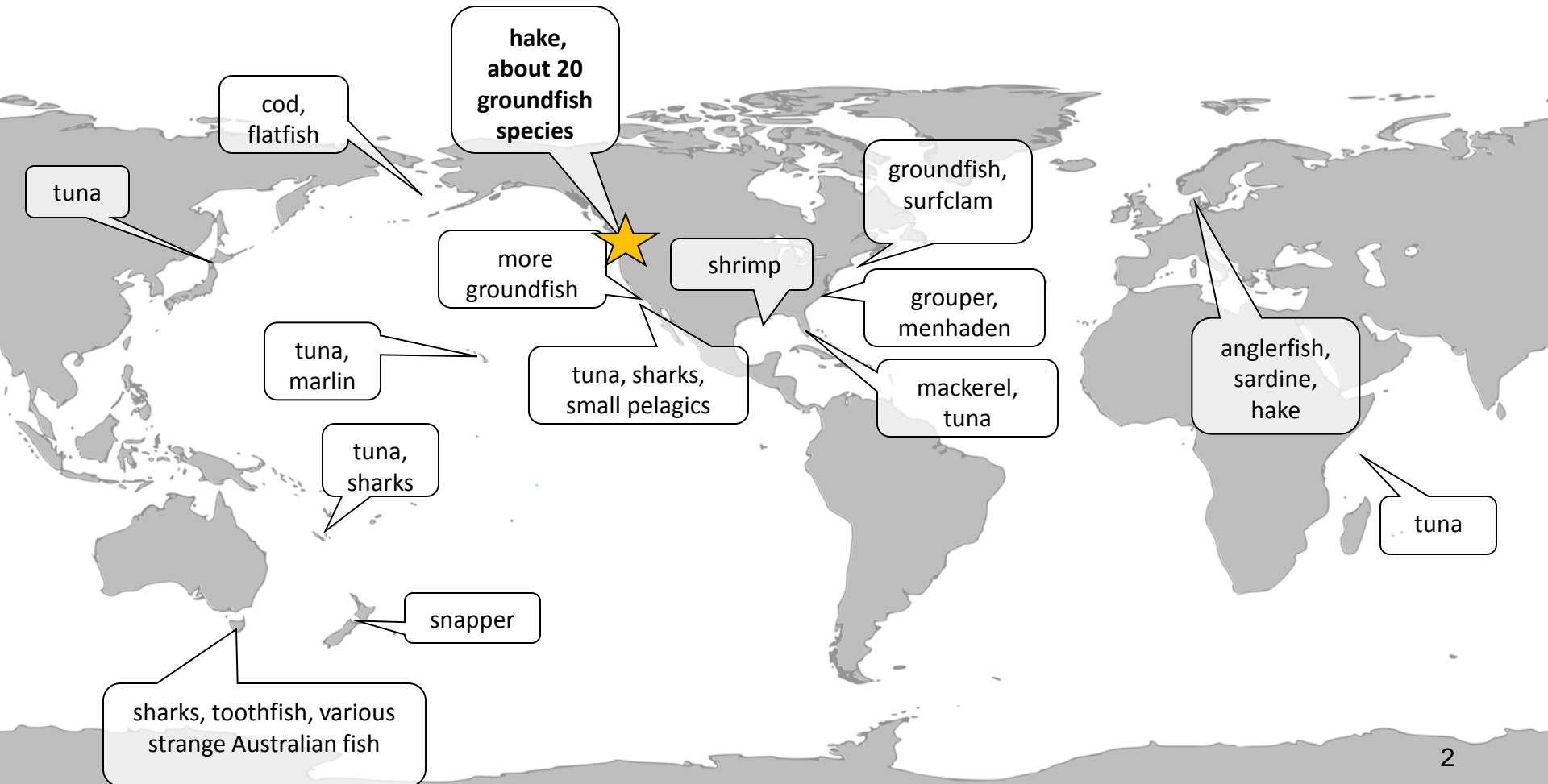


# STOCK SYNTHESIS: Integrated Analysis of Fishery and Survey Size, Age, and Abundance Information for Stock Assessment

Modified from Richard Methot  
NOAA Fisheries

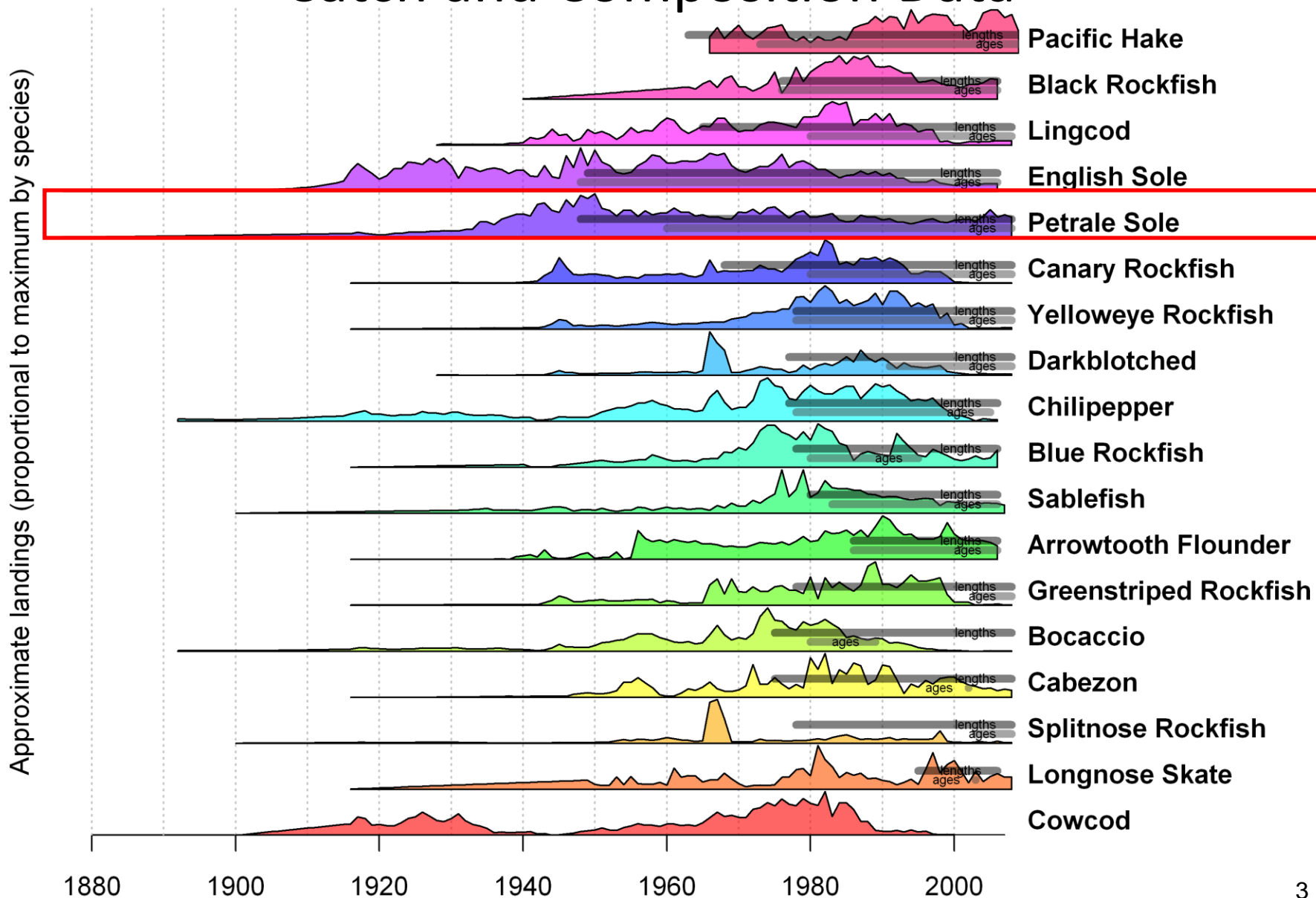
# Stock Synthesis usage

Used to formally assess 61 fishery stocks by 2012: 35 in the US, 10 tuna/billfish stocks in three oceans, 4 European stocks, and 12 Australian stocks. Many additional exploratory SS3 applications for other other stocks underway



# Pacific Coast Groundfish

## Catch and Composition Data



# Benefits of widespread use (of any modeling platform)

- Bugs less likely to escape notice
- More comparison with other models
- More development of associated tools
  - **r4ss** for plotting
  - **ss3sim** for end to end simulation/estimation
- Facilitates sharing knowledge
  - common language among many scientists
  - more advice on building models
  - easier to understand each others' results

# Benefits of Stock Synthesis

- Flexible range of options for many population processes
- Integrates many sources of data
- Propagates uncertainty well
- Works well from very simple to very complex models
- Widely used
- Evolving based on decades of development and exploration

# History of Integrated Analysis

- Fournier & Archibald (1982) provided explicit consideration of errors and use of auxiliary information.
- CAGEAN (Deriso et al 1985) - 10s of parameters
- Stock Synthesis (Methot, 1989) -10s to 100s of parameters; FORTRAN & numerical derivatives
- AD Model Builder (late 1980s) - Computer software to build your own IA, 10s to 1000s of parameters. [www.admb-project.org](http://www.admb-project.org)
- MULTIFAN-CL (1998) - 1000s of parameters (age and size, tag recapture, movement)
- ASAP (Legault & Restrepo, 1998). A flexible forward age-structured assessment program.
- Coleraine (Hilborn, Maunder et al, 2000) – comparable to ASAP
- CASAL (Bull et. al 2004; New Zealand) C++ algorithmic stock assessment laboratory); age and size structured, tag recapture, movement
- GADGET (Begley & Howell, 2004) Globally applicable Area-Disaggregated General Ecosystem Toolbox
- Stock Synthesis 3 (Methot and Wetzel 2013) – ADMB-based; size & age based model with spatial structure, gender and growth-morphs

