Factors affecting reliablity of state-space age-structured assessment models

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Abstract

Keywords

1 Introduction

Application of state-space models in fisheries stock assessment and management has expanded dramatically within ICES, Canada and the Northeast US (Nielsen and Berg, 2014; Cadigan, 2016; Stock and Miller, 2021).

Much is known about the reliability of state-space models that are linear or Gaussian (Aeberhard et al., 2018), but applications in fisheries management are nonlinear and typically include multiple types of observations with varying distributional assumptions. We know relatively little about the statistical reliability of such models. Also, there is a wide range of potential random effects structures in assessment models and we know little about the ability of information criteria to distinguish among such alternative structures.

But those studies focus primarily on Gaussian linear models. review literature on reliability of hidden/latent process models. Primarily in other fields.

Convergence results can be useful for understanding how bad convergence in applications to real data might direct the practitioner to which alternative random effects configurations is be more appropriate. The type of convergence that we might use as a diagnostic is important. And what rule of thumb we use for certain criteria e.g. 1e-6? large SEs/CVs?

Here we conduct a simulation study with operating models varying by degree of observation error uncertainty, sources of process error (M, NAA, q, sel), and fishing history. The simulations from these operating models are fitted with estimating models that make alternative assumptions for sources of process error (M, NAA< q, sel), whether a stock-recruit model was estimated, and whether M is estimated. We evaluate whether AIC can correctly determine the correct source of process error and stock effects on recruitment. We also evaluate the degree of bias in the outputs of the assessment model that are important for management.

2 Methods

Used the WHAM package (Stock and Miller, 2021, commit 77bbd94) (Miller and Stock 2020). This packages has also been used to configure operating and estimating models for closed loop simulations evaluating index-based assessment methods (Legault et al., In press) and is used for management of haddock, butterfish, plaice, bluefish in the Northeast US.

We completed a simulation study with a number of operating models that can be categorized based on where random effects are assumed: abundance at age, natural mortality, fleet selectivity, or index catchability. For each operating model assumptions about variance of process errors and observations are required and the values we used were based on a review of the range of estimates from recent applications of WHAM in management of stocks of haddock, butterfish, and American plaice in the NE US.

We simulated 100 data sets for each operating model. For each simulated data from each operating model we fit a set of estimating models.

Y estimating models fit to each

2.1 Operating models

common to all:

ages = 1 to 10+, M maturity

marginal standard deviations for random effects are defined in tables of operating models.

2.1.1 Population

There are 10 age classes: ages 1 to 10+.

Spawning was assumed to occur 1/4 of the way through the year.

Natural mortality rate was assumed 0.2 when it was constant and the mean of the time series process for operating models with M random effects. maturity a50 = 2.89, slope = 0.88

Weight at age was generated with a LVB growth

$$L_a = L_\infty \left(1 - e^{-k(a-t_0)}\right)$$

where $t_0 = 0$, $L_\infty = 85$, and $k = 0.3$, and a L-W relationship such that

$$W_a = \theta_1 L_a^{\theta_2}$$

where $\theta_1 = e^{-12.1}$ and $\theta_2 = 3.2$.

We assumed a Beverton-Holt stock recruit function with constant pre-recruit mortality parameters for all operating models. All post-recruit productivity components are constant in the NAA and survey catchability process error operating models. Therefore steepness and unfished recruitment are also constant over the time period for those operating models (Miller and Brooks 2021). We specified unfished recruitment $= R_0 = e^{10}$ and $F_{\text{MSY}} = F_{40} = 0.348$ equated to a steepness of 0.69 and $\alpha = 0.60$ and $\beta = 2.4 \times 10^{-5}$ for the

$$N_{1,y} = \frac{\alpha \text{SSB}_{y-1}}{1 + \beta \text{SSB}_{y-1}}$$

Beverton-Holt parameterization.

The magnitude of the overfishing assumptions is based on average estimates of overfishing for NE groundfish stocks from Wiedenmann et al. (20XX). Legault et al. (2023) also used similar approaches to defining fishing mortality histories for operating models.

Currenlty, initial population is configured at the equilibrium distribution fishing at $F = 2.5 \times F_{\text{MSY}}$.

Initial population was configured at the equilibrium distribution fishing at either $F = 2.5 \times$

F_{MSY} or $F = F_{\mathrm{MSY}}$ for the two alternative fishing histories. That is for a deterministic model, the age composition would not change over time when the fishing mortality was constant at the respective level.

For operating models with time-varying random effects for M, steepness is not constant, but we used the same alpha and beta parameters as other operating models this equates to a steepness and R0 at the mean of the time series process for M. For operating models with time-varying random effects for fishery selectivity, Fmsy is also not constant however we use the same F history as other operating models which corresponds to Fmsy at the mean selectivity parameters.

2.1.2 Fleets

We assumed a single fleet operating year round for catch observations with logistic selectivity for the fleet with $a_{50} = 5$ and slope $= 1$. This selectivity is was used to define F_{MSY} for the Beverton-Holt stock recruitment parameters above. We assumed a logistic-normal distribution for the age-composition observations for the fleet.

2.1.3 Fishing histories

All operating models assumed one of two different fishing histories. One : Fishing mortality is equal to Fmsy (0.348) for the whole 40 year period. Two : Fishing mortality is 2.5 times Fmsy for the first 20 years then changes to Fmsy for the last 20 years.

2.1.4 Indices

Two time series of surveys are assumed and observed in numbers rather than biomass for the entire 40 year period with one occurring in the spring (0.25 way through the year) and one in the fall (0.75 way through the year). Actually we have it currently configured that both occur 0.5 way through the year. Catchability of both surveys are assumed to be 0.1.

We assumed logistic selectivity for both indices with $a_{50} = 5$ and slope $= 1$. We assumed a logistic-normal distribution for the age-composition observations.

2.1.5 Observation Uncertainty

Standard deviation for log-aggregate catch was 0.1. There were two levels of observation error variance for indices and age composition for both indices and fleet catch. A low uncertainty specification assumed standard deviation of both series of log-aggregate index observations was 0.1 and the standard deviation of the logistic-normal for age composition observations was 0.3 In the high uncertainty specification the standard deviation for log-aggregate indices was 0.4 and that for the age composition observations was 1.5. For all estimating models, standard deviation for log-aggregate observations was assumed known whereas that for the logistic-normal age composition observations was estimated.

2.1.6 Operating models with random effects on numbers at age

24 operating models, 16 Sel re operating models and 16 q re operating models. Table of process error assumptions

Table 1. Distinguishing characteristics of the operating models with random effects on survival. Standard deviations (SD) are for log-normal distributed indices and logistic normal distributed age composition observations (fleet and indices). Fishing mortality changes after year 20 (of 40) for fishing histories where fishing mortality is not constant.

Model	σ_R	σ_{2+}	Fishing History	Observation Uncertainty
NAA_1	0.5		$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
NAA_2	1.5		$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
NAA_3	0.5	0.25	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
NAA_4	1.5	0.25	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
NAA_5	0.5	0.50	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
NAA_6	1.5	0.50	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
NAA_7	0.5		F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
NAA_8	1.5		F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
NAA_9	0.5	0.25	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
NAA_{10}	1.5	0.25	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
NAA_{11}	0.5	0.50	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
NAA_{12}	1.5	0.50	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
NAA_{13}	0.5		$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
NAA_{14}	1.5		$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
NAA_{15}	0.5	0.25	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
NAA_{16}	1.5	0.25	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
NAA_{17}	0.5	0.50	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
NAA_{18}	1.5	0.50	$2.5F_{\mathrm{MSY}} \rightarrow F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
NAA_{19}	0.5		F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
NAA_{20}	1.5		F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
NAA_{21}	0.5	0.25	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
NAA_{22}	1.5	0.25	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
NAA_{23}	0.5	0.50	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
NAA_{24}	1.5	0.50	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5

2.1.7 Operating models with random effects on natural mortality

16 operating models Table of process error assumptions

NOTE: inv_trans_rho function in set_M.R is mis-defined. Will affect correlation parameters assigned in operating models?

Steepness and BRPs are not constant when M is time-varying (Miller and Brooks 2021). We uses the a/b parameters for the B-H defined for Fmsy = F40 at the mean M = 0.2 as defined above.

Table 2. Distinguishing characteristics of the operating models with random effects on natural mortality. Standard deviations (SD) are for log-normal distributed indices and logistic normal distributed age composition observations (fleet and indices). Fishing mortality changes after year 20 (of 40) for fishing histories where fishing mortality is not constant. For AR1 process errors, σ is defined for the marginal distribution of the processes.

Model	σ_R	σ_M	ρ_M	Fishing History	Observation Uncertainty
M_1	0.5	0.1	0.0	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
M_2	0.5	0.5	0.0	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
M_3	0.5	0.1	0.9	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
M_4	0.5	0.5	0.9	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
M_5	0.5	0.1	0.0	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
M_6	0.5	0.5	0.0	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
M_7	0.5	0.1	0.9	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
M_8	0.5	0.5	0.9	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
M_9	0.5	0.1	0.0	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
M_{10}	0.5	0.5	0.0	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
M_{11}	0.5	0.1	0.9	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
M_{12}	0.5	0.5	0.9	$2.5F_{\text{MSY}} \to F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
M_{13}	0.5	0.1	0.0	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
M_{14}	0.5	0.5	0.0	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
M_{15}	0.5	0.1	0.9	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
M_{16}	0.5	0.5	0.9	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5

2.1.8 Operating models with random effects on fleet selectivity

16 operating models Table of process error assumptions

BRPs are not constant when fleet selectivity is time-varying. We uses the a/b parameters for the B-H defined for Fmsy = F40 at the mean of the time series model for selectivity which is the same as the constant selectivity defined above.

Table 3. Distinguishing characteristics of the operating models with random effects on selectivity. Standard deviations (SD) are for log-normal distributed indices and logistic normal distributed age composition observations (fleet and indices). Fishing mortality changes after year 20 (of 40) for fishing histories where fishing mortality is not constant. For AR1 process errors, σ is defined for the marginal distribution of the processes.

Model	σ_R	σ_{Sel}	ρ_{Sel}	Fishing History	Observation Uncertainty
Sel_1	0.5	0.1	0.0	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
Sel_2	0.5	0.5	0.0	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
Sel_3	0.5	0.1	0.9	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
Sel_4	0.5	0.5	0.9	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
Sel_5	0.5	0.1	0.0	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
Sel_6	0.5	0.5	0.0	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
Sel_7	0.5	0.1	0.9	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
Sel_8	0.5	0.5	0.9	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
Sel_9	0.5	0.1	0.0	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
Sel_{10}	0.5	0.5	0.0	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
Sel_{11}	0.5	0.1	0.9	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
Sel_{12}	0.5	0.5	0.9	$2.5F_{\text{MSY}} \rightarrow F_{\text{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
Sel_{13}	0.5	0.1	0.0	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
Sel_{14}	0.5	0.5	0.0	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
Sel_{15}	0.5	0.1	0.9	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
Sel_{16}	0.5	0.5	0.9	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5

2.1.9 Operating models with random effects on index catchability

16 operating models Table of process error assumptions

Table 4. Distinguishing characteristics of the operating models with random effects on catchability. Standard deviations (SD) are for log-normal distributed indices and logistic normal distributed age composition observations (fleet and indices). Fishing mortality changes after year 20 (of 40) for fishing histories where fishing mortality is not constant. For AR1 process errors, σ is defined for the marginal distribution of the processes.

Model	σ_R	σ_q	ρ_q	Fishing History	Observation Uncertainty
q_1	0.5	0.1	0.0	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
q_2	0.5	0.5	0.0	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
q_3	0.5	0.1	0.9	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
q_4	0.5	0.5	0.9	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.1, Age composition SD = 0.3
q_5	0.5	0.1	0.0	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
q_6	0.5	0.5	0.0	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
q_7	0.5	0.1	0.9	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
q_8	0.5	0.5	0.9	F_{MSY}	Index SD = 0.1, Age composition SD = 0.3
q_9	0.5	0.1	0.0	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
q_{10}	0.5	0.5	0.0	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
q_{11}	0.5	0.1	0.9	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
q_{12}	0.5	0.5	0.9	$2.5F_{\mathrm{MSY}} \to F_{\mathrm{MSY}}$	Index SD = 0.4, Age composition SD = 1.5
q_{13}	0.5	0.1	0.0	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
q_{14}	0.5	0.5	0.0	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
q_{15}	0.5	0.1	0.9	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5
q_{16}	0.5	0.5	0.9	F_{MSY}	Index SD = 0.4, Age composition SD = 1.5

2.2 Estimating models

32 estimating models Table of estimating models

1-20 fit to each NAA RE operating model 5-24 fit to each M RE operating model 5-20,25-28 to each sel RE operating model 5-20, 29-32 to each q RE operating model

SR estimation or not

Make plot of S-R curve, Fmsy = F40 Initial values for BH parameters are the true values. Initial values for mean R model = true R0.

M estimation or not

NAA_re Random effects on Recruitment only or random effects on recruitment and transitions among older numbers at age.

M_re Random effects on Recruitment only, M constant across age .

sel_re Random effects on Recruitment only, fleet logistic selectivity RE model?

q_re Random effects on Recruitment only, one survey catchability RE model?

Simulations were all carried out on the University of Massachusetts Green High-Performance Computing Cluster. Code for completing the simulations and summarization of results can be found at github.com/timjmiller/SSRTWG/Project_0. We used the wham package version 1.X.X (commit 77bbd94).

Summary statitics

Bias

Mohn's rho

marginal AIC

convergence types: 1) whether the optimization completed 2) nlminb convergence flag = 0 3) max abs gradient < 1e-6 4) No NAs for SE of fixed effects returned from TMB::sdreport 5) No SE NAs AND no SE > 100

Table 5. Distinguishing characteristics of the estimating models.

