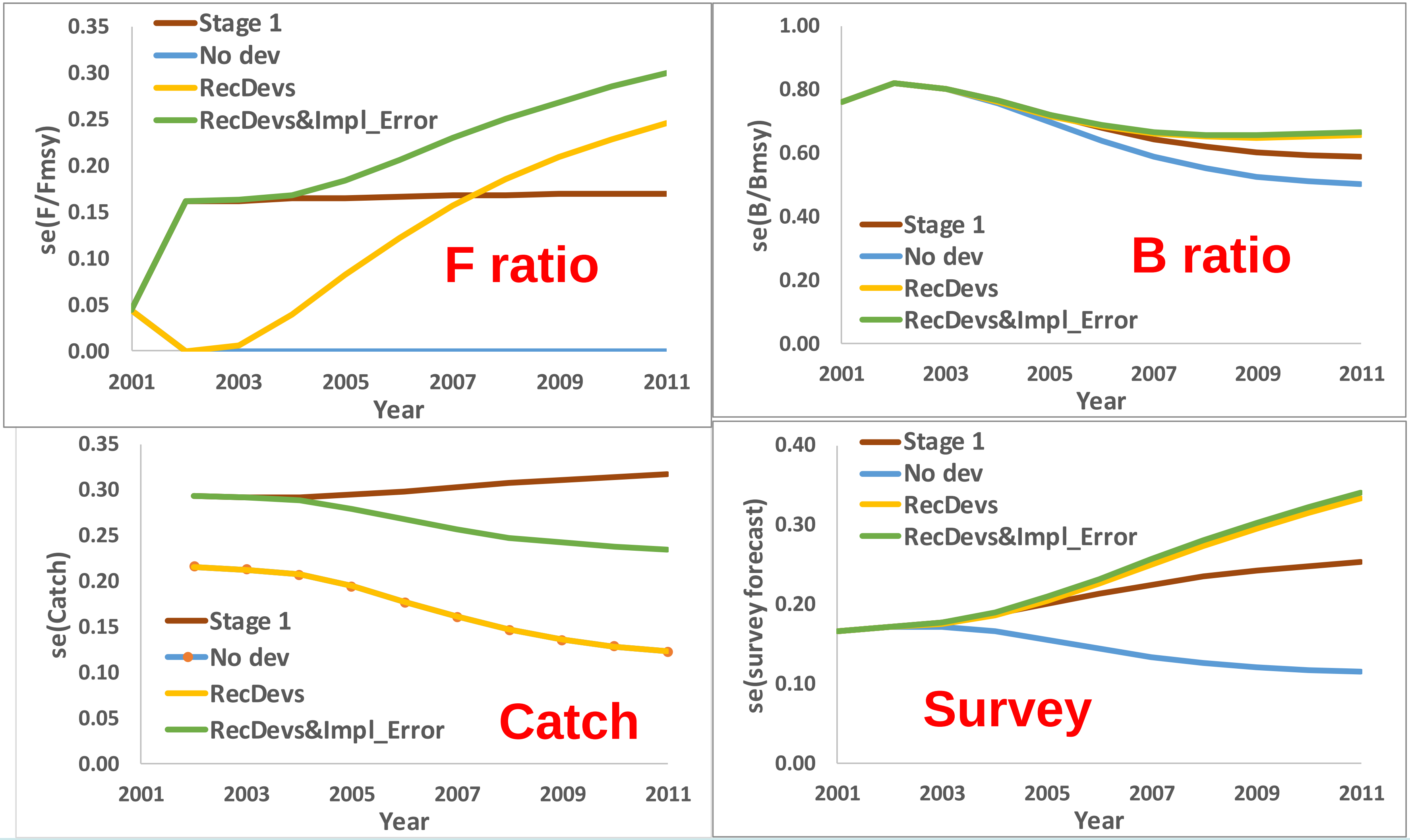
Stage 3 of Forecast

- Calculate effect on stock of catching catch target
  - Use stored quotas from stage 2
  - Turn on stochastic recruitments and implementation error on the catches
  - Environmental effects and other time-varying parameter effects are active***
  - Calculate future F and Biomass
  - Express as ratio of F/Fmsy and B/Bmsy with variance
  - Use variance to calculate annual Pr(overfishing) and Pr(stock at target)

Demonstrate Forecast – 4 Scenarios

- **No Devs** – equilibrium forecast
- **Recr Devs** – recalculate with recr devs after setting future quotas using equilibrium
- **Recr Devs & Impl Error** – add 20% implementation error
- **Stage 1** – Introduce active recr devs in first stage when calculating OFL (e.g. prescient); & 20% implementation error

Forecasting Results at 75% of Fmsy



Next Step: Management Strategy Evaluation

- Forecast module's feedback is a mini-MSE
- In full MSE with feedback SS can be the OM and/or the EM
  - At least three examples, hake, halibut, albacore
  - Project to connect SS as OM to FLR as EM
- New project underway to take lessons from above and build, with R, a generic MSE wrapper for SS
  - Upcoming talks by S. Sagarese and N. Vaughan

Summary - Benefits of Stock Synthesis

- **Flexible set of population processes**
- **Allows diverse data**
- **Propagates uncertainty well**
- **Seamless from data-limited to complex**
- **Widely used: research and assessment**
- **R tools – r4ss, ss3sim, SSS, diagnostics**
- **Evolving based on decades of development and exploration**

Shortcomings of Stock Synthesis

- **Large and complex code**
- **Single primary developer**
- **Growth overhead penalizes speed for all**
- **Inelegant input**
- **No random effects; only penalized devs**
- **Not multi-species; only predator as fleet**
- **Not highly spatial; 2-6 is feasible**
- **Too many options; not enough guidance**

Stock Synthesis – Looking Ahead

- Continued support for user community
- “Minor” augmentations of features
- More rigorous testing of model changes
- Research on good practices for model approaches
- Consultations with next gen model developers

Resources

- Stock Synthesis – VLAB Link:
  https://vlab.ncep.noaa.gov/web/stock-synthesis/home
  - Github.com/r4ss/r4ss
  - Github.com/ss3sim/ss3sim