Modeling Recruitment in Stock Synthesis

extracted from presentation at

2017 CAPAM Recruitment Workshop

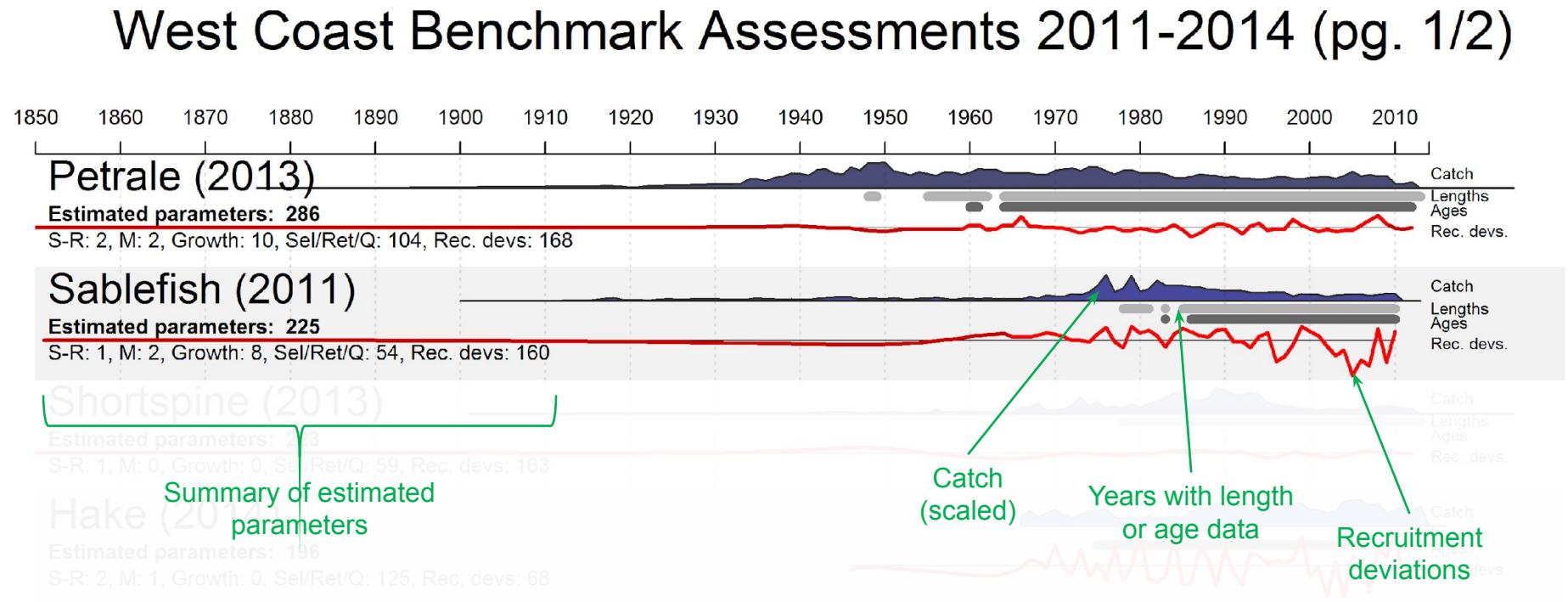
https://github.com/iantaylor-NOAA/SSrecruitment

Outline

- Big picture
- Stock Recruit Relationships
  - Beverton-Holt, Shepherd, Maunder-Taylor-Methot
- Recruitment deviations
  - Overview
  - SigmaR
  - Bias adjustment
  - Eras (Init/Early, Main, Late/Forecast)
- Apportionment of recruitment

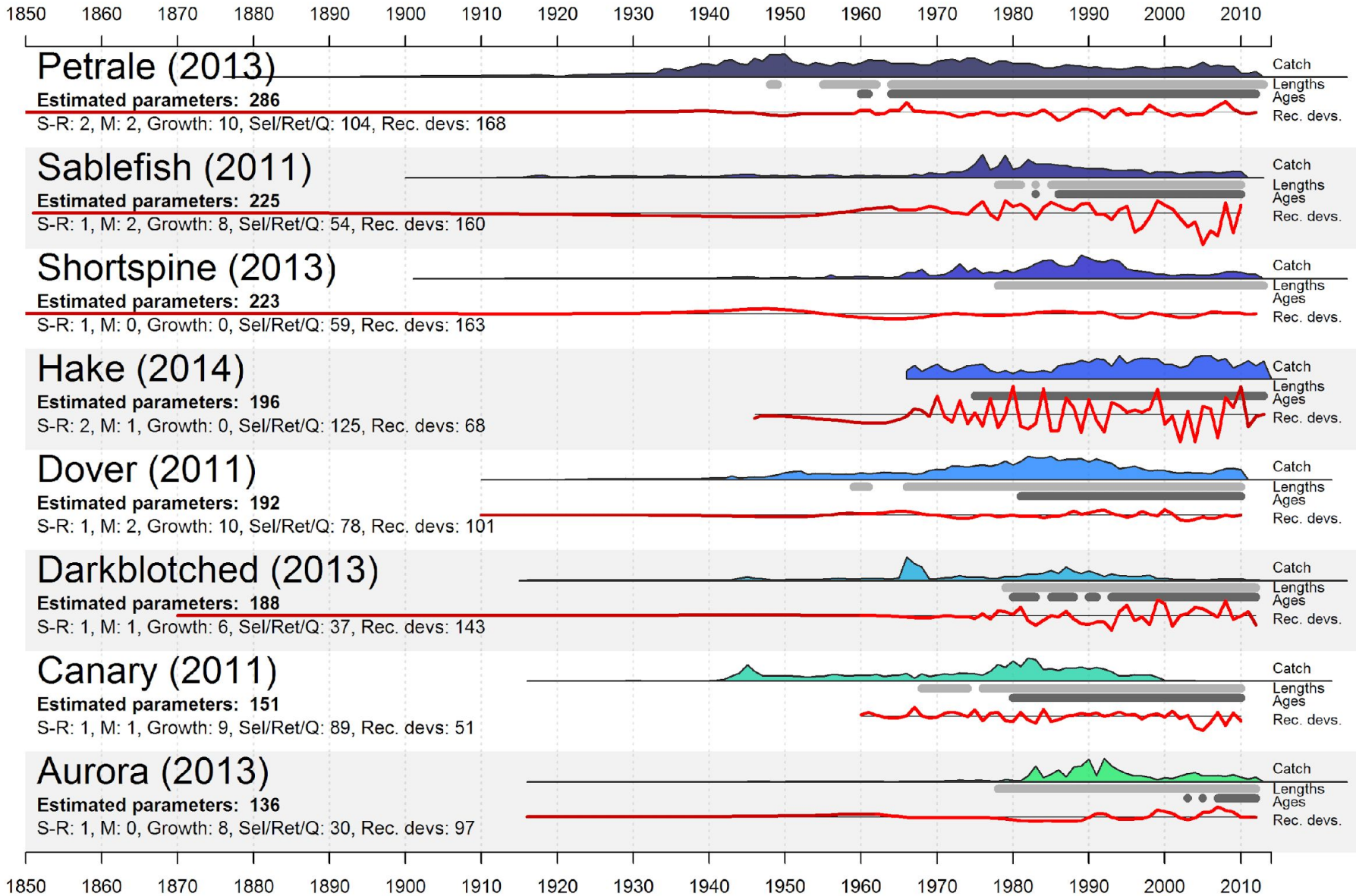
Big Picture

- Stock synthesis (SS3) has lots of options, especially related to recruitment
- Most SS3 models have recruitment deviates around a parametric stock-recruit relationship
- Age-structured surplus production models can be achieved by fixing deviations to zero
- Recruits can be partitioned by area, season, etc., but there is always a single spawning stock (no metapopulation dynamics)