Model	Recruitment model	Mean M	Process error assumption
EM_1	Mean recruitment	0.2	Recruitment (σ_R estimated)
EM_2	Beverton-Holt	0.2	Recruitment (σ_R estimated)
EM_3	Mean recruitment	Estimated	Recruitment (σ_R estimated)
EM_4	Beverton-Holt	Estimated	Recruitment (σ_R estimated)
EM_5	Mean recruitment	0.2	Recruitment and survival (σ_R, σ_{2+} estimated)
EM_6	Beverton-Holt	0.2	Recruitment and survival (σ_R, σ_{2+} estimated)
EM_7	Mean recruitment	Estimated	Recruitment and survival (σ_R, σ_{2+} estimated)
EM_8	Beverton-Holt	Estimated	Recruitment and survival (σ_R, σ_{2+} estimated)
EM_9	Mean recruitment	0.2	Recruitment and uncorrelated natural mortality (σ_R, σ_M estimated, $\rho_M = 0$)
EM_{10}	Beverton-Holt	0.2	Recruitment and uncorrelated natural mortality (σ_R, σ_M estimated, $\rho_M = 0$)
EM_{11}	Mean recruitment	Estimated	Recruitment and uncorrelated natural mortality (σ_R, σ_M estimated, $\rho_M = 0$)
EM_{12}	Beverton-Holt	Estimated	Recruitment and uncorrelated natural mortality (σ_R, σ_M estimated, $\rho_M = 0$)
EM_{13}	Mean recruitment	0.2	Recruitment and uncorrelated fleet selectivity (σ_R, σ_{Sel} estimated, $\rho_{\text{Sel}} = 0$)
EM_{14}	Beverton-Holt	0.2	Recruitment and uncorrelated fleet selectivity (σ_R, σ_{Sel} estimated, $\rho_{\text{Sel}} = 0$)
EM_{15}	Mean recruitment	Estimated	Recruitment and uncorrelated fleet selectivity (σ_R, σ_{Sel} estimated, $\rho_{\text{Sel}} = 0$)
EM_{16}	Beverton-Holt	Estimated	Recruitment and uncorrelated fleet selectivity (σ_R, σ_{Sel} estimated, $\rho_{\text{Sel}} = 0$)
EM_{17}	Mean recruitment	0.2	Recruitment and uncorrelated catchability (spring index) (σ_R, σ_q estimated, $\rho_q = 0$)
EM_{18}	Beverton-Holt	0.2	Recruitment and uncorrelated catchability (spring index) (σ_R, σ_q estimated, $\rho_q = 0$)
EM_{19}	Mean recruitment	Estimated	Recruitment and uncorrelated catchability (spring index) (σ_R, σ_q estimated, $\rho_q = 0$)
EM_{20}	Beverton-Holt	Estimated	Recruitment and uncorrelated catchability (spring index) (σ_R, σ_q estimated, $\rho_q = 0$)
EM_{21}	Mean recruitment	0.2	Recruitment and AR1 natural mortality (σ_R, σ_M, ρ_M estimated)
EM_{22}	Beverton-Holt	0.2	Recruitment and AR1 natural mortality (σ_R, σ_M, ρ_M estimated)
EM_{23}	Mean recruitment	Estimated	Recruitment and AR1 natural mortality (σ_R, σ_M, ρ_M estimated)
EM_{24}	Beverton-Holt	Estimated	Recruitment and AR1 natural mortality (σ_R, σ_M, ρ_M estimated)
EM_{25}	Mean recruitment	0.2	Recruitment and AR1 selectivity (σ_R, σ_{Sel}, ρ_{Sel} estimated)
EM_{26}	Beverton-Holt	0.2	Recruitment and AR1 selectivity (σ_R, σ_{Sel}, ρ_{Sel} estimated)
EM_{27}	Mean recruitment	Estimated	Recruitment and AR1 selectivity (σ_R, σ_{Sel}, ρ_{Sel} estimated)
EM_{28}	Beverton-Holt	Estimated	Recruitment and AR1 selectivity (σ_R, σ_{Sel}, ρ_{Sel} estimated)
EM_{29}	Mean recruitment	0.2	Recruitment and AR1 catchability (spring index) (σ_R, σ_q, ρ_q estimated)
EM_{30}	Beverton-Holt	0.2	Recruitment and AR1 catchability (spring index) (σ_R, σ_q, ρ_q estimated)
EM_{31}	Mean recruitment	Estimated	Recruitment and AR1 catchability (spring index) (σ_R, σ_q, ρ_q estimated)
EM_{32}	Beverton-Holt	Estimated	Recruitment and AR1 catchability (spring index) (σ_R, σ_q, ρ_q estimated)

3 Results

Do each of these by type of operating model (Naa, M, sel, q)

3.1 Convergence performance

convergence types: 1) whether the optimization completed 2) nlminb convergence flag = 0 3) max abs gradient $<$ 1e-6 4) No NAs for SE of fixed effects returned from TMB::sdreport 5) No SE NAs AND no SE $>$ 100

Probability of convergence was better for models that assumed the correct source of process error, assumed M was known, and did not assume stock-recruit relationships.

3.1.1 R, R+S operating models

Fig. 1. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structures R and R+S. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is fixed at the true value.

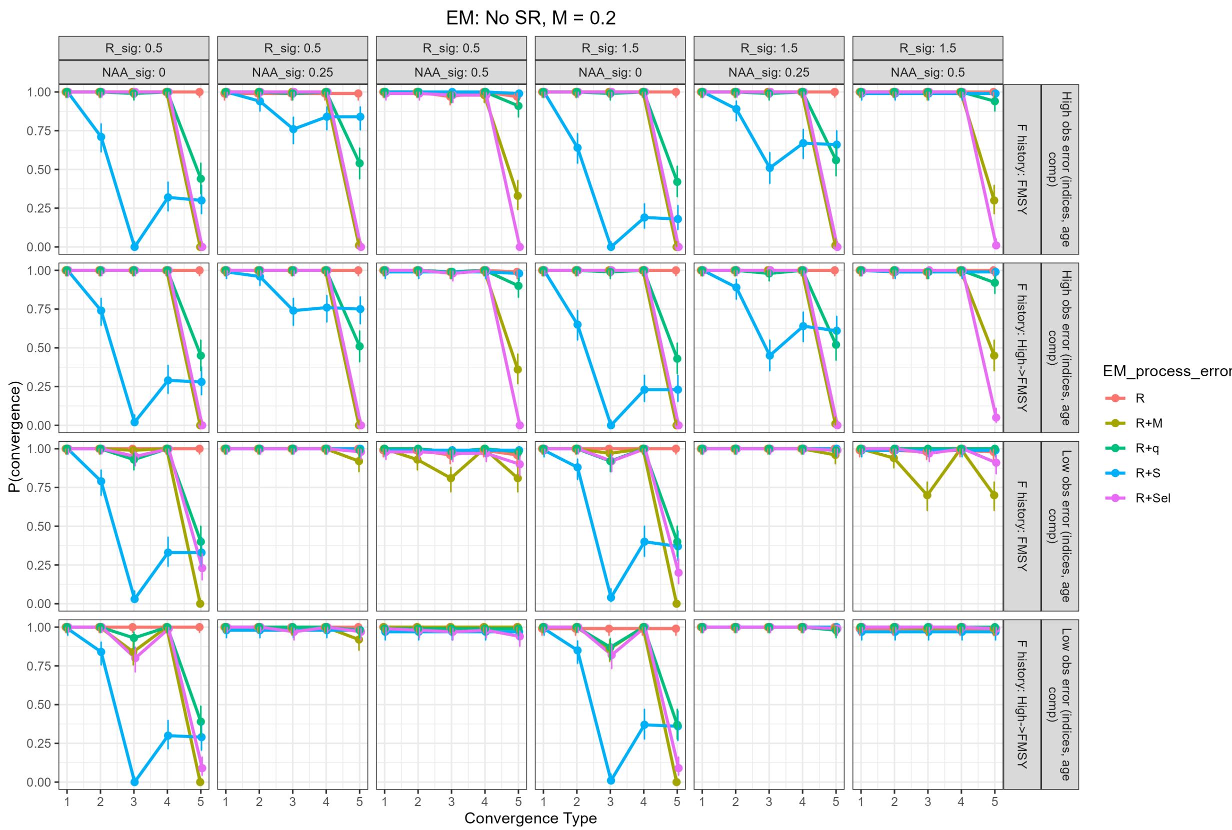


Fig. 2. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structures R and R+S. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is estimated.

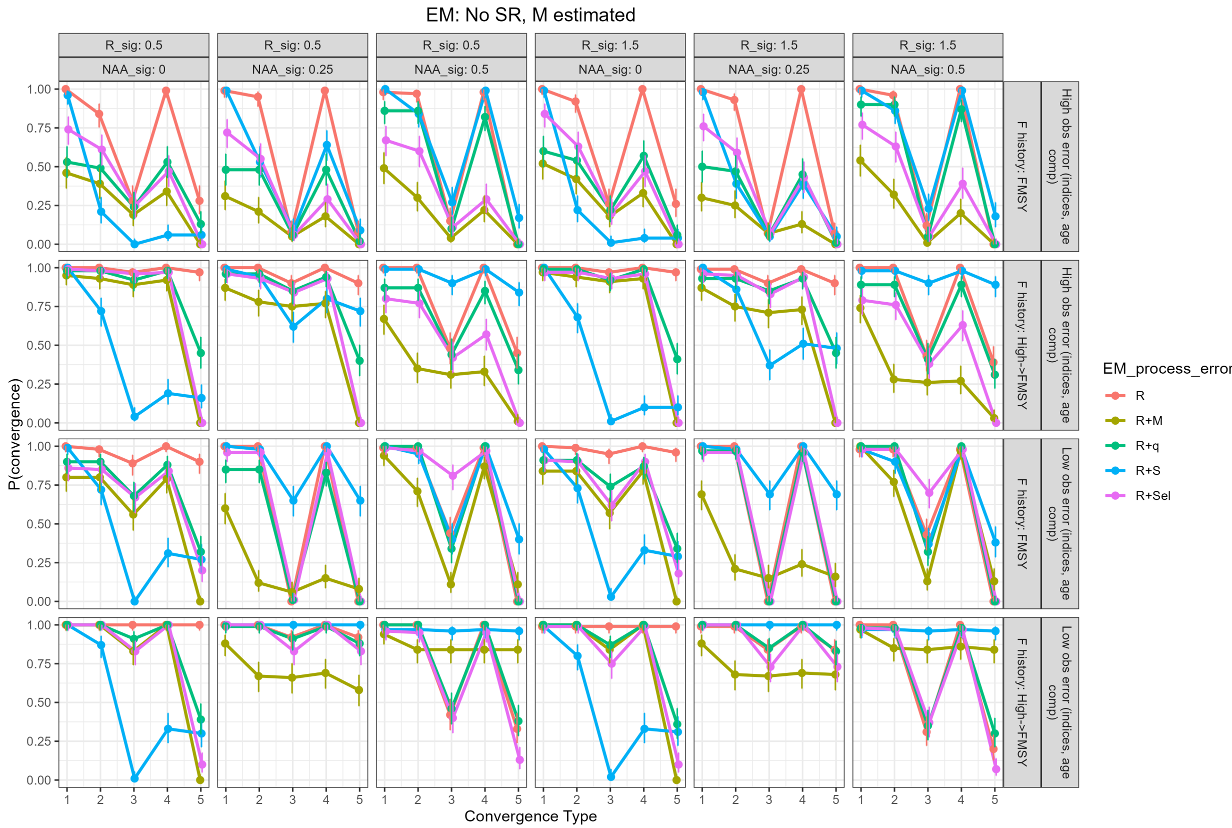


Fig. 3. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structures R and R+S. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is fixed at the true value.