# Sub-Models of SS

- **Population Model**
  - Recruitment, mortality, growth
  - Age and/or 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**
- **Propagate uncertainty onto confidence interval for management quantities**

# Bring Model to the Data

- Don't transform data to meet rigid model structure
- Do add processes to model to develop expected values for diverse, lightly processed data
  - Improves understanding of processes
  - Allows simultaneous use of more types of data
  - Statistical properties of data are preserved and transferred to variance of final model results



# Tuning a Model: From Data to Results

- Result will be a complex weighted average of fit to all included data;
  - Type, contrast and precision of data determine its influence
  - Examine residuals and root mean squared error of fit to data
  - Parsimoniously, add enough process to remove pattern to residuals
  - Judicious re-weighting of inputs to make error assumptions consistent

# Data, Penalties, Priors

- Penalties and Priors are information about parameters in a model
  - Example: maximum age used to create prior on  $M$
- Data are information about a derived quantity
  - Expected value for this quantity is derived from model parameters and structure
  - Example: Age composition of catch from a fleet
- In IA, the expected value for maximum observed age could be derived as a function of  $M$ , then observed maximum age could be included as model data
- Concept of Data and Priors blur; it's all information

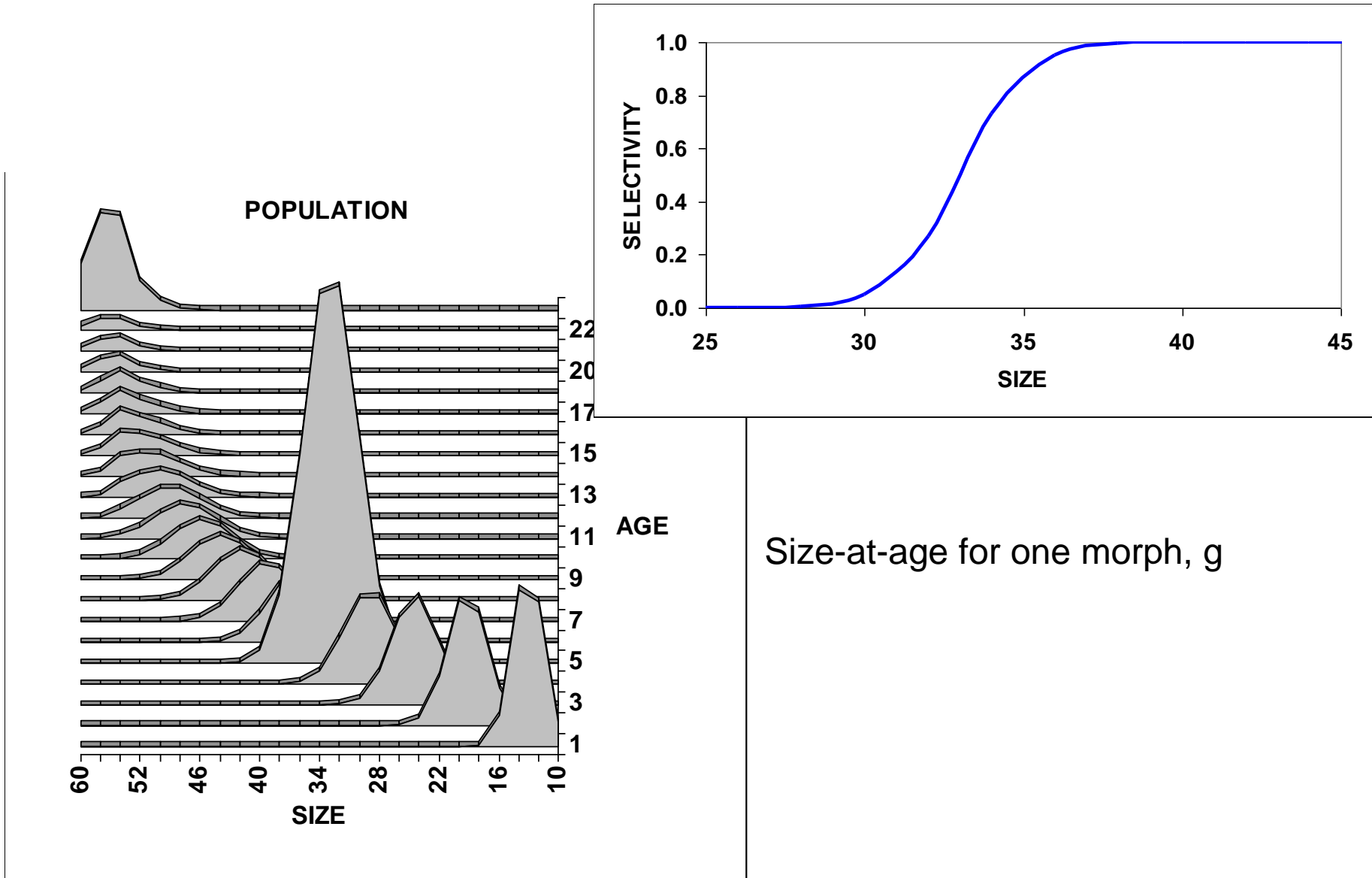
# Stock Synthesis

- An implementation of IA
- Age and size structured, with geographic areas
- High diversity of data types, including tags
- Fully integrates population estimation, benchmark calculation, and forecasting