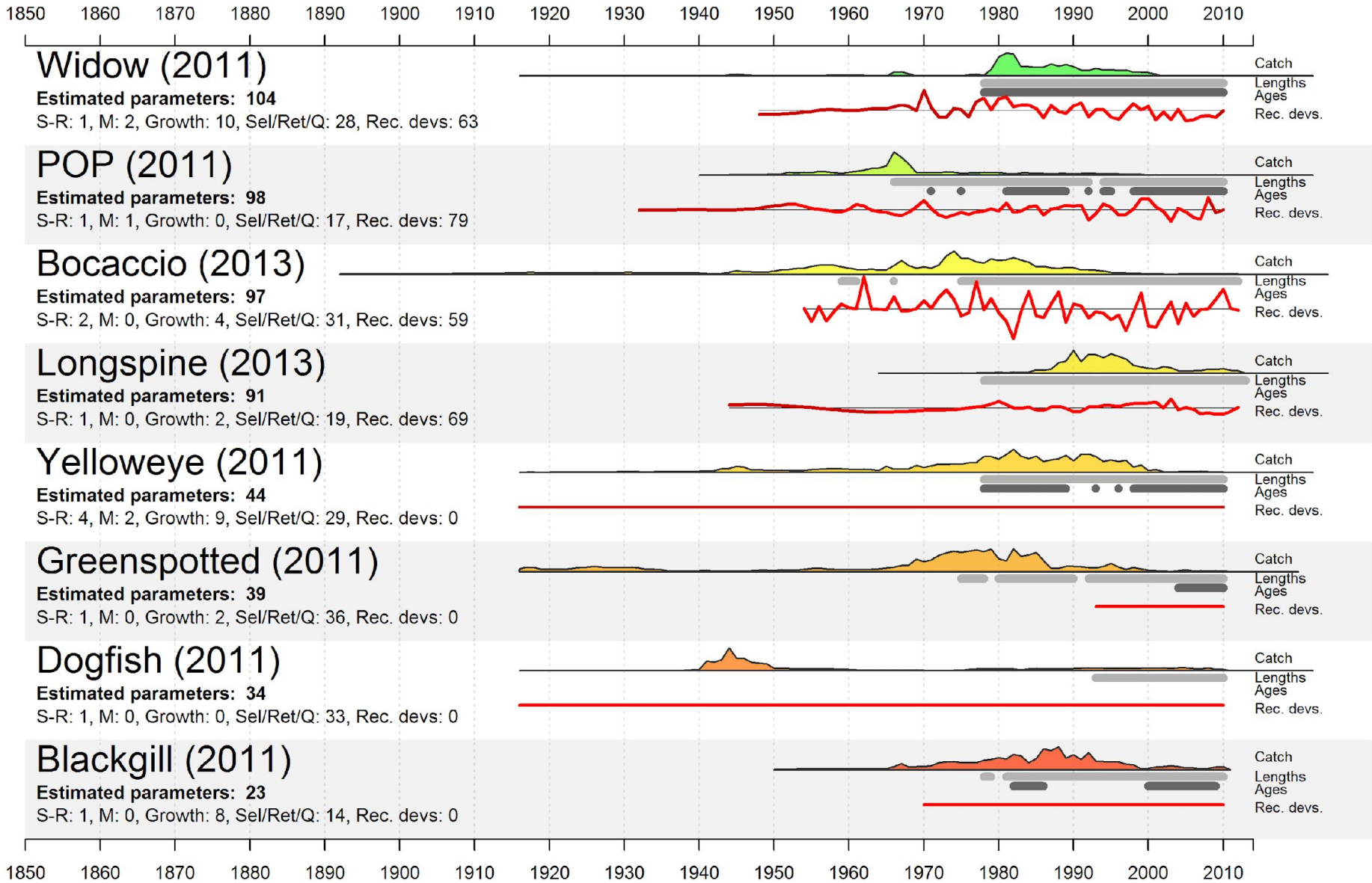


Modeling recruitment over the full history of commercial fishing

West Coast Benchmark Assessments 2011-2014 (pg. 1/2)



West Coast Benchmark Assessments 2011-2014 (pg. 2/2)



Motivation for use of stock-recruit relationships

- Provides underlying structure allowing recruitment estimation outside range of composition data
- Many alternative approaches are available
- Stock Synthesis includes enough options to allow comparison among approaches

Stock Recruit Relationships

Control file setup for stock-recruit function

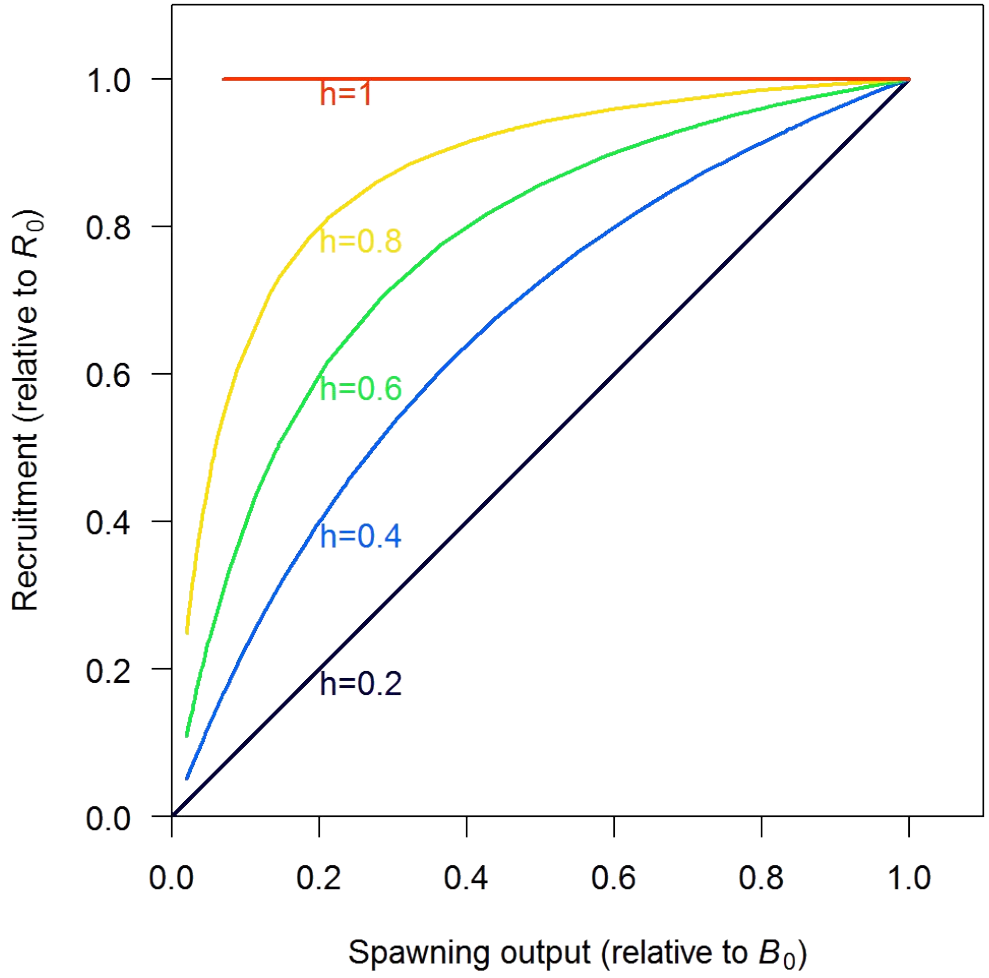
```
#_Spawner-Recruitment
3 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey;
  # 6=B-H_flattop; 7=survival_3Parm; 8=Shepard_3Parm
0 # 0/1 to use steepness in initial equ recruitment calculation
0 #  future feature: 0/1 to make realized sigmaR a function of SR curvature
#_LO   HI    INIT   PRIOR   PR_SD    PR_type PHASE    ... # parm_name
5      20    10.6   10      5        0       1        ... # SR_LN(R0)
0.2    1     0.6    0.718   0.158    0       3        ... # SR_BH_steep
0.5    1.2   0.5    0.67    99       0       -6       ... # SR_sigmaR
-5     5     0      0       99       0       -50      ... # SR_regime
0      2     0      1       99       0       -50      ... # SR_autocorr
```

Beverton-Holt

Equations from
SS User Manual (3.30.08)

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

- Beverton-Holt is most common choice by far
- R_0 is key scale parameter for most models,
- *h* difficult to estimate, often doesn't have strong impact on fit to data, but plays big role in reference points and forecasts