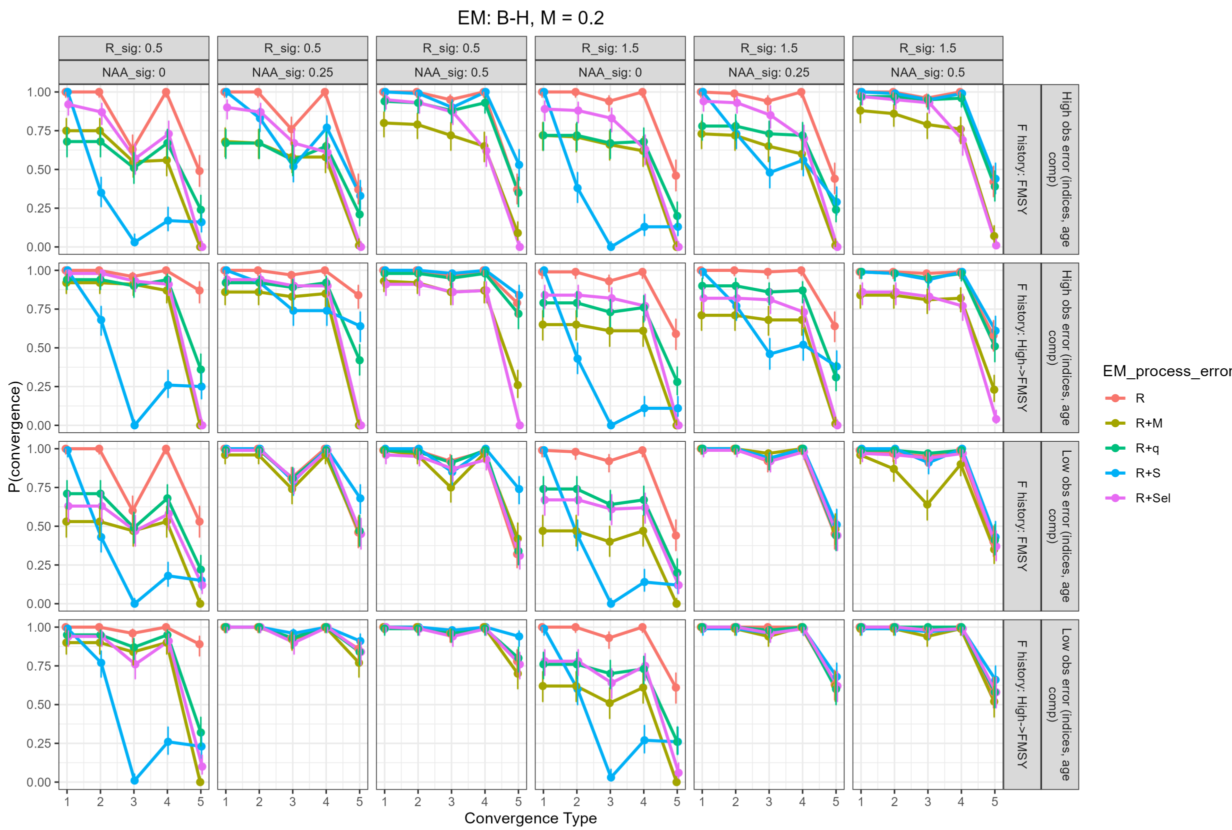
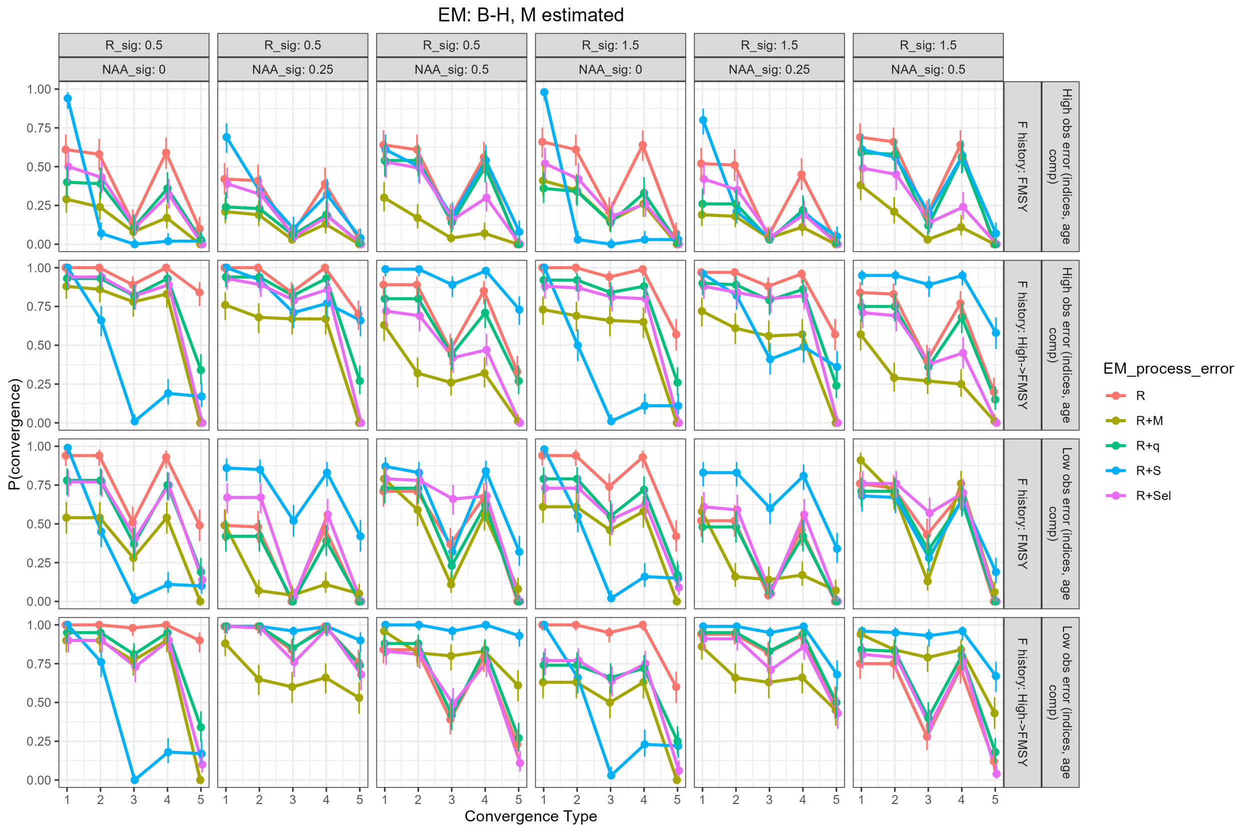


Fig. 4. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structures R and R+S. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is estimated.



3.1.2 R+M operating models

Fig. 5. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+M. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is fixed at the true value.

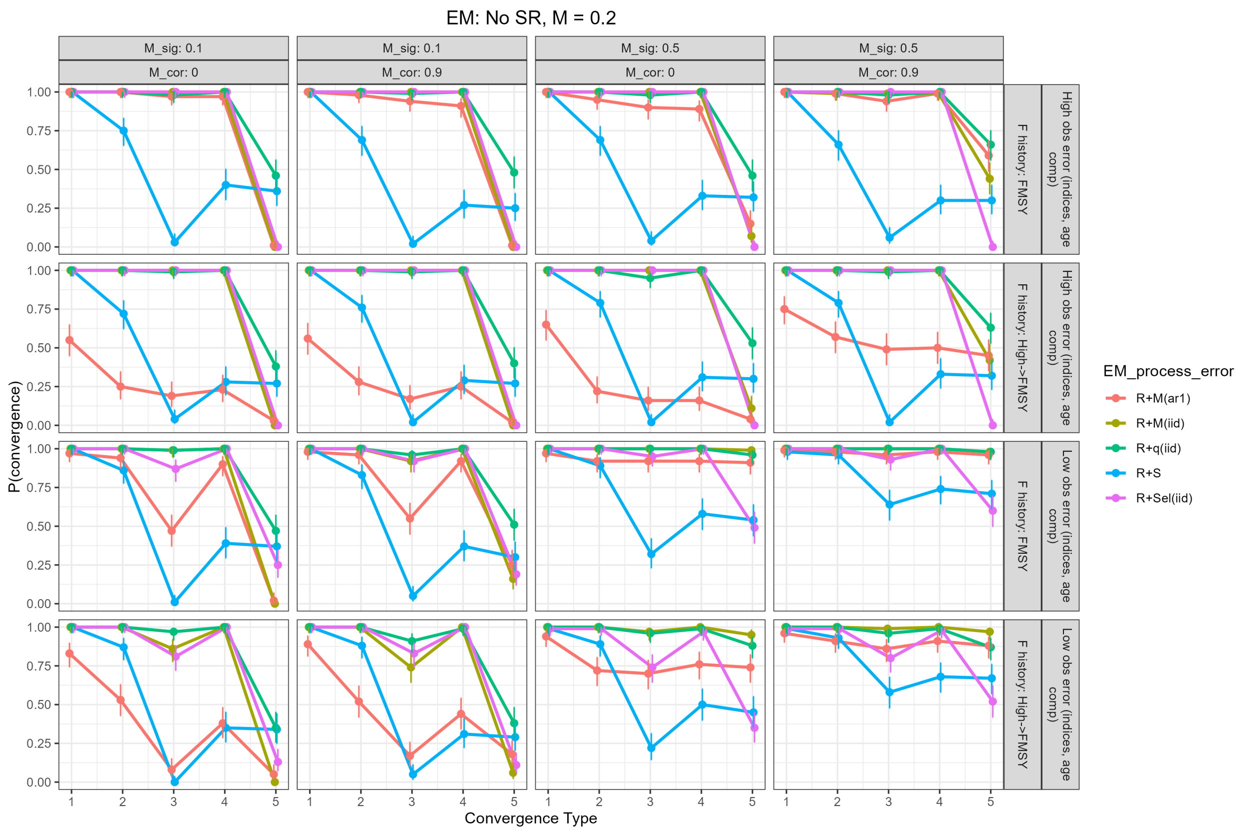


Fig. 6. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+M. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is estimated.

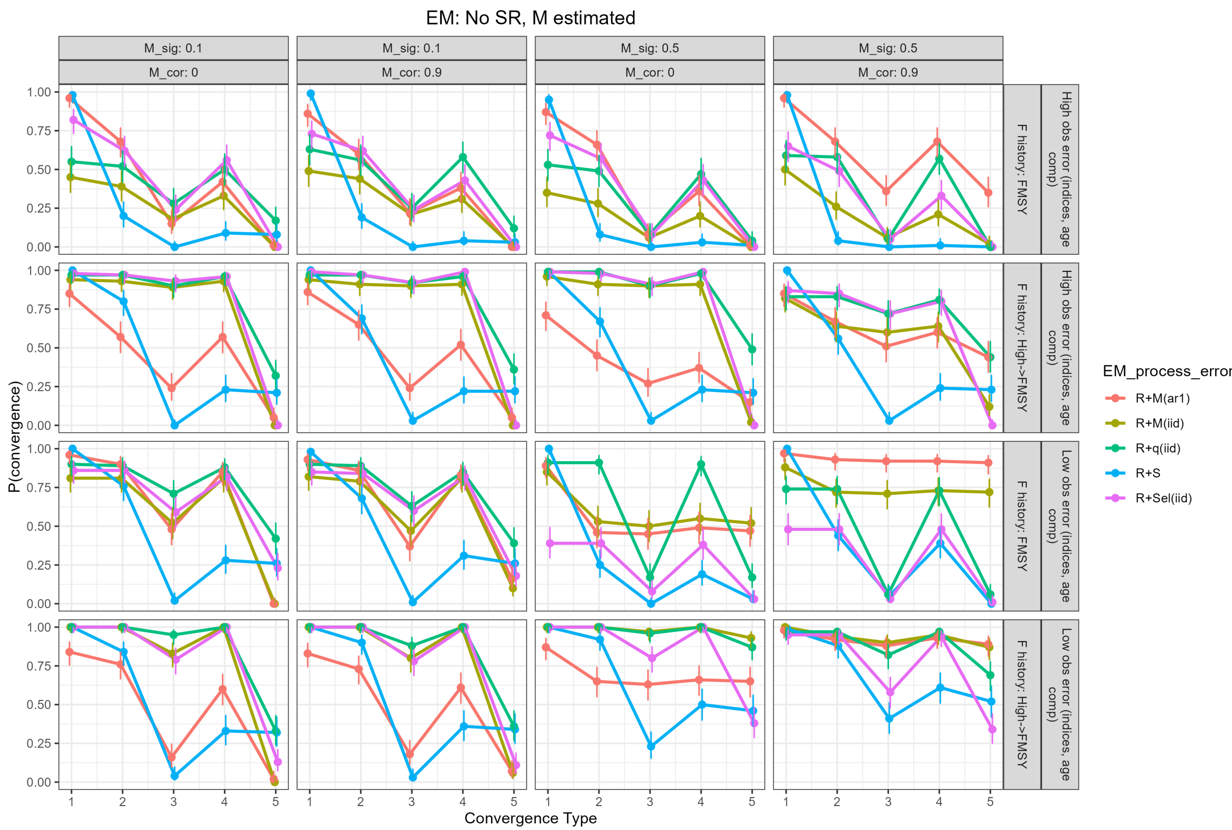


Fig. 7. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+M. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is fixed at the true value.