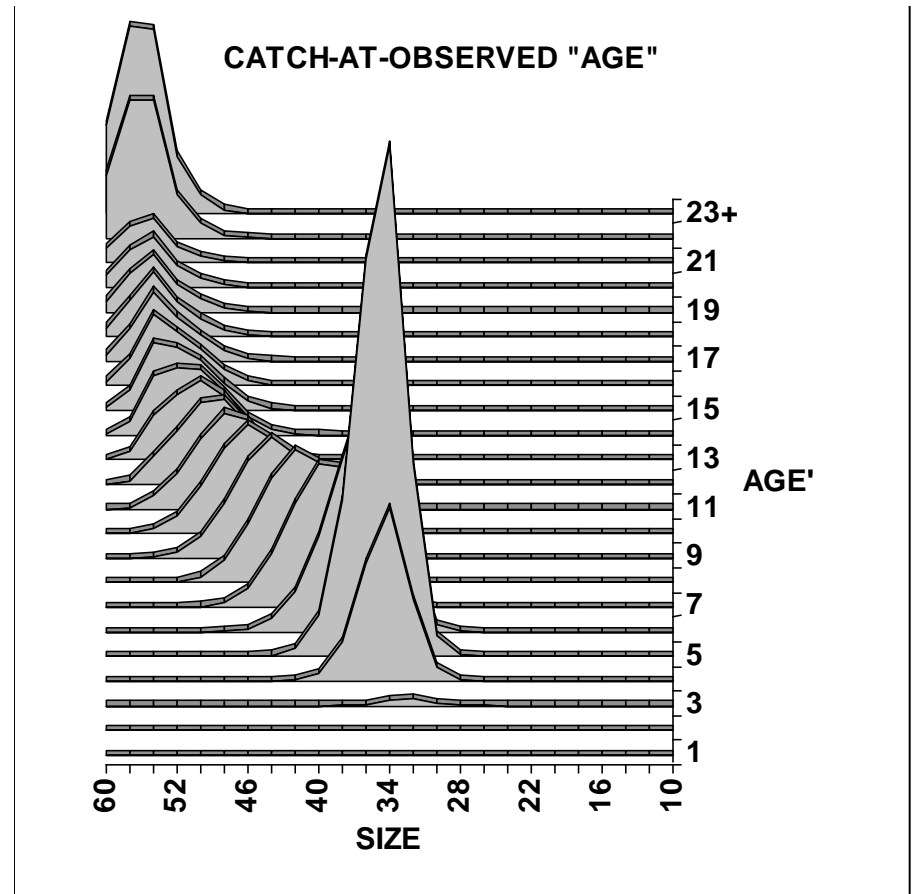
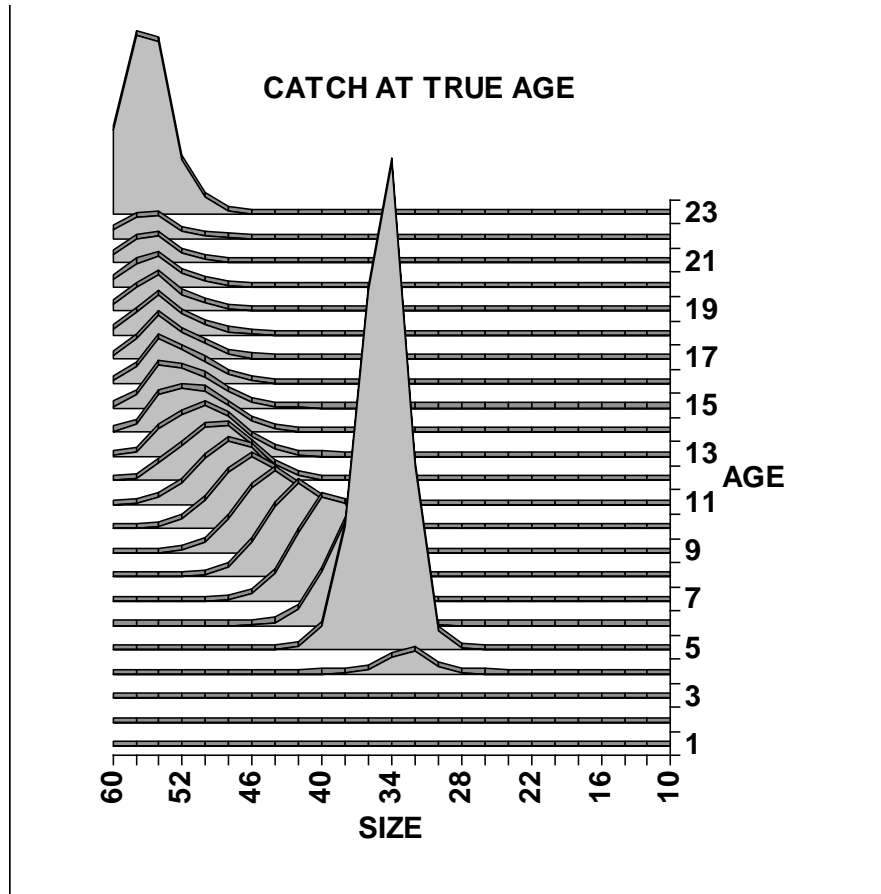
# SS Outline