Recruitment deviations

Overview

SigmaR

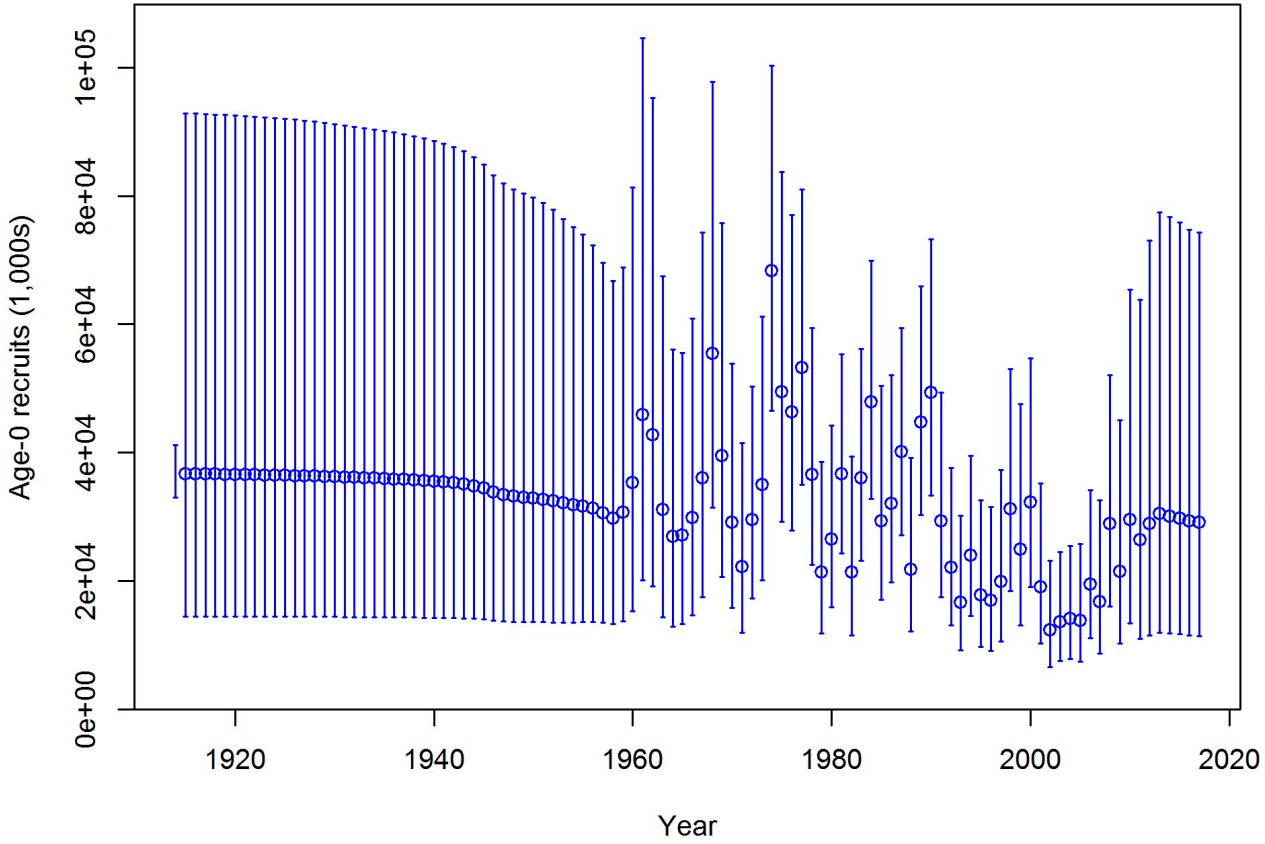
Bias adjustment

Eras (Init/Early, Main, Late/Forecast)

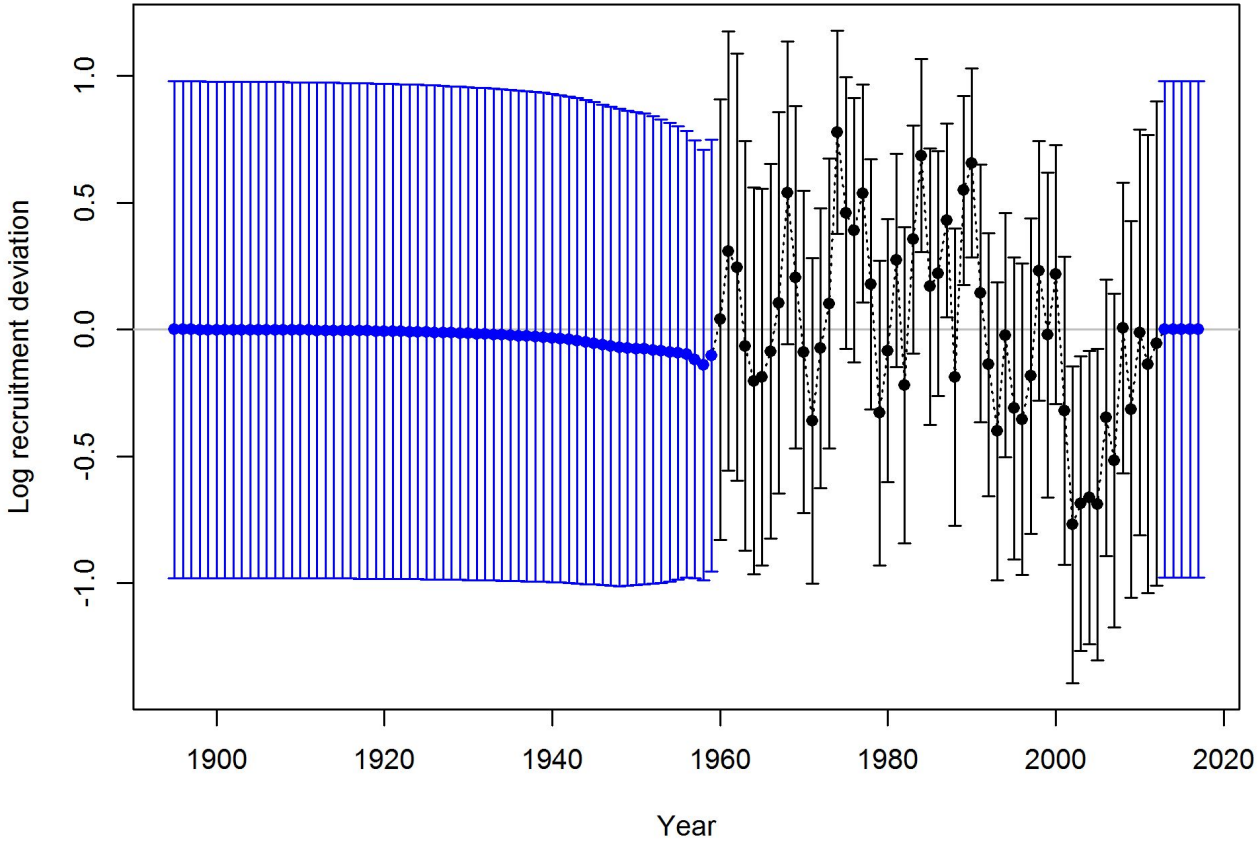
- Statisticians say that all this would be simpler if recruitment deviations were modeled as a true random effects