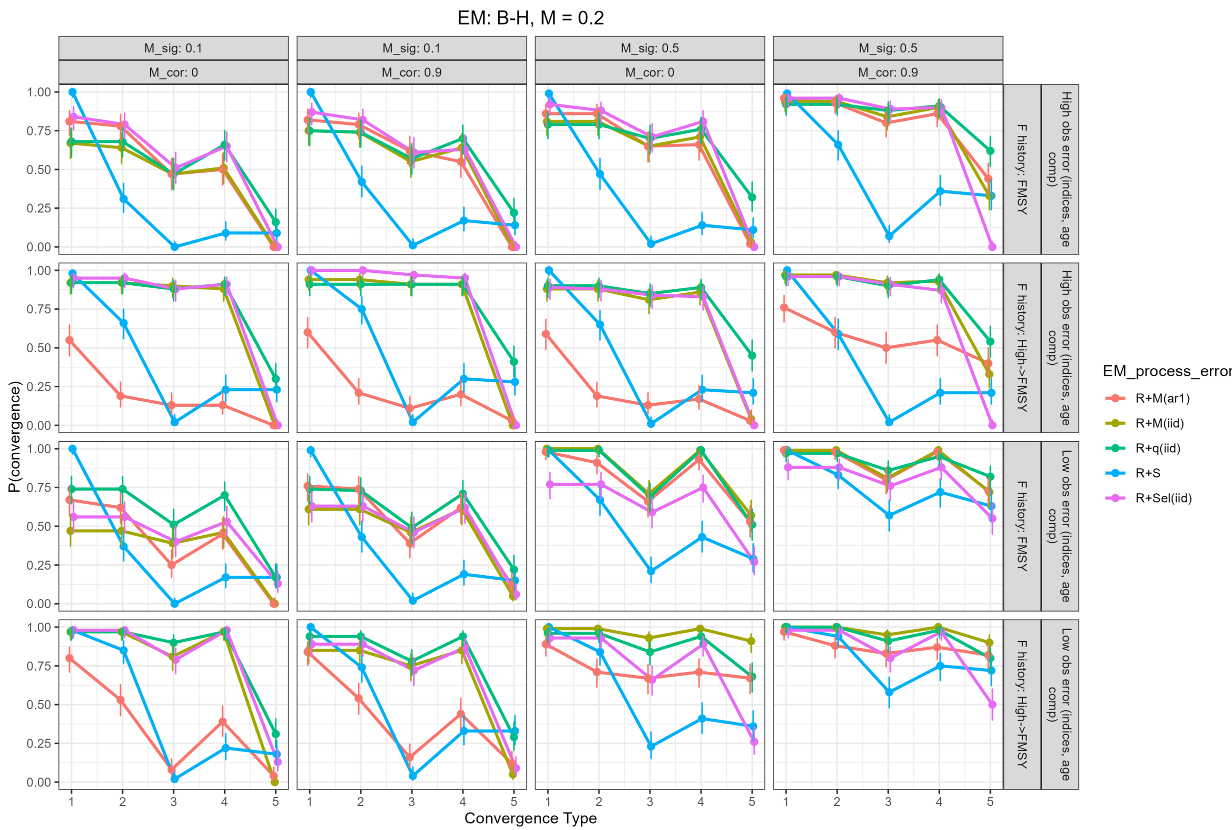
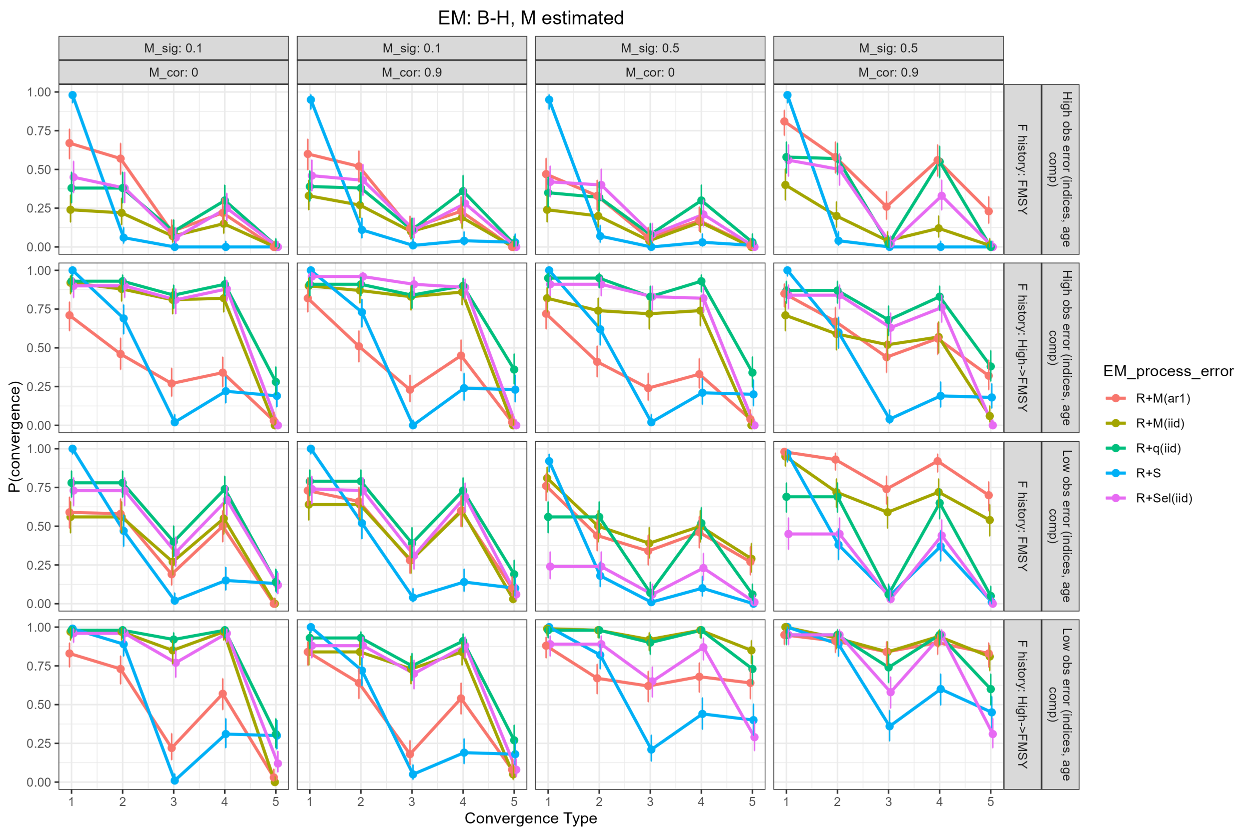


Fig. 8. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+M. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is estimated.



3.1.3 R+Sel operating models

Fig. 9. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+Sel. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is fixed at the true value.

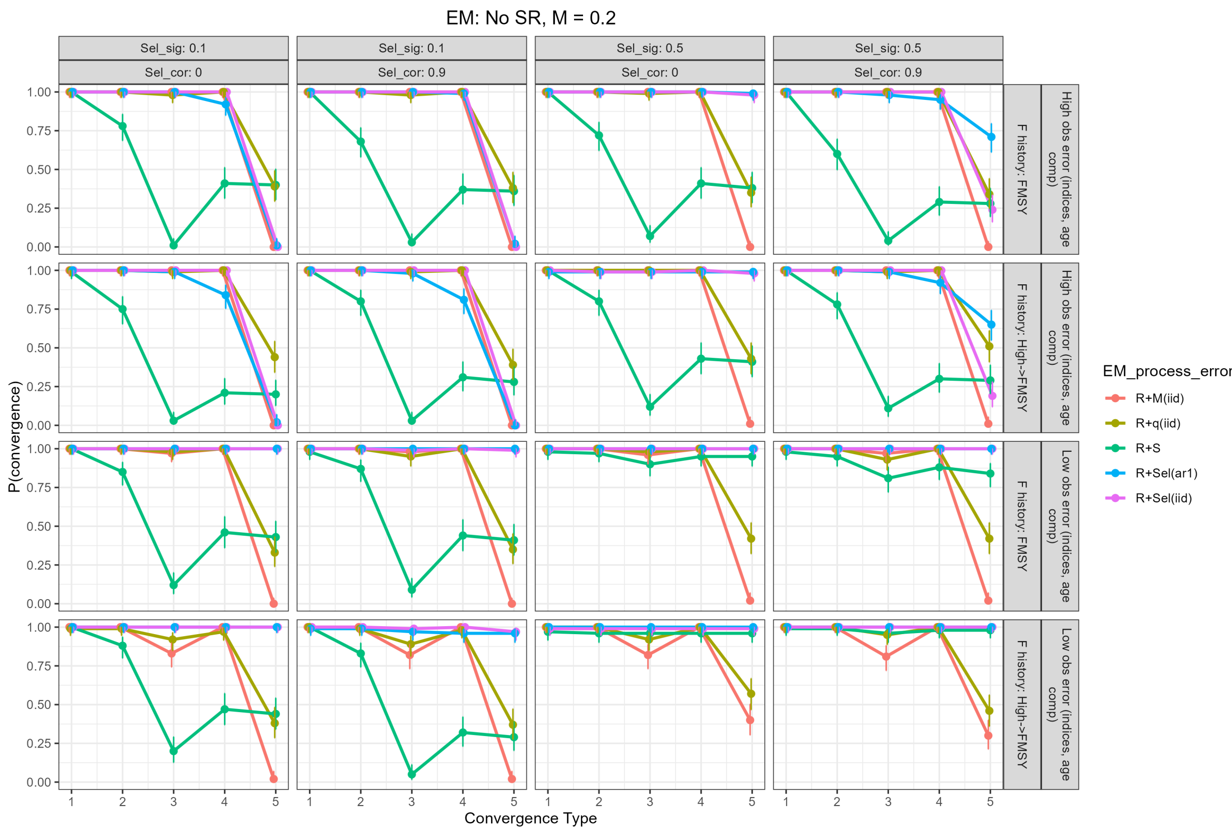


Fig. 10. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+Sel. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is estimated.

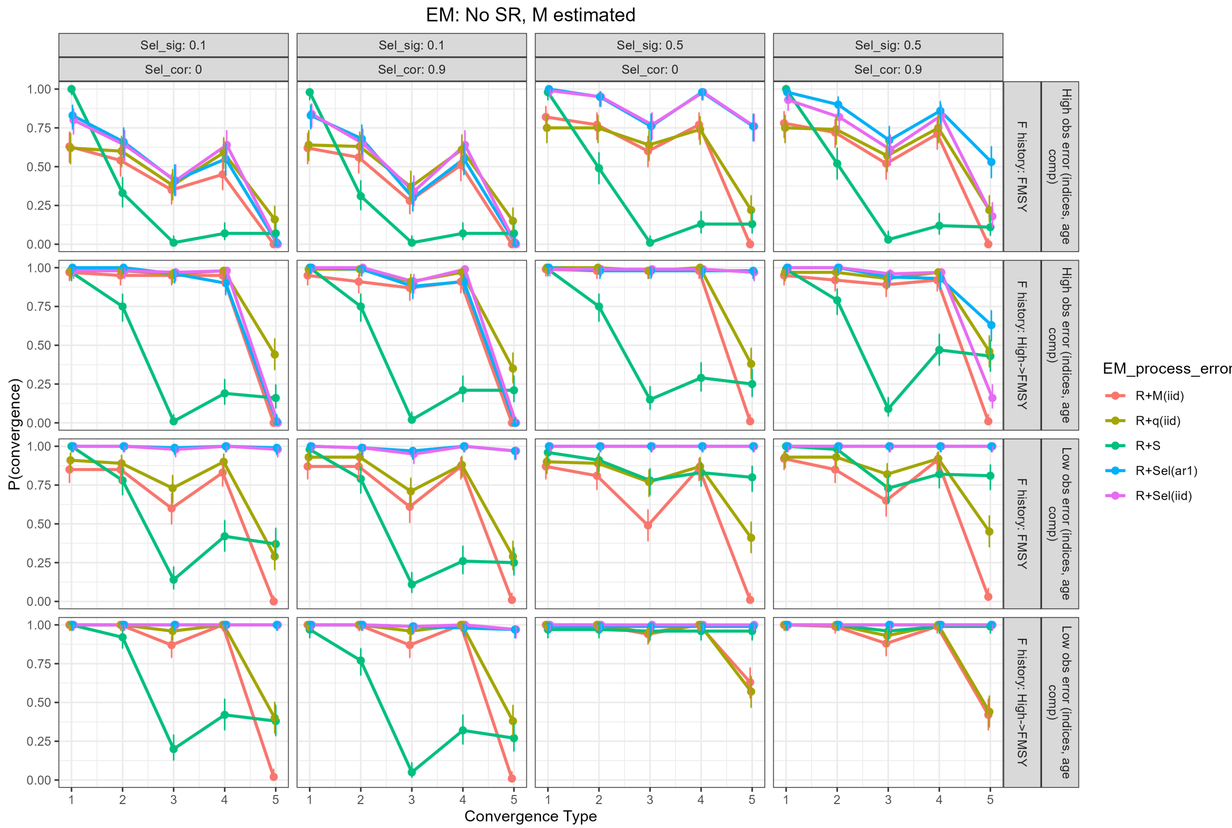


Fig. 11. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+Sel. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is fixed at the true value.