- Length and age structured population
- Derived life history quantities
- Data options
- Model structural options
- Biology: M, growth, reproduction
- Recruitment
- Catchability
- Selectivity

# Age-Length Structured Population



# Sampling & Observation Processes



# Life History Quantities

- Weight-at-age not necessarily an input, although use of empirical weights available
- Mean and variability of size-at-age is calculated from growth parameters
- Normal distribution of size-at-age is parsed into size bins,  $ALK_{a,l}$
- Weight-at-length and fecundity-at-length are used to calculate the equivalent at-age quantities for the population:

$$W_a = \sum_{l=1}^n W_l * ALK_{a,l}$$

# Fishery Selectivity

- Fishery size selectivity causes unique weight-at-age for each fleet:

$$W_{f,a} = \sum_{l=1}^n W_l * S_{f,l} * ALK_{a,l}$$

- Overall fishery selectivity-at-age involves one component as a direct function of age and another as an effect of size selectivity:

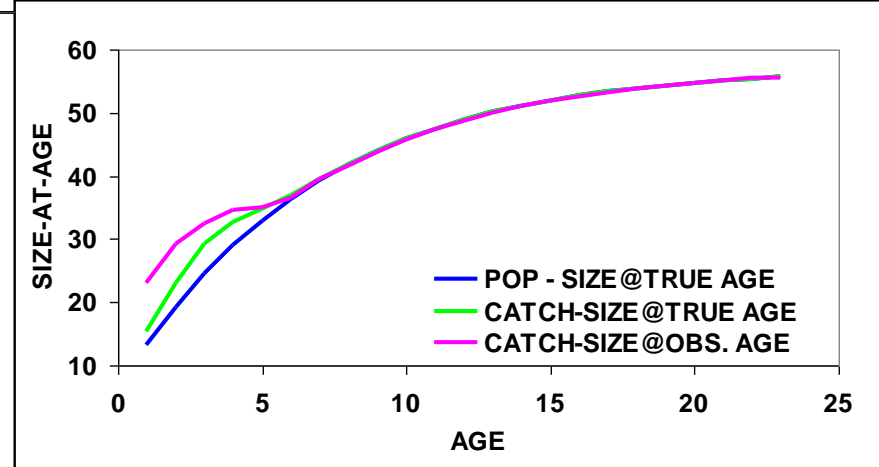
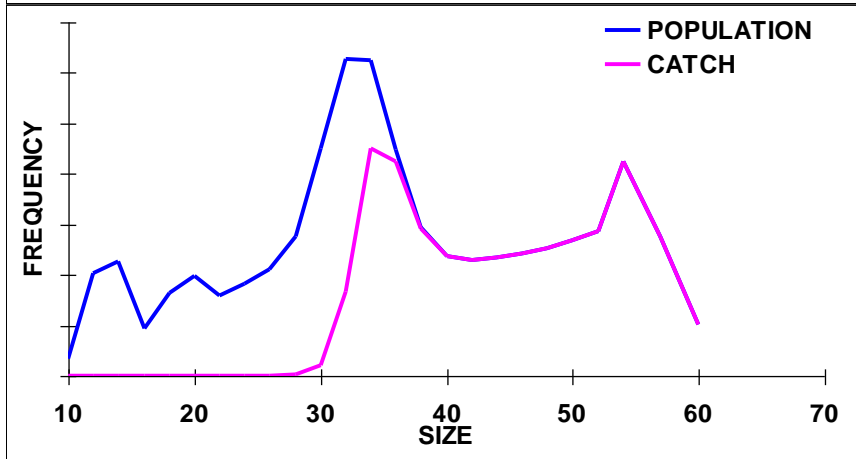
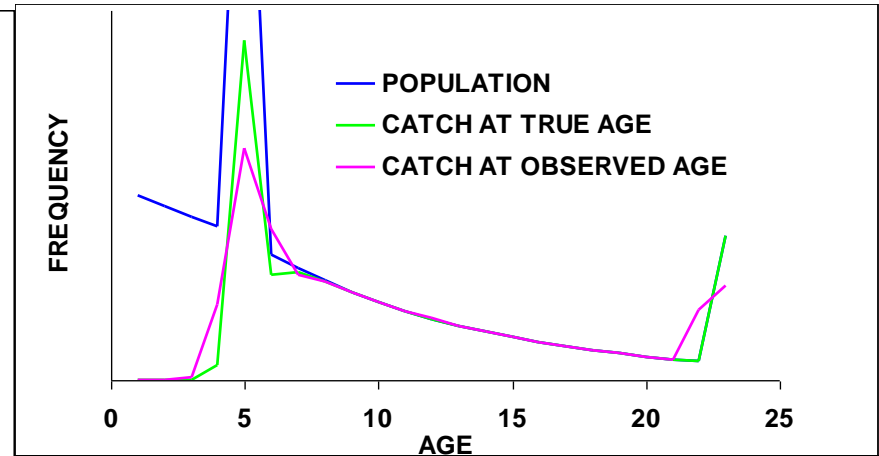
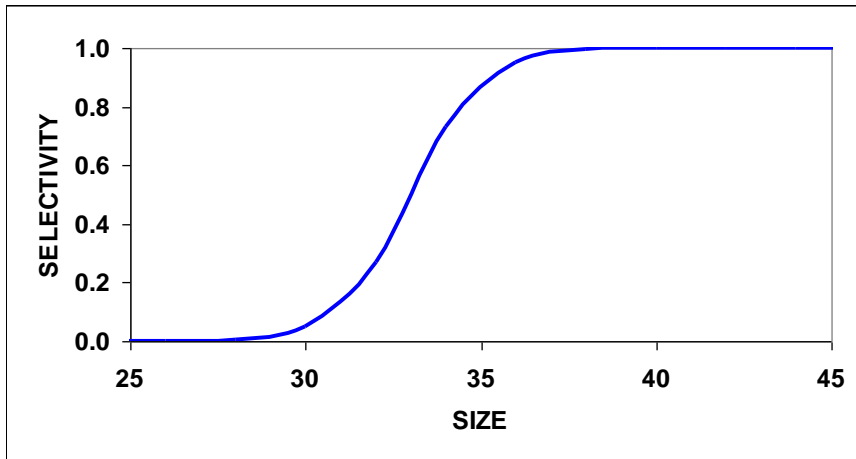
$$S'_{f,a} = S_{f,a} * \sum_{l=1}^n S_{f,l} * ALK_{a,l}$$