Recruitment in Rockfish Example

Recruitment estimates



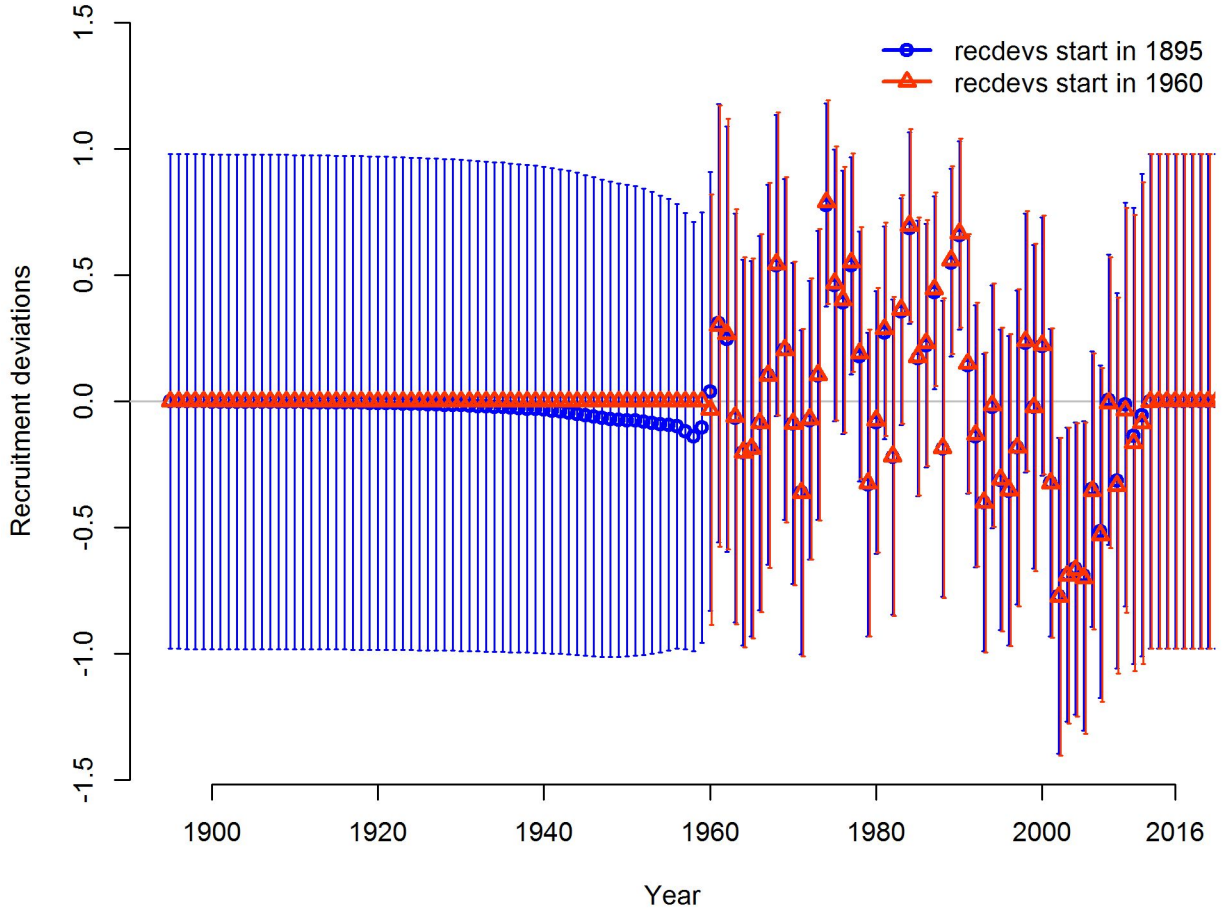
Recruitment deviations

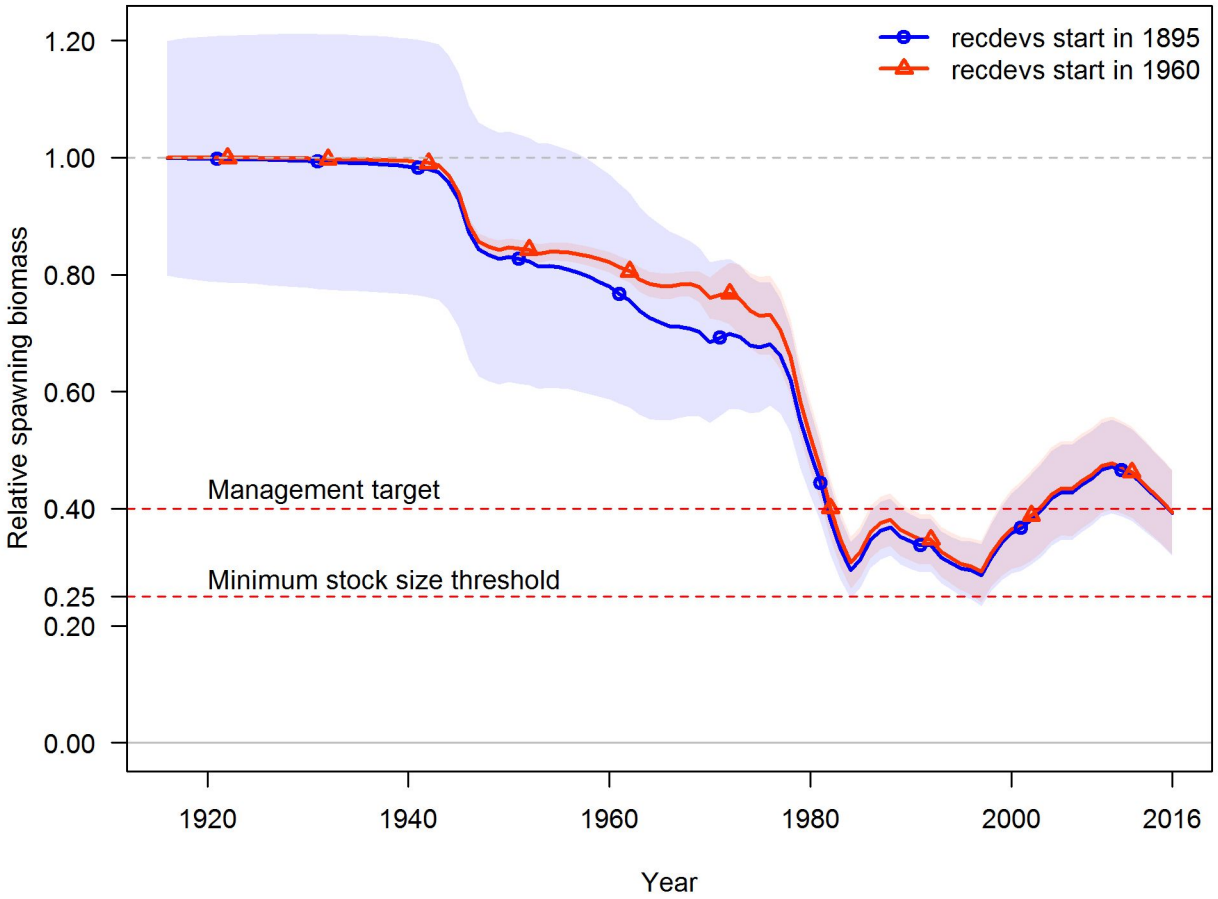


Control file setup for recruit deviations

```
1 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1960 # first year of main recr_devs; early devs can preceed this era
2012 # last year of main recr_devs; forecast devs start in following year
2 #_recdev phase
1 # (0/1) to read 13 advanced options
 1895 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
 5 #_recdev_early_phase
 5 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
 1 #_lambda for Fcast_recr_like occurring before endyr+1
 1948.8 #_last_early_yr_nobias_adj_in_MPD
 1974.9 #_first_yr_fullbias_adj_in_MPD
 2006.5 #_last_yr_fullbias_adj_in_MPD
 2012.5 #_first_recent_yr_nobias_adj_in_MPD
 0.7034 #_max_bias_adj_in_MPD (-1 to override ramp and set biasadj=1.0 for all estimated recdevs)
 0 #_period of cycles in recruitment (N parms read below)
 -6 #min rec_dev
 6 #max rec_dev
 0 #_read_recdevs
#_end of advanced SR options
```