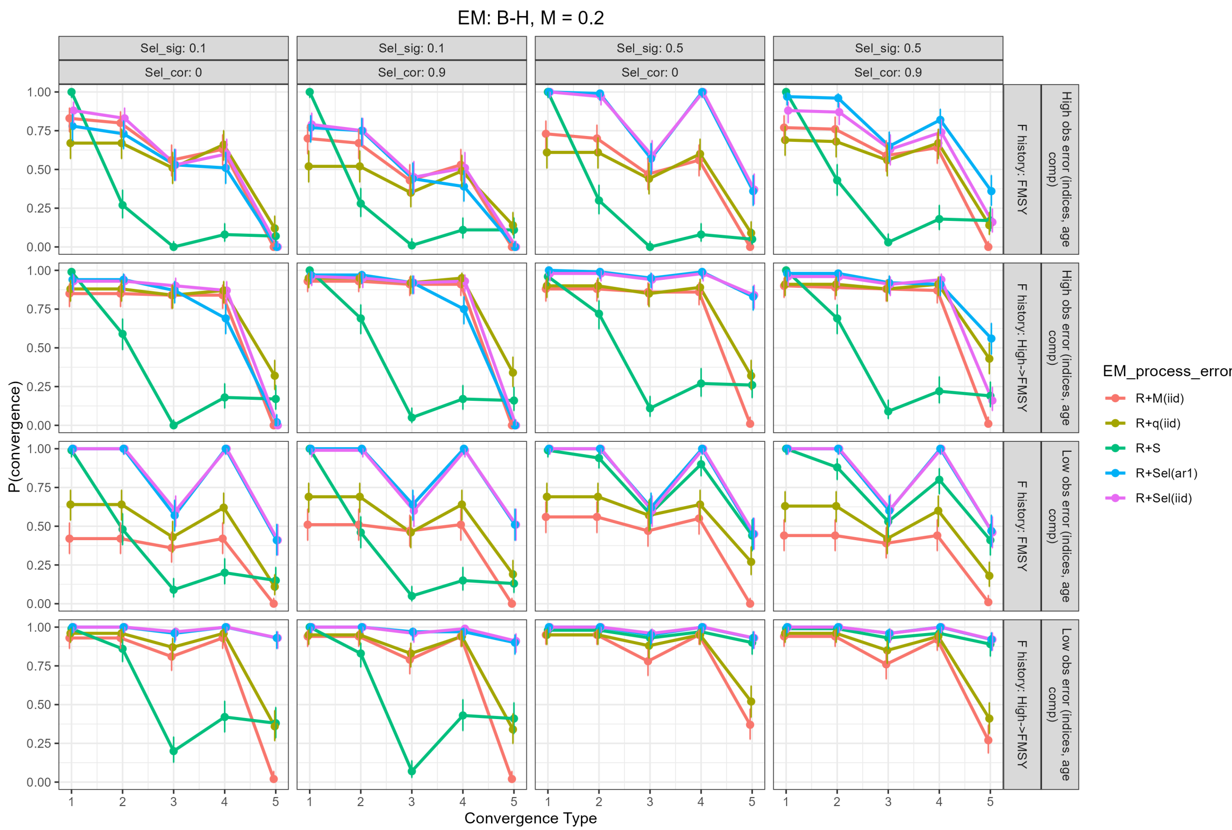
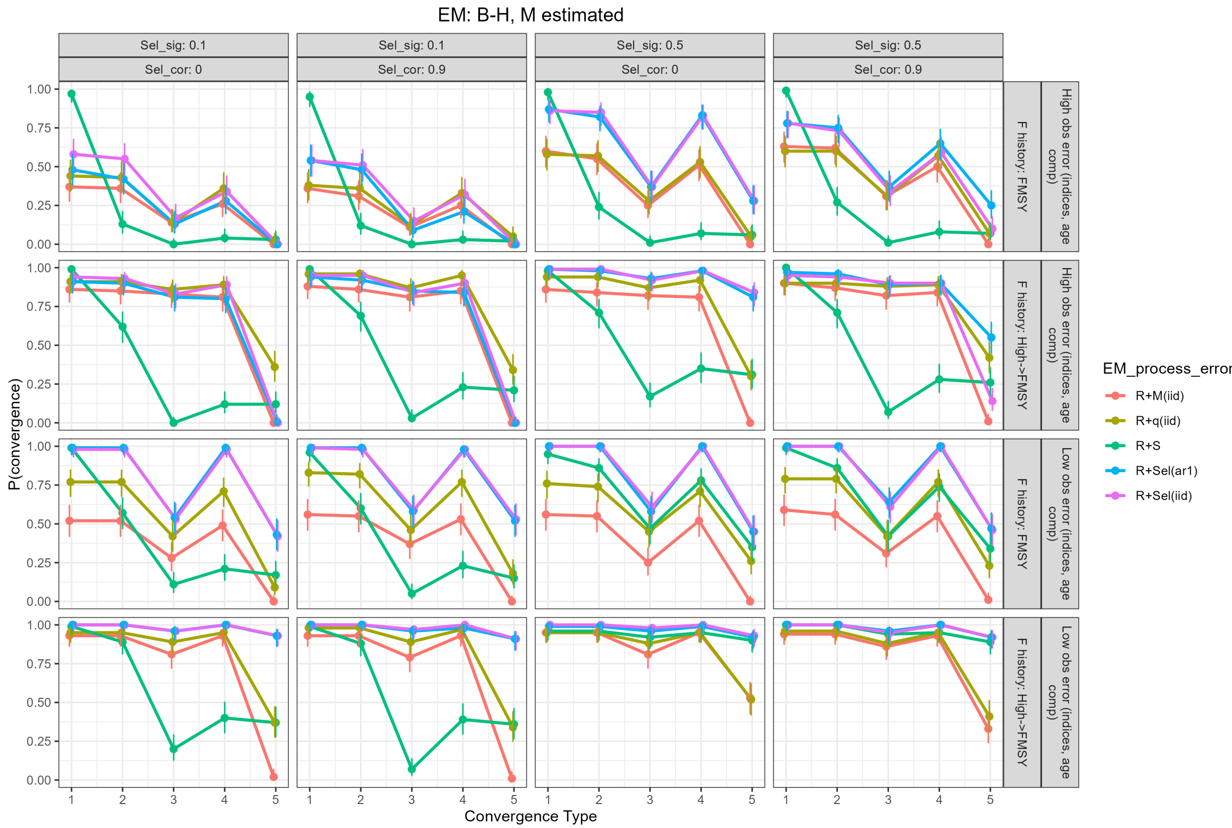


Fig. 12. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+Sel. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is estimated.



3.1.4 R+q operating models

Fig. 13. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+q. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is fixed at the true value.

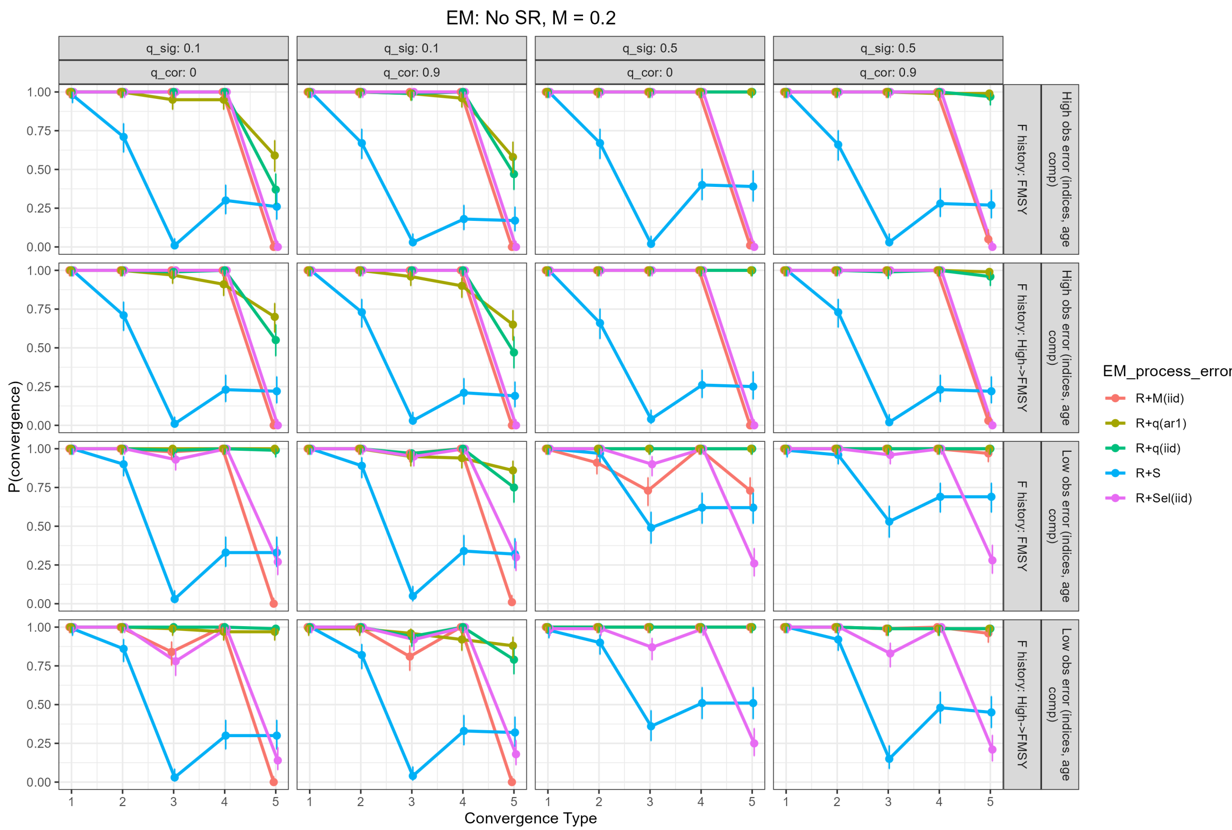


Fig. 14. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+q. vertical lines represent 95% confidence intervals. All estimating models estimate mean recruitment rather than a stock-recruit relationship and and M is estimated.

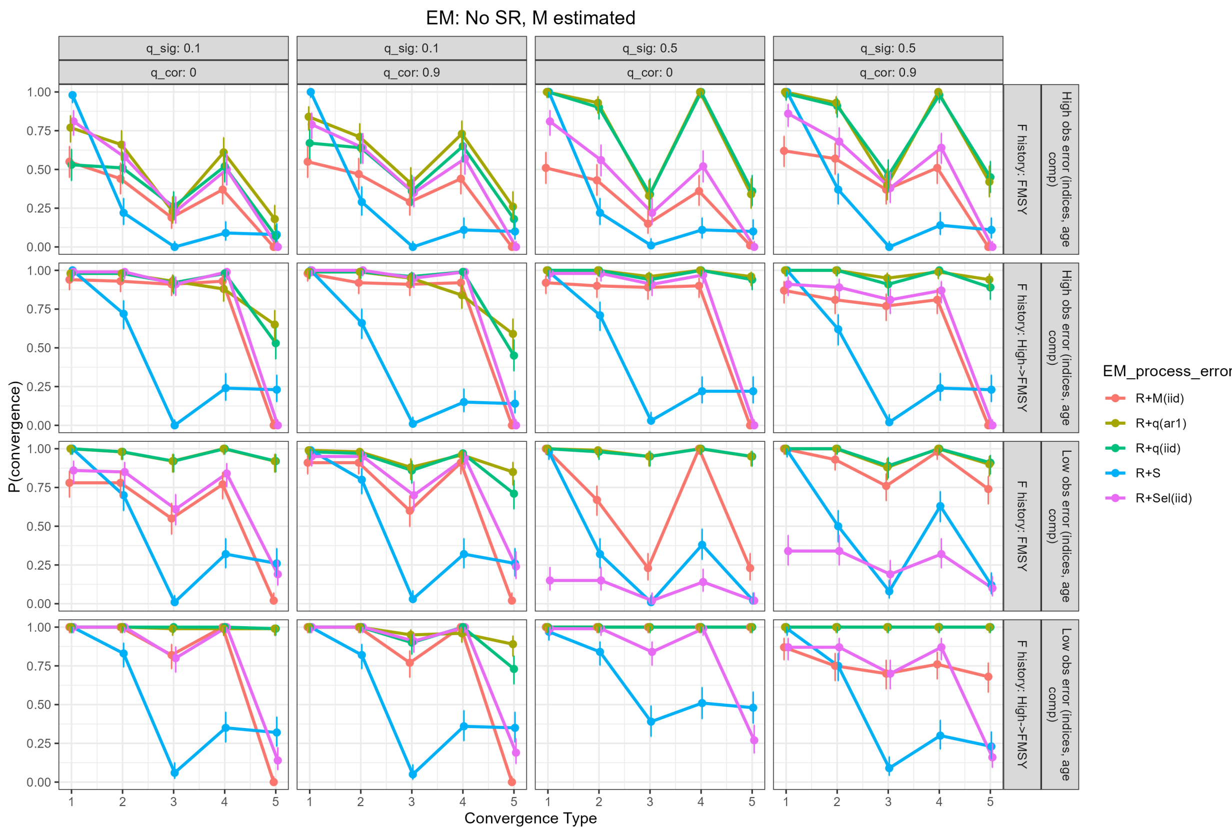


Fig. 15. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+q. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is fixed at the true value.