# Real and Perceived Quantities

- Real: Fishery body weight and selectivity are used in SS catch equations as described on the previous slide
- Perceived: If there are observations of fishery weight-at-age or length-at-age, these will take into account imprecision in the ageing process which blurs across the age dimension

# Expected Values for Observations



# Stock Synthesis Data

## **CATCH**

- Retained catch

## **ABUNDANCE**

- Fishery or survey CPUE or fishery effort

## **SPECIAL**

- Discard (% or amount)
- Mean body weight
- Tag-recapture
- Stock composition

## **COMPOSITION DATA**

- Age' composition
  - Across all lengths, or
  - Within length range
- Size composition
  - By biomass or numbers
  - Weight bins or length bins
- Mean length-at-age'
- Mean weight-at-age'

# CATCH

- Retained catch
  - Each fleet in biomass (mt) or numbers (1000s)
  - Can mix bio or num in same model
  - MSY always calculated in terms of biomass
  - Retained catch is tuning quantity because discard often has missing values
- Normally, catch cannot have any missing values and the  $F$ 's are calculated to match the observed catch
  - Except if  $F_{\text{method}}=2$  (parameters), effort data exist, nominal catch data are assigned low precision

# ABUNDANCE

- For fisheries or for surveys
- Units can be CPUE (biomass or numbers) or effort
  - Effort is considered as a survey of  $F$ , comparable to CPUE being a survey of abundance
- Error structure can be normal or lognormal (neg. binomial to come)
- $Q$  is set up later in the control file

# COMPOSITION OVERVIEW

- For fisheries or for surveys
- Multiple observations for each fleet/time allowed
- Male/female:
  - (1/2) Selected sex in 2 sex model
  - (3) Joint distribution preserves sex ratio info
  - (0) Combined male and female expected values are summed to compare to combined gender observation
- Discard/Retained/Total

# AGE COMPOSITION

- By age' bins, not by true age
- Scaled to sum to 1.0 after reading
- Error structure is multinomial, optional added constant
- Each observation specifies:
  - age-age' transition matrix to use
  - Min and max length range to use
    - Pick single size bin (row of ALK) for conditional age-at-length
    - or entire size range
  - Effective sample size (scales the variance)

Yr	Seas	Flt/Svy Number	Gender	Retain/ Discard/ Total	Ageerr	Lbin_lo	Lbin_hi	Nsamp	datavector
1971	1	1	3	0	2	-1	-1	200	<vector with female, then male data>

# SIZE COMPOSITION

- Size bins for size composition data can differ from size bins for population, but cannot be narrower
- Error structure is multinomial, optional added constant