Impact of including early recruitment deviations

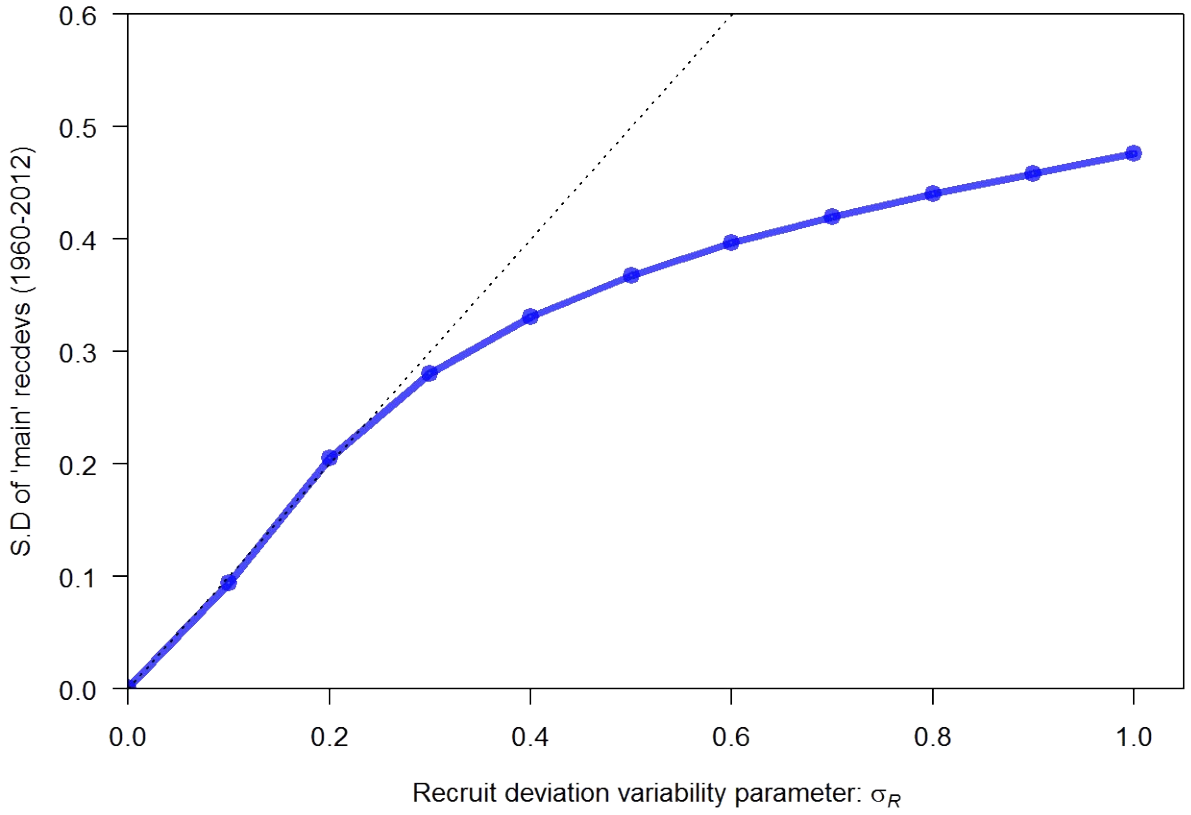


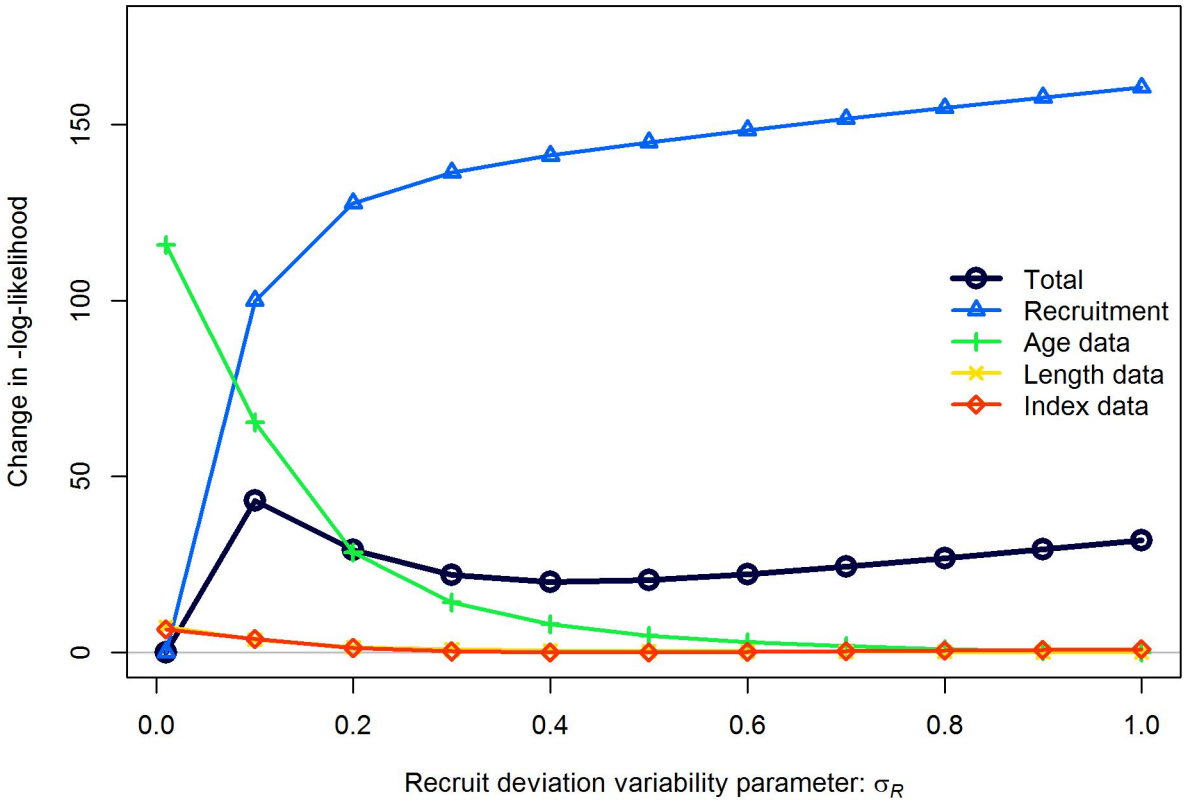


Recruit deviation variability parameter: σ_R

- Estimated variability highly dependent on σ_R
- Global minimum (in some cases) at $\sigma_R = 0$ not useful
- Statisticians say that MLE of random effects variance is biased

$$\tilde{R}_y \sim N(0; \sigma_R^2)$$





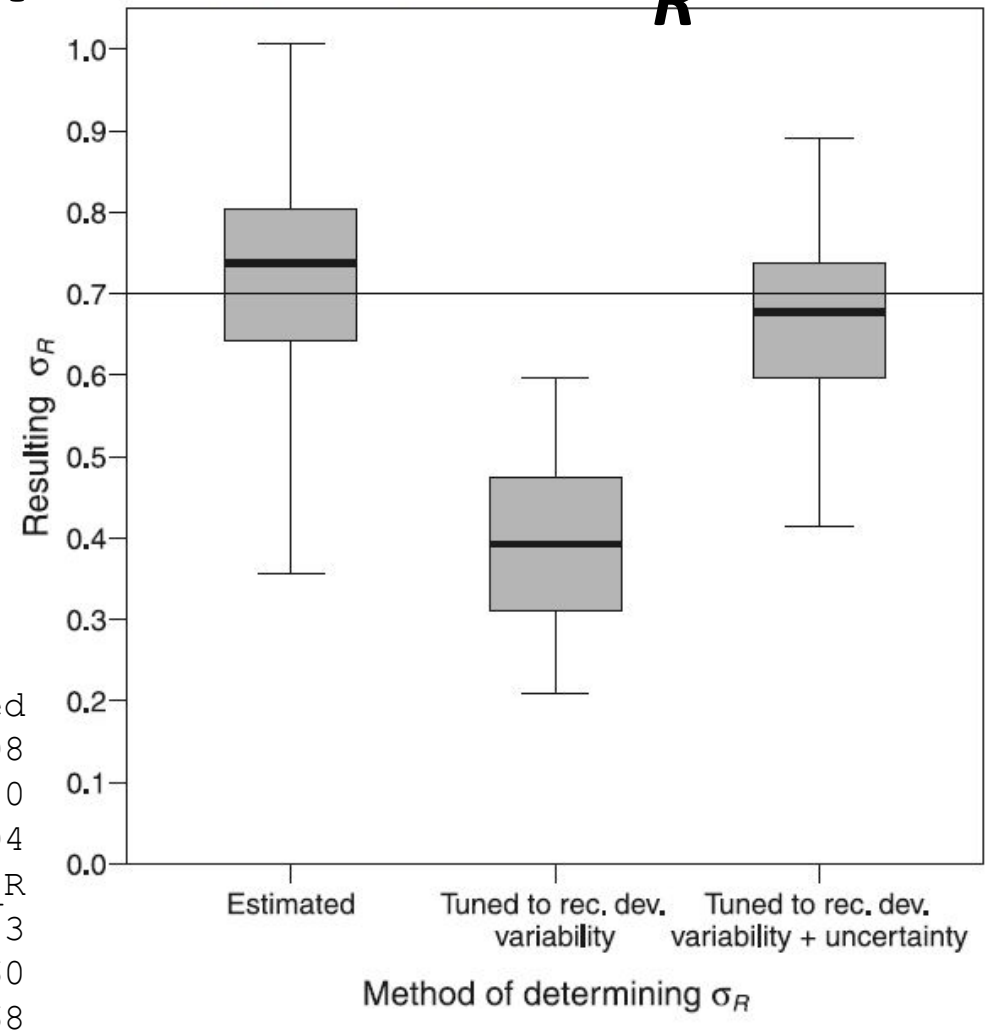
Recruit deviation variability parameter: σ_R