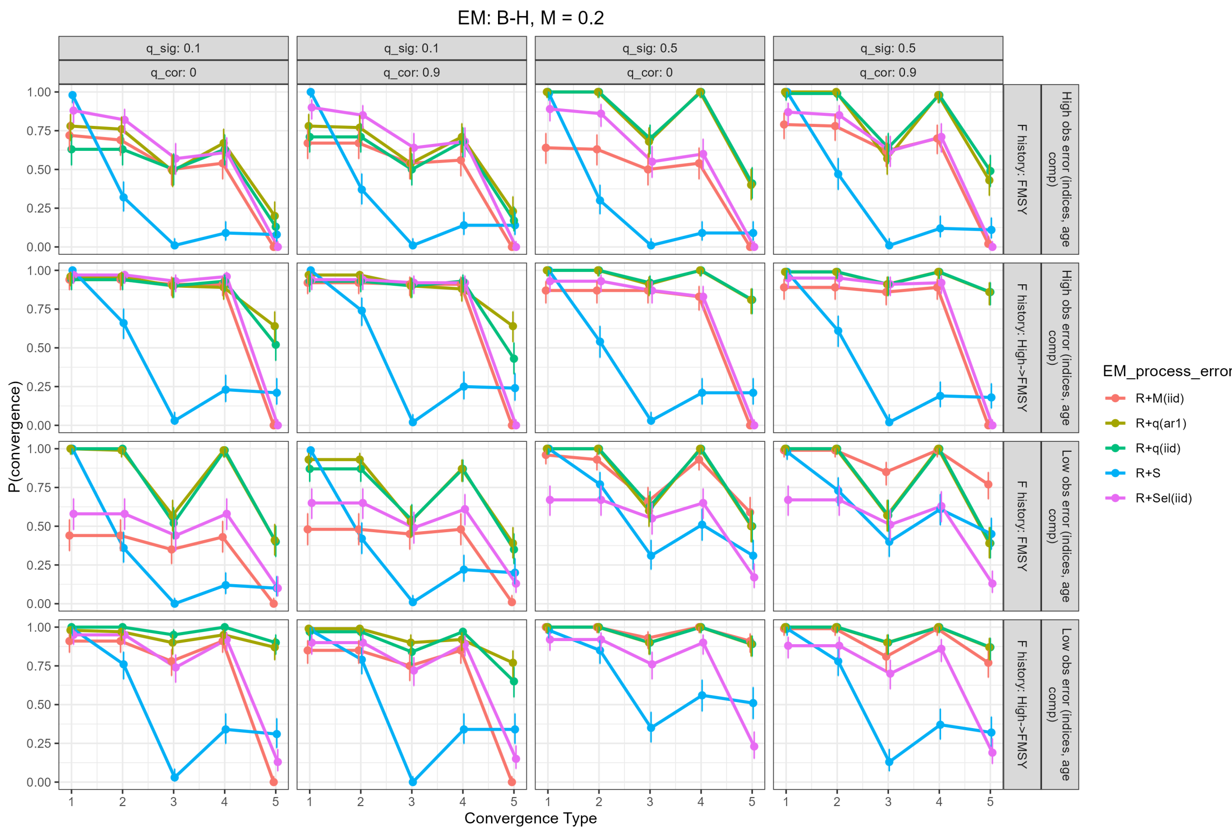
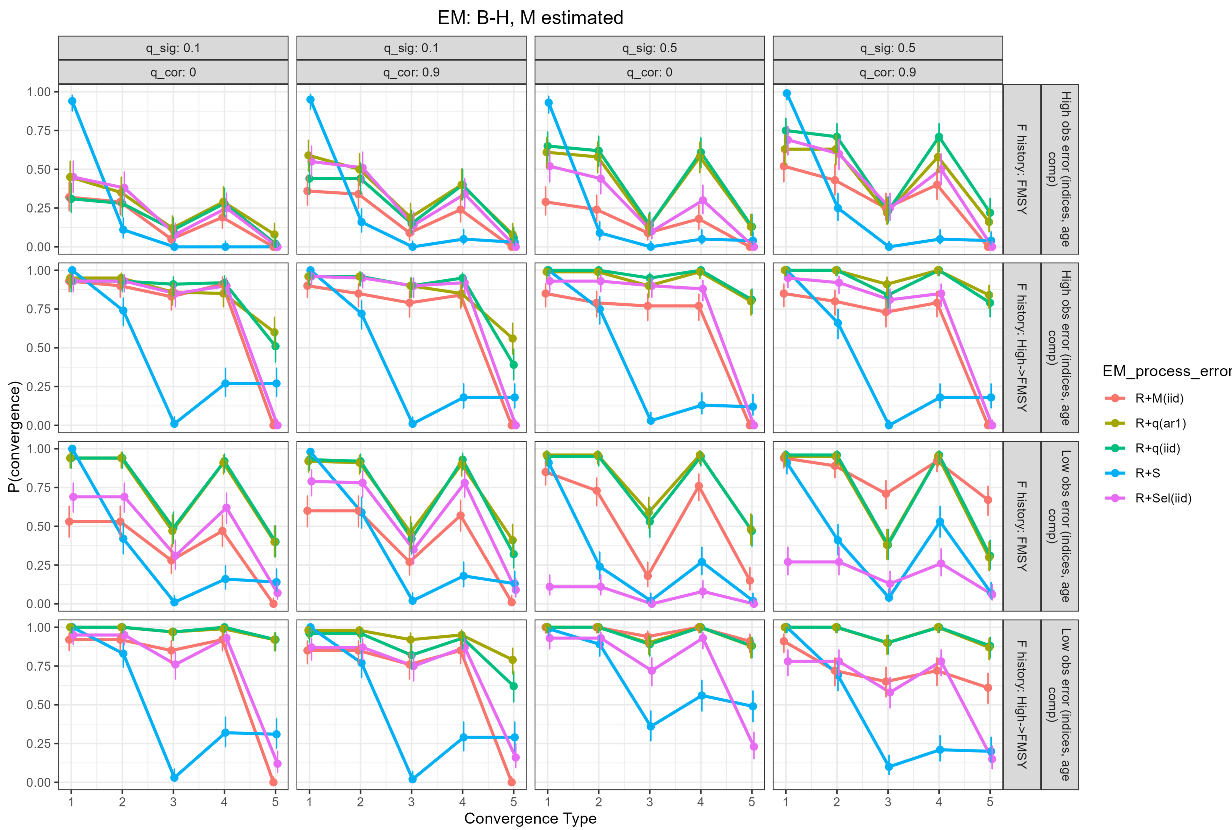


Fig. 16. Probability of each type of convergence of estimating models with alternative process error assumptions for operating models that have process error structure R+q. vertical lines represent 95% confidence intervals. All estimating models estimate a Beverton-Holt stock-recruit relationship and and M is estimated.



3.2 AIC performance for process error structure

3.2.1 Numbers at age operating models

3.3 Estimating models include alternative random effects options: NAA, M, sel, q

Table 6. NAA operating models, estimating models all assume a B-H stock recruit relationship and M is fixed at the true value.

σ_R	σ_N	F-history	Obs Error	R only	NAA	M	Sel	q
0.5		H-MSY	L	98	0	0	0	2
1.5		H-MSY	L	97	0	0	0	3
0.5	0.25	H-MSY	L	0	100	0	0	0
1.5	0.25	H-MSY	L	0	99	1	0	0
0.5	0.50	H-MSY	L	0	100	0	0	0
1.5	0.50	H-MSY	L	0	99	1	0	0
0.5		MSY	L	97	0	0	1	2
1.5		MSY	L	95	0	0	1	4
0.5	0.25	MSY	L	0	100	0	0	0
1.5	0.25	MSY	L	0	100	0	0	0
0.5	0.50	MSY	L	0	100	0	0	0
1.5	0.50	MSY	L	0	100	0	0	0
0.5		H-MSY	H	94	0	0	0	6
1.5		H-MSY	H	94	0	0	1	5
0.5	0.25	H-MSY	H	47	50	0	0	3
1.5	0.25	H-MSY	H	66	30	0	0	4
0.5	0.50	H-MSY	H	0	100	0	0	0
1.5	0.50	H-MSY	H	1	98	0	0	1
0.5		MSY	H	93	0	0	0	7
1.5		MSY	H	95	0	0	0	5
0.5	0.25	MSY	H	45	53	0	0	2
1.5	0.25	MSY	H	64	30	0	0	6
0.5	0.50	MSY	H	0	100	0	0	0
1.5	0.50	MSY	H	0	99	0	0	1

Table 7. NAA operating models, estimating models all assume a B-H stock recruit relationship and M is estimated.

σ_R	σ_N	F-history	Obs Error	R only	NAA	M	Sel	q
0.5		H-MSY	L	98	0	0	0	2
1.5		H-MSY	L	97	0	0	0	3
0.5	0.25	H-MSY	L	0	99	0	1	0
1.5	0.25	H-MSY	L	0	99	1	0	0
0.5	0.50	H-MSY	L	0	100	0	0	0
1.5	0.50	H-MSY	L	0	96	3	1	0
0.5		MSY	L	90	6	0	1	3
1.5		MSY	L	91	5	0	0	4
0.5	0.25	MSY	L	0	86	3	8	0
1.5	0.25	MSY	L	0	83	4	5	0
0.5	0.50	MSY	L	0	87	8	3	2
1.5	0.50	MSY	L	0	68	28	3	1
0.5		H-MSY	H	94	0	0	0	6
1.5		H-MSY	H	97	0	0	0	3
0.5	0.25	H-MSY	H	49	48	0	0	3
1.5	0.25	H-MSY	H	70	27	0	0	3
0.5	0.50	H-MSY	H	0	99	0	0	0
1.5	0.50	H-MSY	H	3	94	0	0	1
0.5		MSY	H	57	30	0	1	6
1.5		MSY	H	63	31	0	0	3
0.5	0.25	MSY	H	26	42	0	1	5
1.5	0.25	MSY	H	37	41	0	0	3
0.5	0.50	MSY	H	12	61	2	1	7
1.5	0.50	MSY	H	7	61	2	0	10

Table 8. NAA operating models, estimating models all estimate a mean recruitment and M is fixed at the true value.

σ_R	σ_N	F-history	Obs Error	R only	NAA	M	Sel	q
0.5		H-MSY	L	98	0	0	0	2
1.5		H-MSY	L	97	0	0	0	3
0.5	0.25	H-MSY	L	0	98	2	0	0
1.5	0.25	H-MSY	L	0	100	0	0	0
0.5	0.50	H-MSY	L	0	97	3	0	0
1.5	0.50	H-MSY	L	0	97	3	0	0
0.5		MSY	L	97	0	0	1	2
1.5		MSY	L	97	0	0	0	3
0.5	0.25	MSY	L	0	100	0	0	0
1.5	0.25	MSY	L	0	100	0	0	0
0.5	0.50	MSY	L	0	99	1	0	0
1.5	0.50	MSY	L	0	99	1	0	0
0.5		H-MSY	H	94	0	0	0	6
1.5		H-MSY	H	95	0	0	0	5
0.5	0.25	H-MSY	H	49	48	0	0	3
1.5	0.25	H-MSY	H	66	30	0	0	4
0.5	0.50	H-MSY	H	1	99	0	0	0
1.5	0.50	H-MSY	H	0	99	0	0	1
0.5		MSY	H	93	0	0	0	7
1.5		MSY	H	95	0	0	0	5
0.5	0.25	MSY	H	45	53	0	0	2
1.5	0.25	MSY	H	64	30	0	0	6
0.5	0.50	MSY	H	0	100	0	0	0
1.5	0.50	MSY	H	0	98	1	0	1

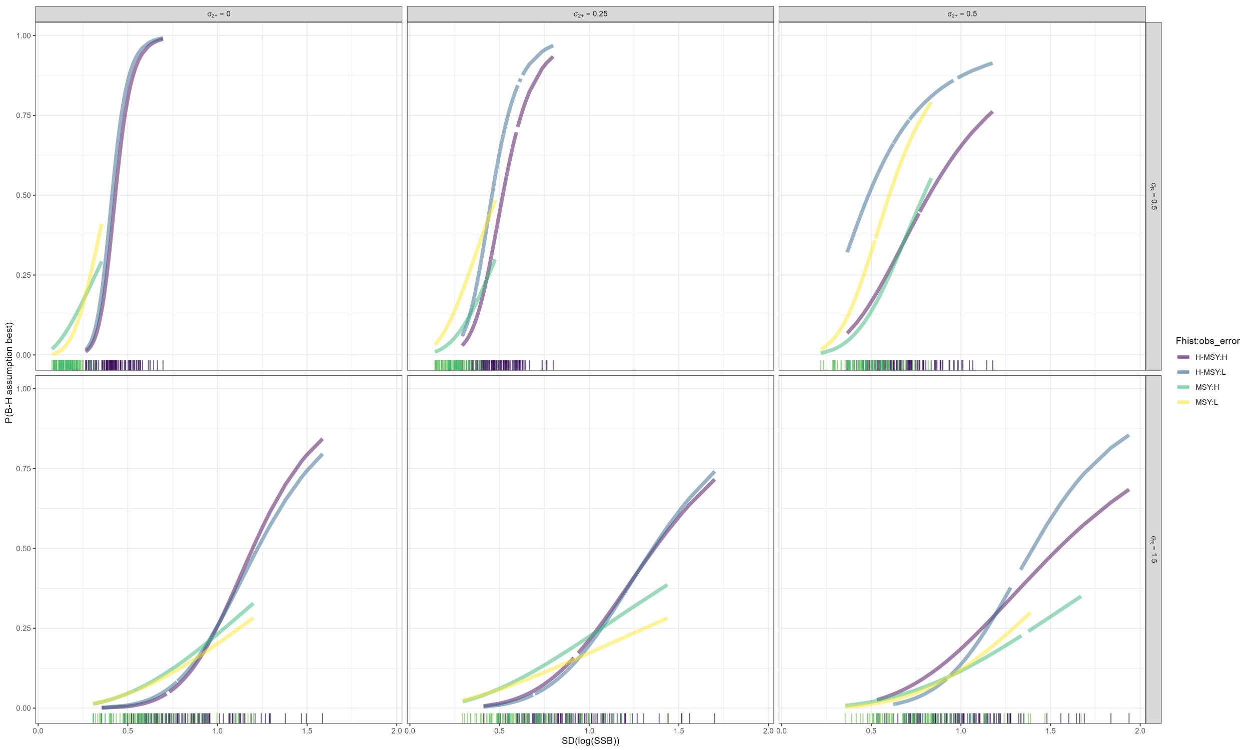
Table 9. NAA operating models, estimating models all estimate a mean recruitment and M estimated.

σ_R	σ_N	F-history	Obs Error	R only	NAA	M	Sel	q
0.5		H-MSY	L	98	0	0	0	2
1.5		H-MSY	L	97	0	0	0	3
0.5	0.25	H-MSY	L	0	98	2	0	0
1.5	0.25	H-MSY	L	0	100	0	0	0
0.5	0.50	H-MSY	L	0	97	3	0	0
1.5	0.50	H-MSY	L	0	97	3	0	0
0.5		MSY	L	97	0	0	1	2
1.5		MSY	L	97	0	0	0	3
0.5	0.25	MSY	L	0	100	0	0	0
1.5	0.25	MSY	L	0	100	0	0	0
0.5	0.50	MSY	L	0	99	1	0	0
1.5	0.50	MSY	L	0	99	1	0	0
0.5		H-MSY	H	94	0	0	0	6
1.5		H-MSY	H	95	0	0	0	5
0.5	0.25	H-MSY	H	49	48	0	0	3
1.5	0.25	H-MSY	H	66	30	0	0	4
0.5	0.50	H-MSY	H	1	99	0	0	0
1.5	0.50	H-MSY	H	0	99	0	0	1
0.5		MSY	H	93	0	0	0	7
1.5		MSY	H	95	0	0	0	5
0.5	0.25	MSY	H	45	53	0	0	2
1.5	0.25	MSY	H	64	30	0	0	6
0.5	0.50	MSY	H	0	100	0	0	0
1.5	0.50	MSY	H	0	98	1	0	1

3.4 AIC performance for stock-recruit relationship

3.4.1 R, R+S operating models

Fig. 17. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Operating and estimating models have matching R or R+S process error structures. Estimating models assume mean M is fixed at the true value.