Yr	Seas	Flt/Svy Number	Gender	Retain/ Discard/ Total	Nsamp	datavector
1971	1	1	3	0	200	<vector with female, then male data>



# GENERALIZED SIZE COMPOSITION

- Originally created for weight composition data
- Multiple “methods” can be defined
- Each has unique:
  - N bins
  - Units (kg, lbs, cm, inches)
  - Bin boundaries (in selected units)
  - Biomass or numbers accumulation
  - So, units=cm and accumulation=numbers is same as original size composition method
- Error structure is multinomial, optional added constant
- Example application: shrimp composition data in terms of tail count per pound with 7 bins

# MEAN SIZE-at-AGE

- Mean sizes are by age' bins, not true age
- Values can be in units of body length or weight
- Each age' has a sample size, N entered
- Error structure is normal, with:
- $se = \text{stddev}(\text{size-at-age}') / \text{sqrt}(N)$

# SS Structure

- Numbers-at-age for each of several “morphs”
- Recruitment =  $f(\text{SpawnOutput}) * \exp^{(\text{dev})}$
- Growth: defines normal dist. of size-at-age
- Selectivity
- Catchability
- Fishing and Natural Mortality
- Catch: can partition into discard and retained
- Areas with movement

# Numbers-at-Age

- Apportioned among biological morphs (growth patterns, birth seasons, areas) according to model parameters
- Each is split male:female with specified ratio
- Further split among sub-morphs with specified ratio
- Each retains biological characteristics when move among areas

# Stock Synthesis Data

- Retained catch
- CPUE and survey abundance

- Discard (% or total)
- Mean body weight
- Tag-recapture
- Stock composition

- Age composition
  - Within length range
- Size composition
  - By biomass or numbers
  - Within gender and discard/retained
  - Weight bins or length bins
- Mean length-at-age

# Stock Synthesis Structure

## NUMBERS-AT-AGE

Cohorts: gender, birth season, growth pattern;

“Morphs” can be nested within cohorts to achieve size-survivorship;

Distributed among areas

## RECRUITMENT

Expected recruitment is a function of total female spawning biomass;

Optional environmental input; apportioned among cohorts and morphs;

Forecast recruitments are estimated, so get variance

## AREA

Age-specific movement between areas

## FLEET / SURVEY

Length-, age-, gender selectivity

## CATCH

F to match observed catch;

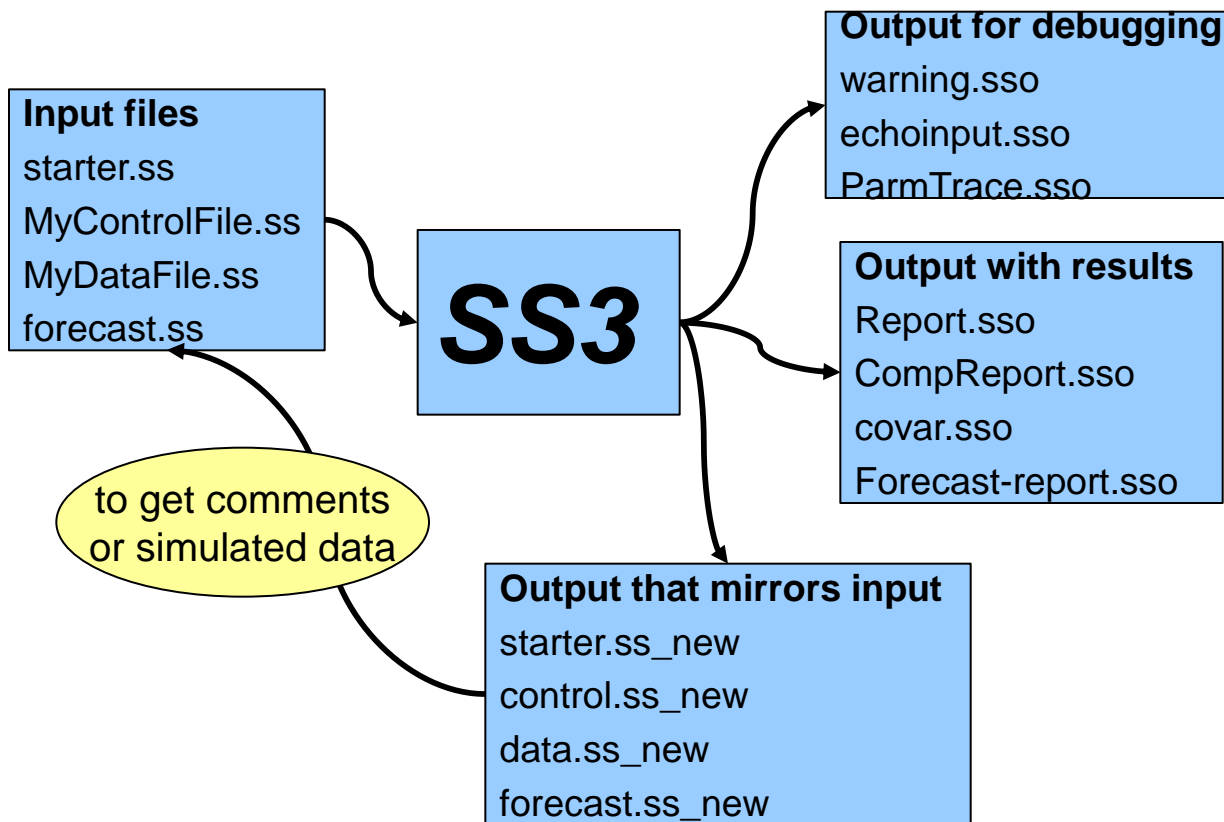
Catch partitioned into retained and discarded, with discard mortality