- Accounting for uncertainty around recdev estimates improved estimation of σ_R:

$$\sigma_R^2 = \mathrm{Var}(\hat{r}) + \overline{\mathrm{SE}(\hat{r}_y)}^2$$

Thorson says square first, then take mean

- List created by `r4ss::SS_output()` includes table: `$sigma_R_info`




```
> ex1$sigma_R_in
[1] 0.5
> ex1$sigma_R_info
           period N_devs SD_of_devs Var_of_devs mean_SE mean_SEsquared
1            Main     53     0.3682     0.13558  0.3076         0.0998
2      Early+Main    118     0.2473     0.06113  0.4079         0.1770
3 Early+Main+Late    122     0.2432     0.05912  0.4109         0.1794
  sqrt_sum_of_components SD_of_devs_over_sigma_R sqrt_sum_over_sigma_R
1                 0.4852                 0.7364                0.9703
2                 0.4880                 0.4945                0.9760
3                 0.4884                 0.4863                0.9768
  alternative_sigma_R
1              0.4852
2              0.4880
3              0.4884
```


Methot, R.D. and Taylor, I.G., 2011. Adjusting for Bias due to Variability of Estimated Recruitments in Fishery Assessment Models. Can. J. Fish. Aquat. Sci. 68, 1744–1760.

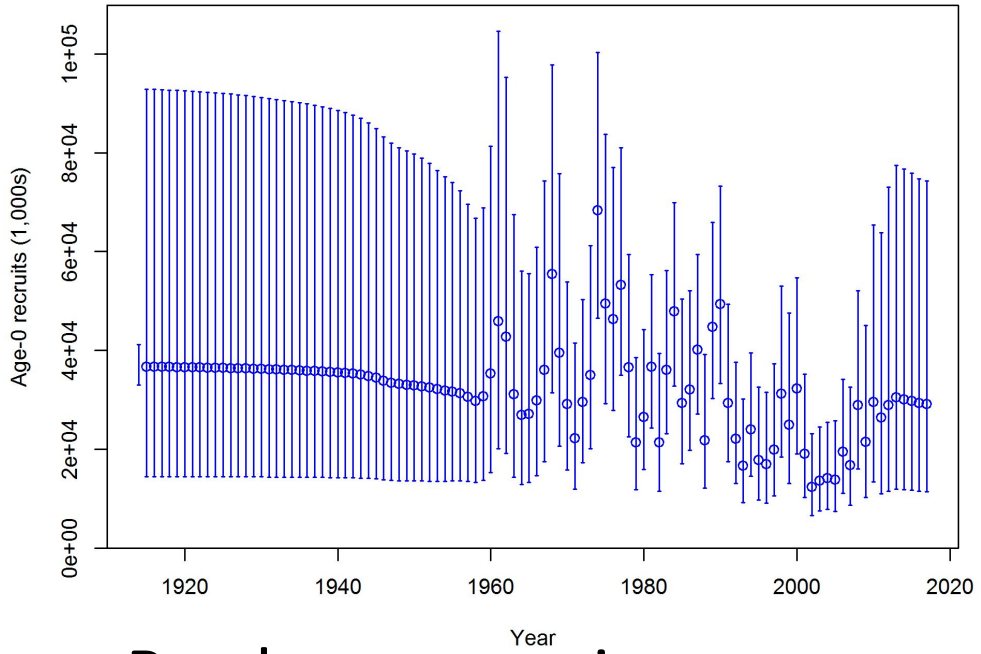
Bias adjustment of recdevs

- Difference between median and mean of lognormal distribution requires adjustment

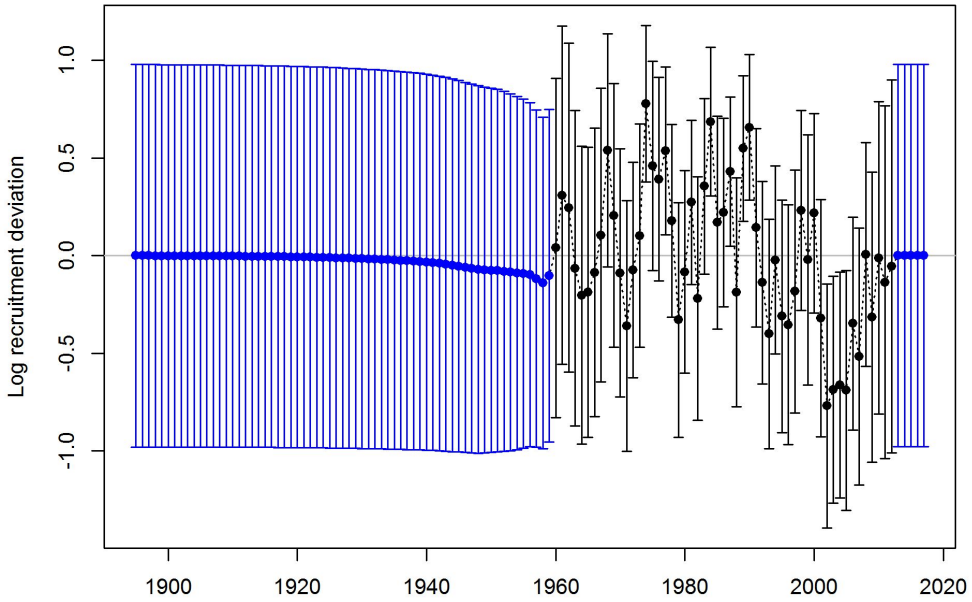
$$R_y = \frac{4hR_0SB_y}{SB_0(1-h)+SB_y(5h-1)}e^{-0.5b_y\sigma_R^2+\tilde{R}_y} \qquad \tilde{R}_y \sim N(0;\sigma_R^2) \qquad (5)$$

- However, periods with little information on recruitment will have no variability among deviations and thus not need the bias adjustment