3.4.2 R+M operating models

3.4.3 R+Sel operating models

3.4.4 R+q operating models

Table 10. Operating models and estimation models all assume matching R or R+S process error structure, estimating models assume mean recruitment or a B-H stock recruit relationship and M is either fixed at the true value or estimated.

σ_R	σ_N	F-history	Obs Error	R (M fix)	BH (M fix)	R (M est)	BH (M est)
0.5		H-MSY	L	46	54	45	55
1.5		H-MSY	L	81	19	81	19
0.5		MSY	L	94	6	94	6
1.5		MSY	L	91	9	92	8
0.5		H-MSY	H	52	48	56	44
1.5		H-MSY	H	82	18	81	19
0.5		MSY	H	91	9	92	8
1.5		MSY	H	90	10	91	9
0.5	0.25	H-MSY	L	43	57	45	55
1.5	0.25	H-MSY	L	84	16	84	16
0.5	0.50	H-MSY	L	30	70	29	71
1.5	0.50	H-MSY	L	78	22	78	22
0.5	0.25	MSY	L	84	16	84	16
1.5	0.25	MSY	L	90	10	91	9
0.5	0.50	MSY	L	68	32	68	32
1.5	0.50	MSY	L	91	9	90	10
0.5	0.25	H-MSY	H	57	43	62	38
1.5	0.25	H-MSY	H	83	17	81	19
0.5	0.50	H-MSY	H	63	37	65	35
1.5	0.50	H-MSY	H	79	21	81	18
0.5	0.25	MSY	H	93	7	86	13
1.5	0.25	MSY	H	88	12	71	29
0.5	0.50	MSY	H	85	15	89	11
1.5	0.50	MSY	H	91	9	92	7

Fig. 18. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Estimating models allow estimation of mean M.

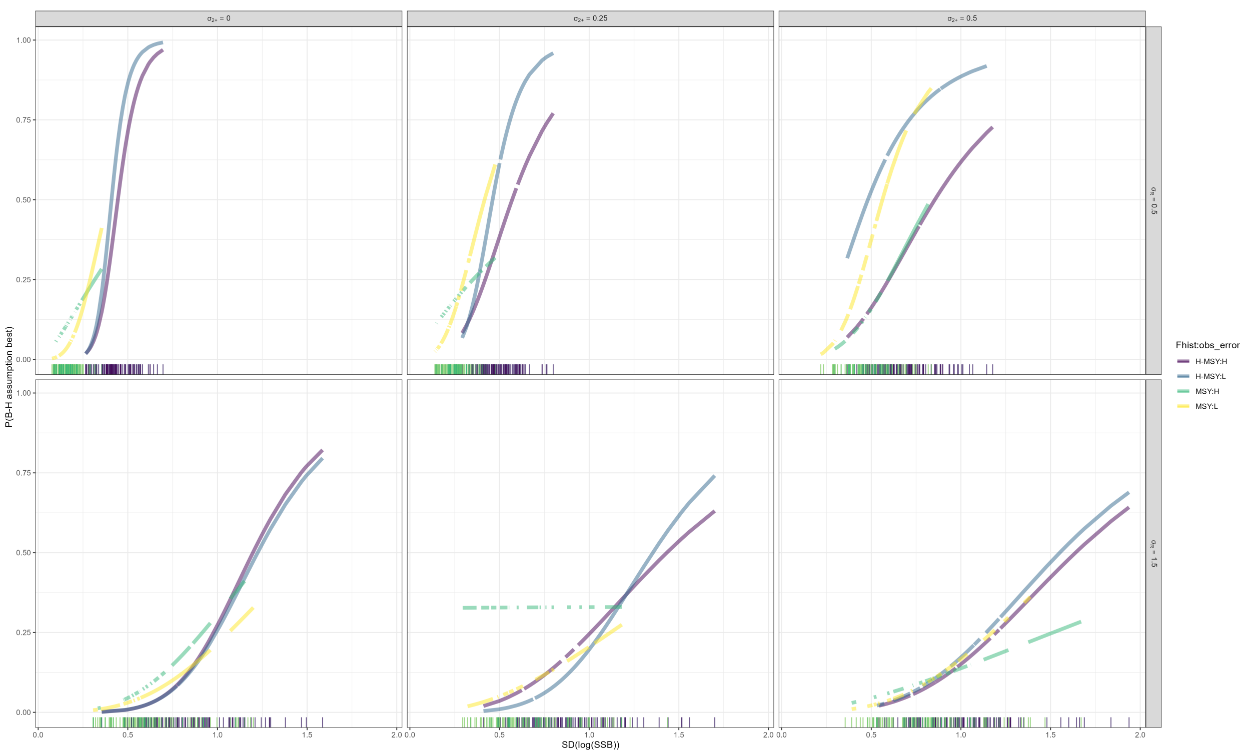


Table 11. Operating models and estimation models all assume matching R+M process error structure, estimating models assume mean recruitment or a B-H stock recruit relationship and M is either fixed at the true value or estimated.

σ_M	ρ_M	F-history	Obs Error	R (M fix)	BH (M fix)	R (M est)	BH (M est)
0.1	0.0	H-MSY	L	45	55	46	54
0.5	0.0	H-MSY	L	34	66	33	67
0.1	0.0	MSY	L	94	6	76	7
0.5	0.0	MSY	L	87	13	73	22
0.1	0.0	H-MSY	H	42	58	46	52
0.5	0.0	H-MSY	H	55	45	57	41
0.1	0.0	MSY	H	96	4	45	9
0.5	0.0	MSY	H	91	9	32	15
0.1	0.9	H-MSY	L	40	56	39	52
0.5	0.9	H-MSY	L	26	72	25	74
0.1	0.9	MSY	L	95	4	91	5
0.5	0.9	MSY	L	61	38	60	39
0.1	0.9	H-MSY	H	32	39	49	45
0.5	0.9	H-MSY	H	33	50	40	51
0.1	0.9	MSY	H	92	8	82	8
0.5	0.9	MSY	H	63	37	59	41

Fig. 19. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Operating and estimating models have matching R+M process error structures. Estimating models assume mean M is fixed at the true value.

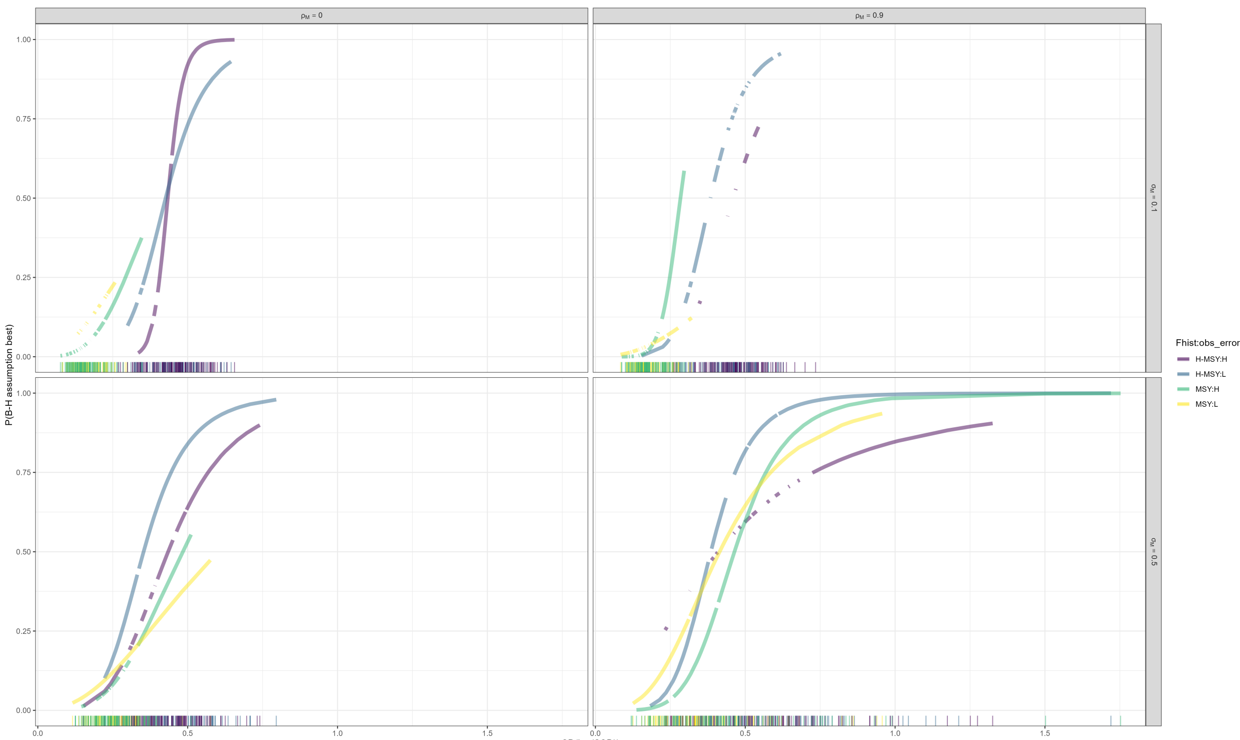


Fig. 20. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Operating and estimating models have matching R+M process error structures. Estimating models allow estimation of mean M.

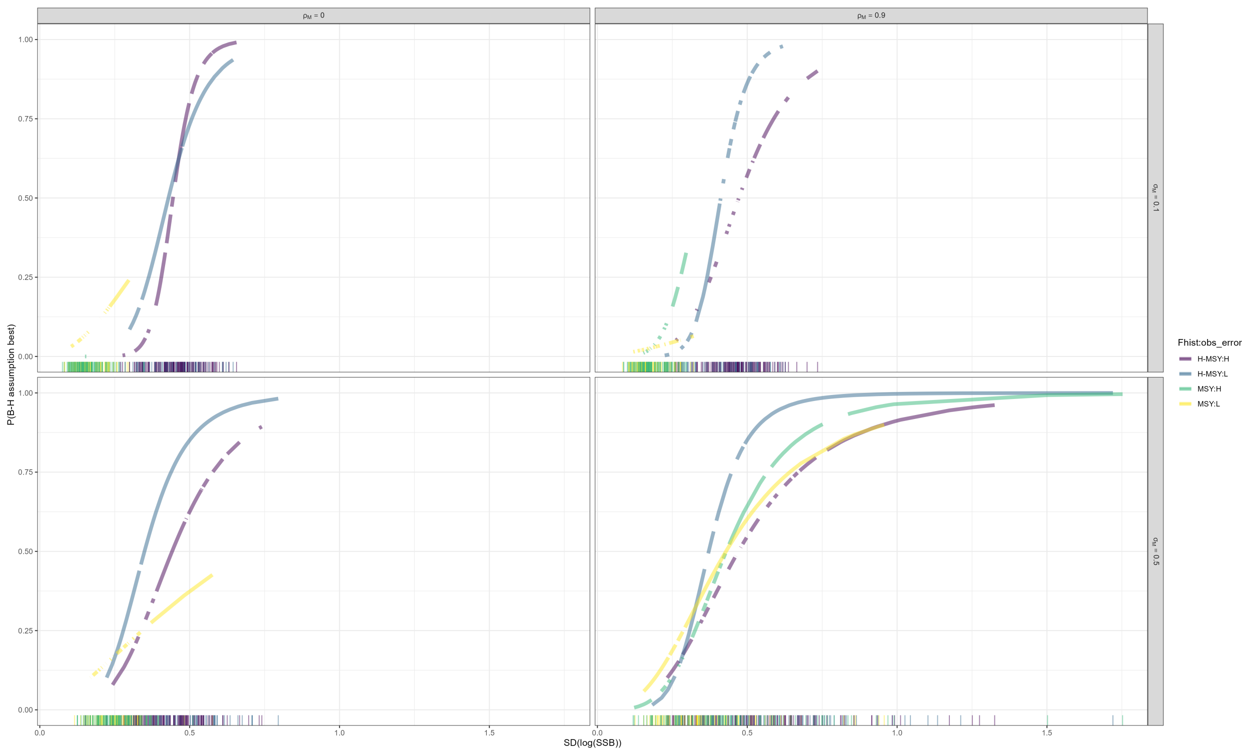


Table 12. Operating models and estimation models all assume matching R+Sel process error structure, estimating models assume mean recruitment or a B-H stock recruit relationship and M is either fixed at the true value or estimated.

σ_{Sel}	ρ_{Sel}	F-history	Obs Error	R (M fix)	BH (M fix)	R (M est)	BH (M est)
0.1	0.0	H-MSY	L	40	60	40	60
0.5	0.0	H-MSY	L	27	73	25	75
0.1	0.0	MSY	L	94	6	95	5
0.5	0.0	MSY	L	95	5	94	6
0.1	0.0	H-MSY	H	51	49	55	44
0.5	0.0	H-MSY	H	41	59	41	58
0.1	0.0	MSY	H	95	5	77	11
0.5	0.0	MSY	H	95	5	94	6
0.1	0.9	H-MSY	L	50	50	48	52
0.5	0.9	H-MSY	L	42	58	45	55
0.1	0.9	MSY	L	92	8	94	6
0.5	0.9	MSY	L	94	6	94	6
0.1	0.9	H-MSY	H	48	52	52	48
0.5	0.9	H-MSY	H	53	47	54	46
0.1	0.9	MSY	H	97	3	80	9
0.5	0.9	MSY	H	96	4	95	3

Fig. 21. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Operating and estimating models have matching R+Sel process error structures. Estimating models assume mean M is fixed at the true value.