## PARAMETERS

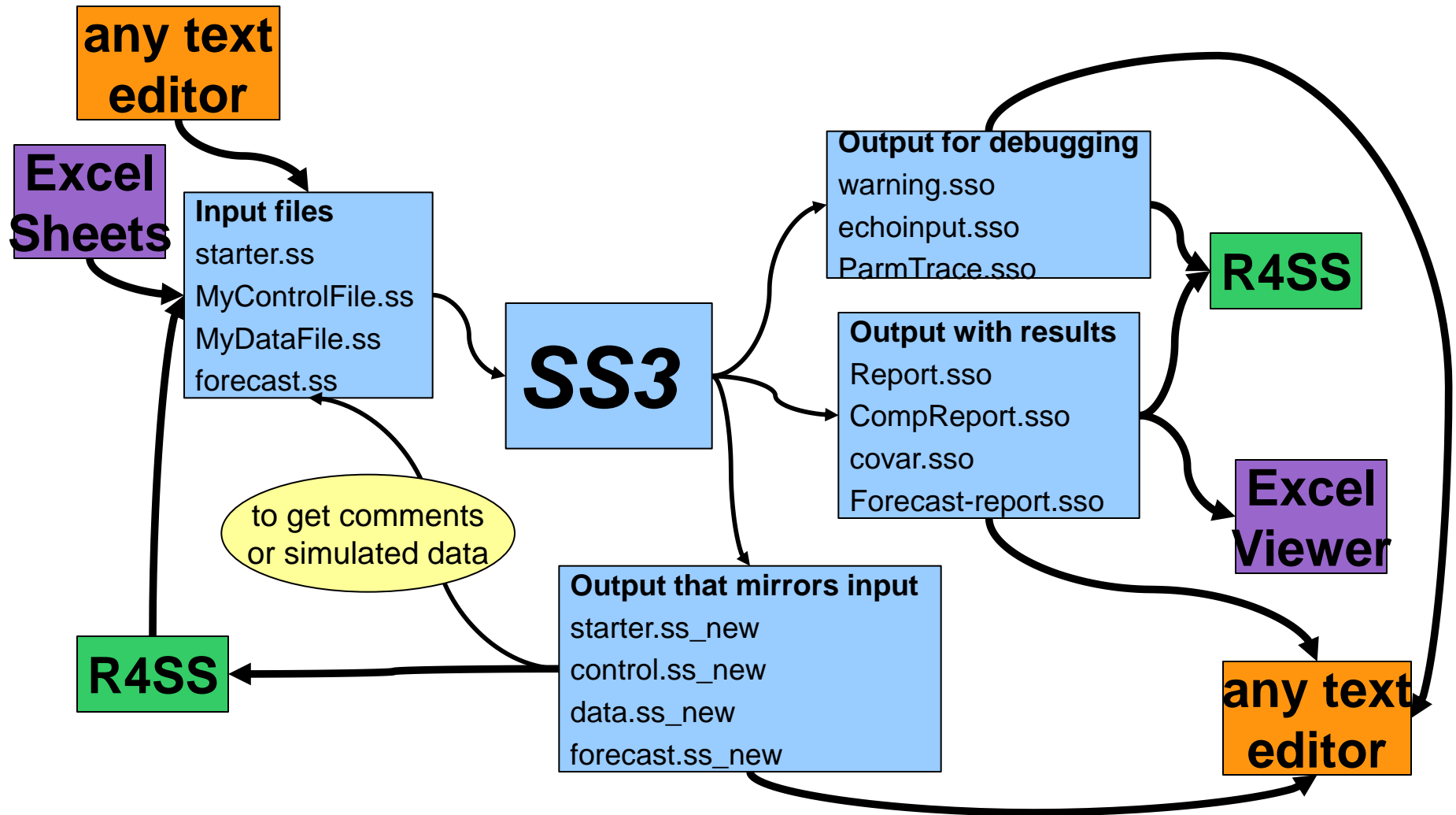
Can have prior/penalty;

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

# SS I/O & Associated Tools



# SS I/O & Associated Tools





# SS I/O & Associated Tools