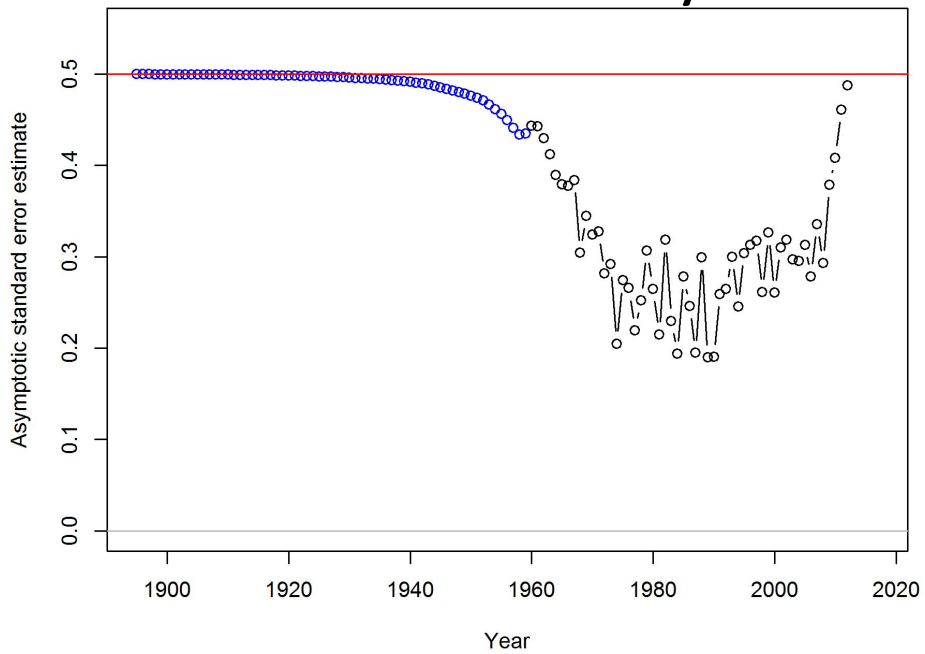
Recruitment estimates



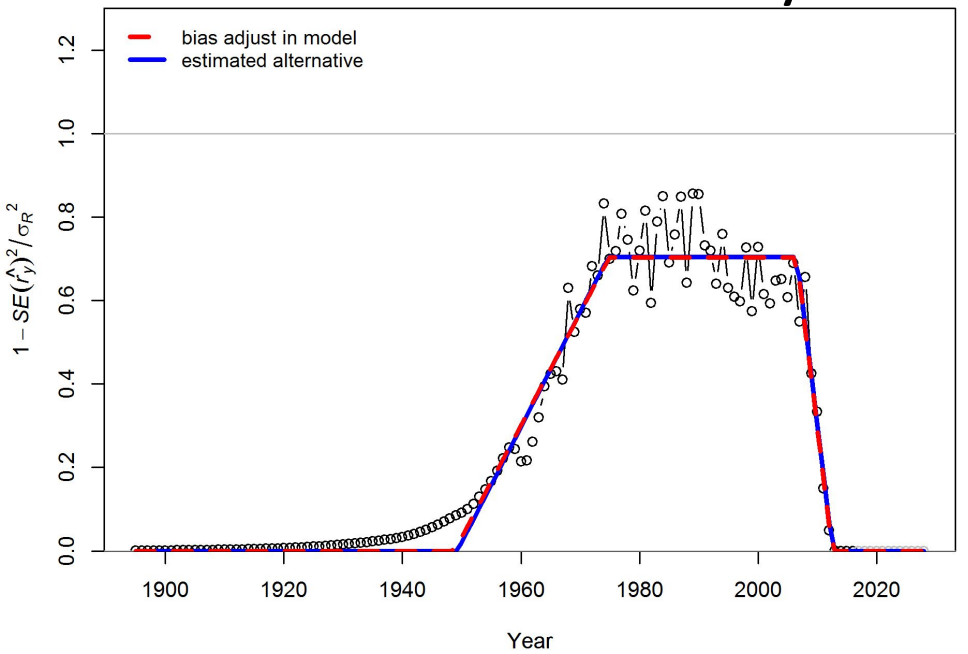
Recruitment deviations



Recdev uncertainty

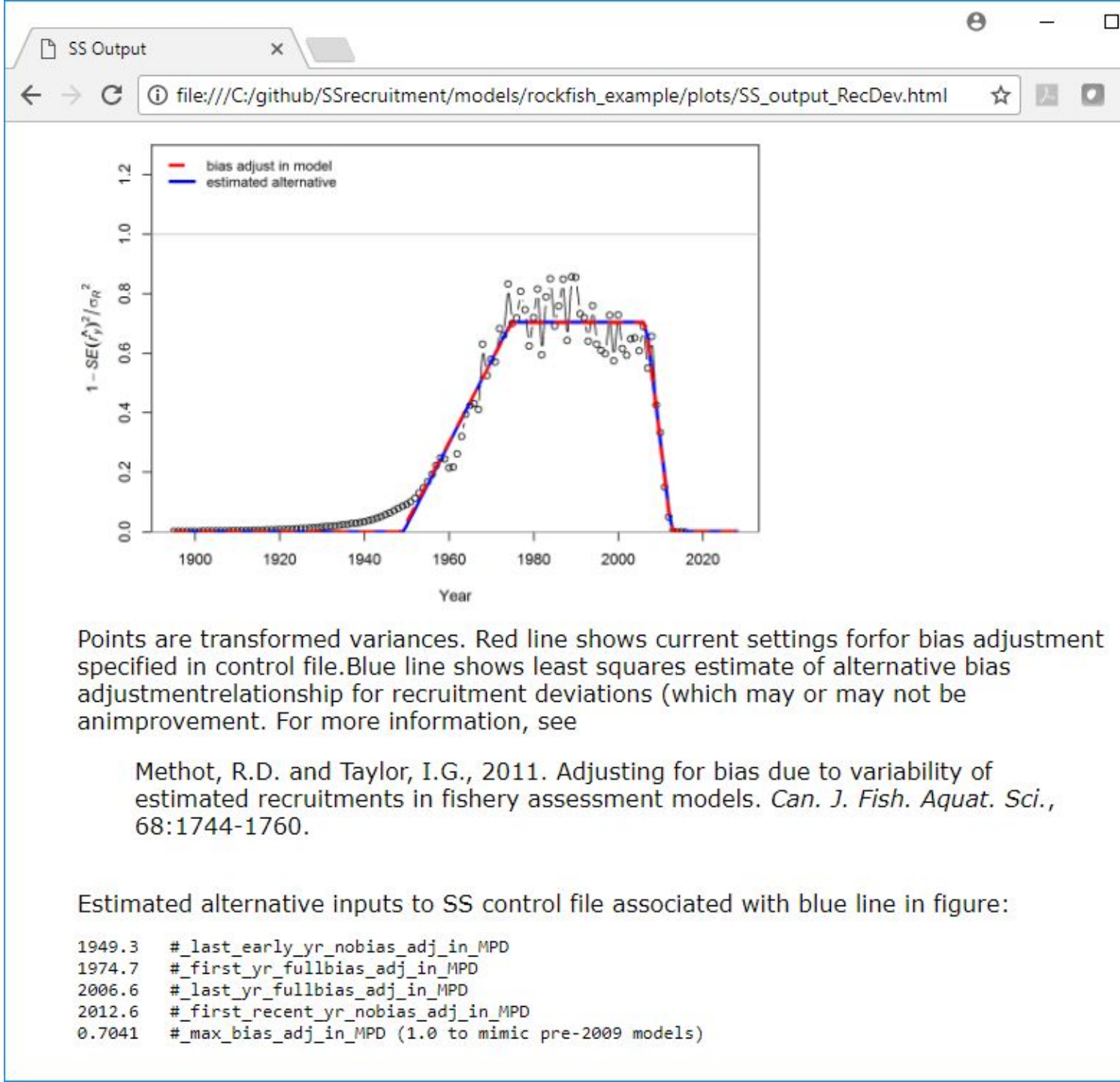


Transformed uncertainty

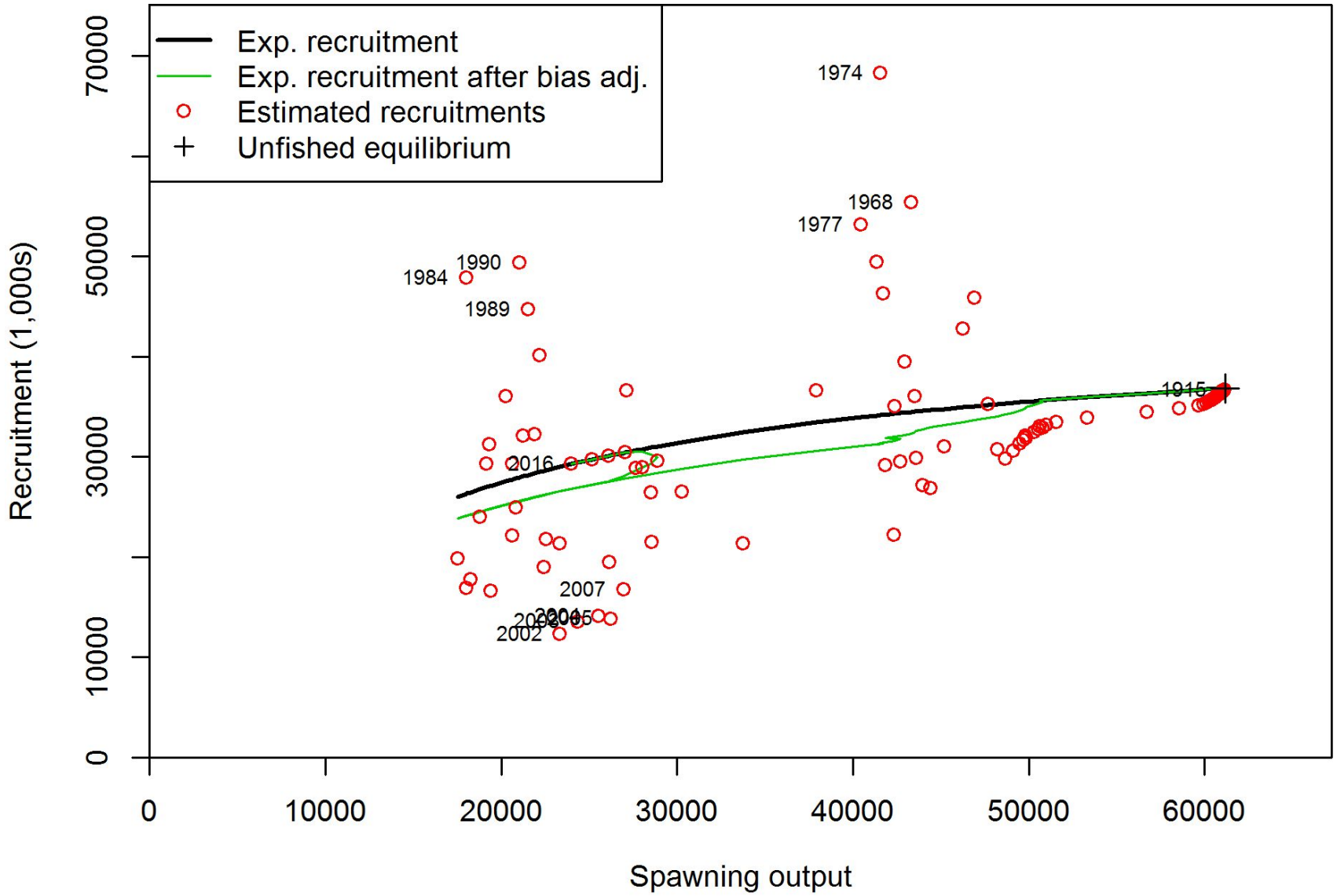


Bias adjustment

- r4ss function `SS_plots()` calls `SS_fitbiasramp()` which estimates values for input to control file

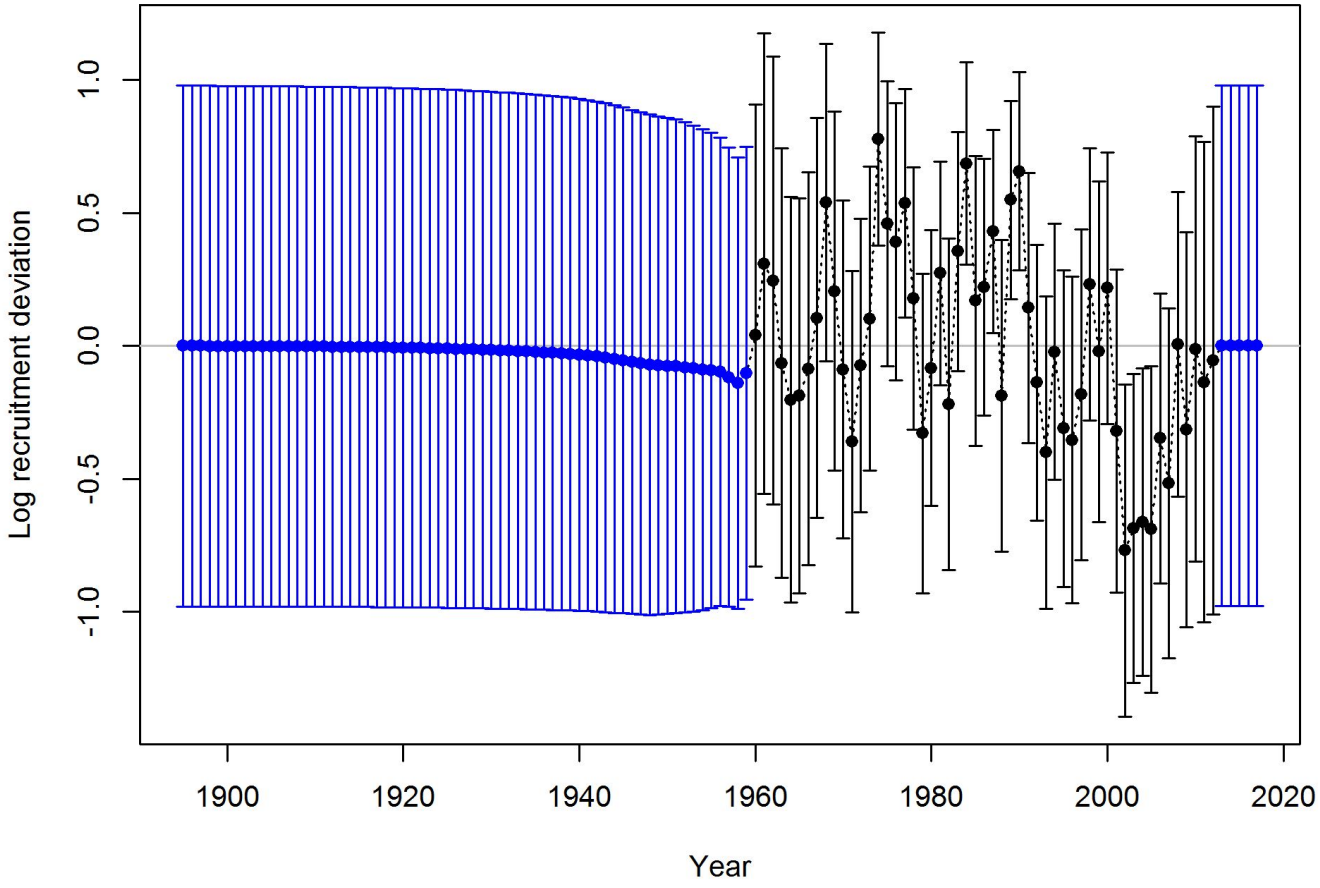


Impact of bias adjustment on stock-recruit curve



Eras (Init/Early, Main, Late/Forecast)

- Intent of option is to prevent recdevs in periods with little information from being used to compensate for above- or below-average recruitment in data-rich period
- Common practice is to use ‘main’ era only for period with information on recruitment
- Easy to test impact of alternative assumptions
- Recdevs prior to start year are used to adjust the initial age structure



Eras part 2

- In recent years the SS3 users (at least at NWFSC) have been using recdev option 2 = “simple deviations” more than option 1 = zero-centered deviations (“devvector” in ADMB)

```
#do_recdev:  0=none; 1=devvector; 2=simple deviations
```

- The goal of the zero-centering is to force the R0 parameter to represent the central tendency of the recruitments.
- However, in general the average recdev is close to 0 due to the sigmaR penalty on deviations away from zero
- The zero-centered vector does not work with MCMC due to a limitation of ADMB.
- Using simple deviations means that you don’t have to worry about separate vectors for early, main, and late deviations.
- The Yelloweye and Widow updates both use option 1 so any exploration of option 2 should probably be a sensitivity analysis.

Apportionment of recruitment

(to multiple areas, growth patterns, or settlement events)

Control file setup for recruit distribution

```
2 # recr_dist_method for parameters:
  #  2=main effects for GP, Settle timing, Area;
  #  3=each Settle entity;
  #  4=none when N_GP*Nsettle*pop==1
1 # Recruitment: 1=global; 2=by area (future option)
2 #  number of recruitment settlement assignments
0 # year_x_area_x_settlement_event interaction requested (only for
recr_dist_method=1)
#GPattern month area  age (for each settlement assignment)
 1        1     1     0
 1        1     2     0
```

Distribution of recruitment

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

- When multiple Growth Patterns, Areas, or Seasons are specified at the top of the data file, the model will expect additional parameters
- Fix first parameter at 0
- Estimate (or fix) additional parameters within a range like -4 to 4
  - transformation above converts to -4 to 4 to a fraction of 0.02 to 0.98 for each bin when apportioning to two bins
- Recruitment distribution can be time-varying (but isn't for yelloweye)
  - Need to think about interaction between variability of recruitment distribution and σ_R
  - No clear guidance on bias adjustment of recdevs in this context

Control file parameters for recruit distribution

```
#_LO   HI    INIT   PRIOR   PR_SD   PR_type   PHASE   ...
  0    2     1      1       99      0         -50     ...   # RecrDist_GP_1
 -4    4     0      0       99      0         -50     ...   # RecrDist_Area_1
 -4    4     -0.1   0       99      0           3     ...   # RecrDist_Area_2
  0    2     1      1       99      0         -50     ...   # RecrDist_Bseas_1
```