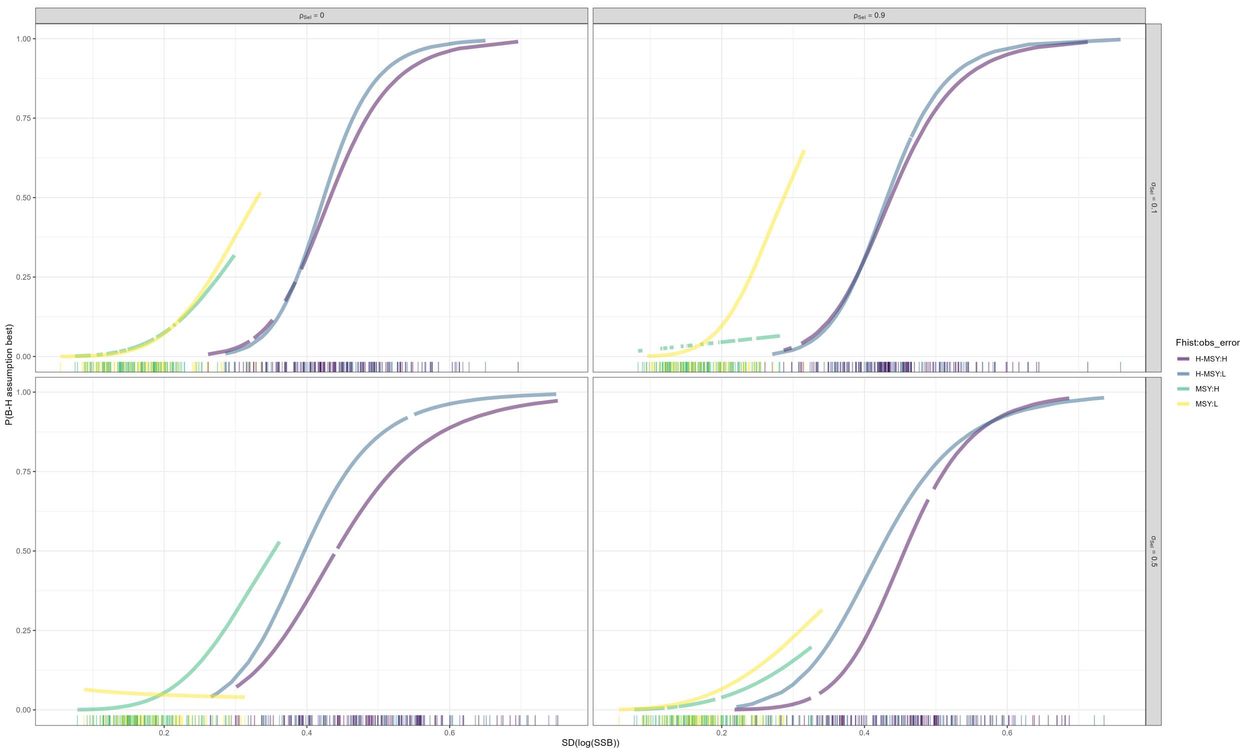


Fig. 22. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Operating and estimating models have matching R+Sel process error structures. Estimating models allow estimation of mean M.

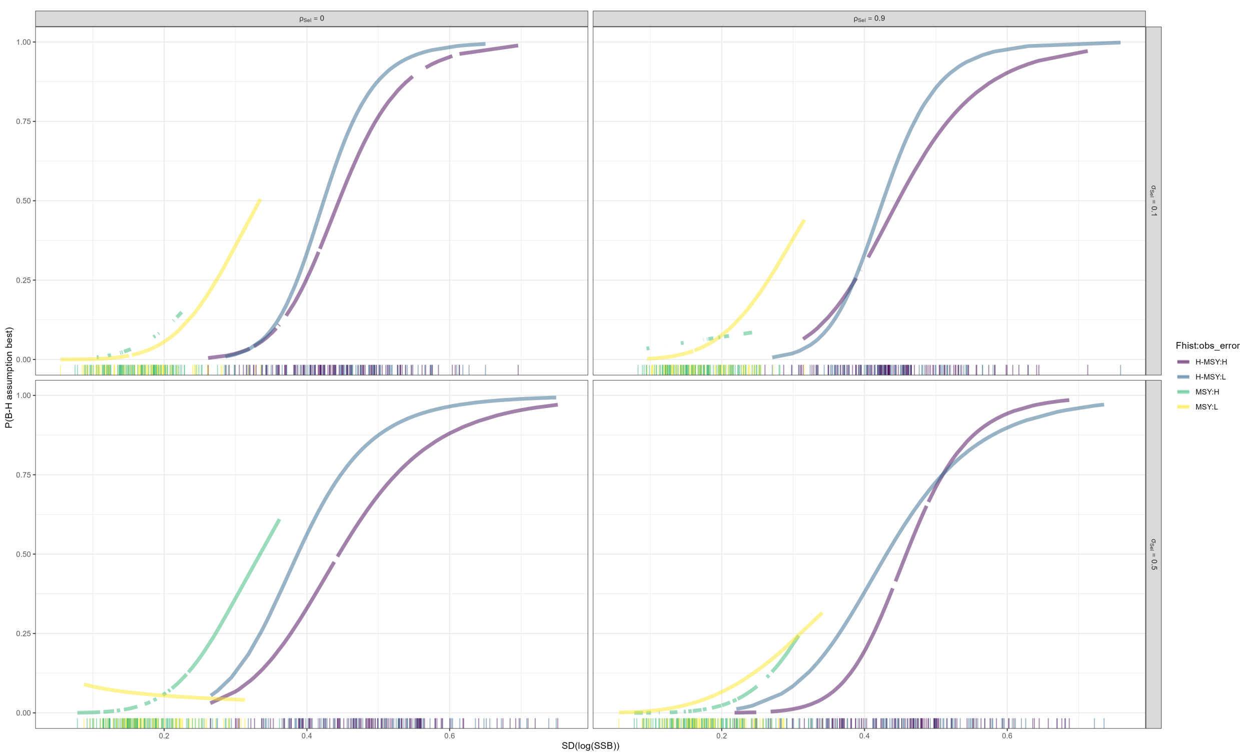


Table 13. Operating models and estimation models all assume matching R+q process error structure, estimating models assume mean recruitment or a B-H stock recruit relationship and M is either fixed at the true value or estimated.

σ_q	ρ_q	F-history	Obs Error	R (M fix)	BH (M fix)	R (M est)	BH (M est)
0.1	0.0	H-MSY	L	39	61	41	59
0.5	0.0	H-MSY	L	46	54	45	55
0.1	0.0	MSY	L	95	5	95	5
0.5	0.0	MSY	L	97	3	95	5
0.1	0.0	H-MSY	H	47	53	52	48
0.5	0.0	H-MSY	H	55	45	62	38
0.1	0.0	MSY	H	92	8	49	6
0.5	0.0	MSY	H	96	4	95	5
0.1	0.9	H-MSY	L	38	62	40	60
0.5	0.9	H-MSY	L	45	55	47	53
0.1	0.9	MSY	L	96	4	94	5
0.5	0.9	MSY	L	97	3	97	3
0.1	0.9	H-MSY	H	51	49	56	44
0.5	0.9	H-MSY	H	51	49	56	44
0.1	0.9	MSY	H	98	2	81	6
0.5	0.9	MSY	H	97	3	97	3

Fig. 23. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Operating and estimating models have matching R+q process error structures. Estimating models assume mean M is fixed at the true value.

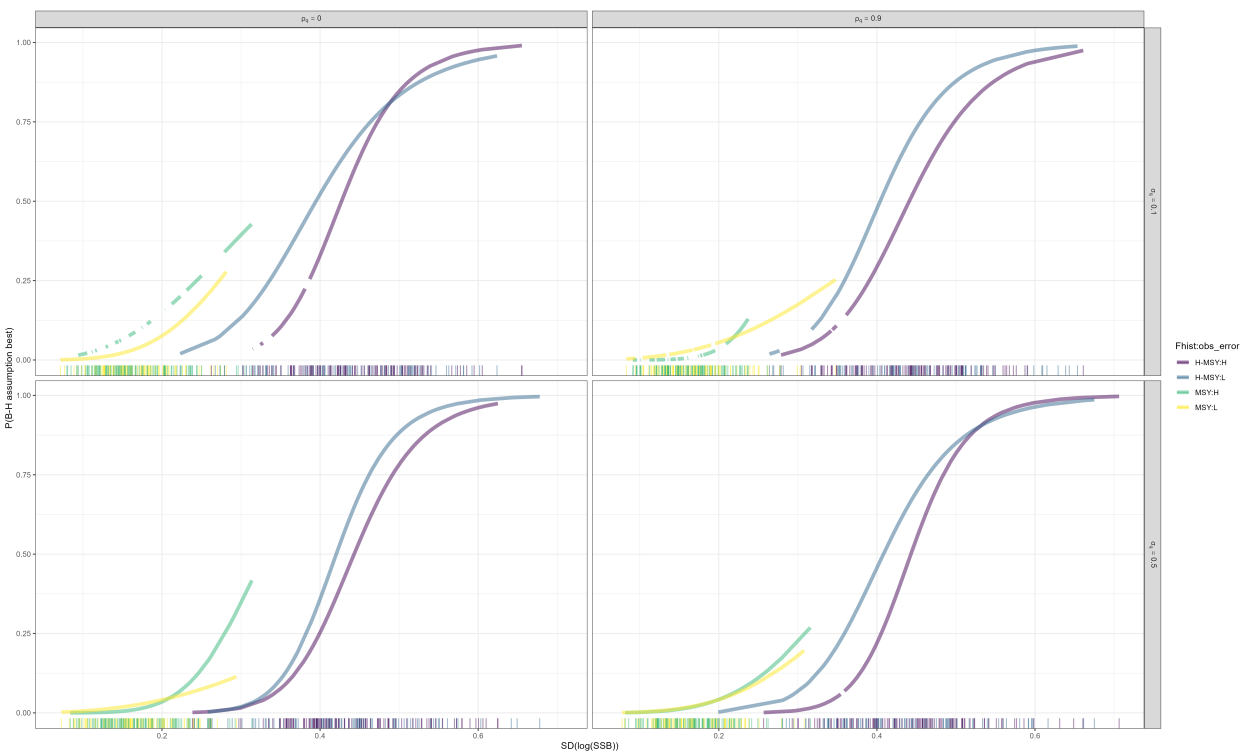
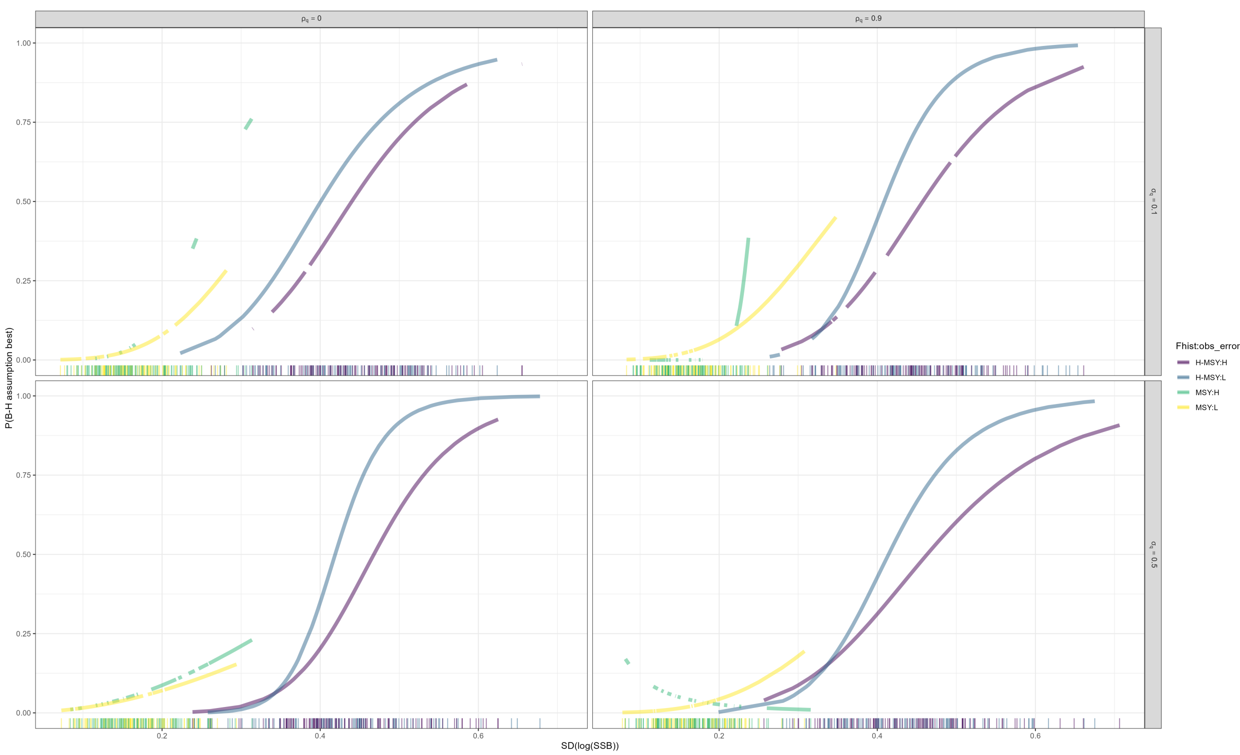


Fig. 24. Predicted probability of AIC preferring BH model as a function of the variation of population SSB. Operating and estimating models have matching R+q process error structures. Estimating models allow estimation of mean M.



3.5 Bias, Mean Square error

Certain basic parameters (stock-recruit pars, M, variance parameters) SSB, F, R, BRPs

Fig. 25. Median relative bias of for SSB for estimating models that estimate mean recruitment and M is fixed at the true value.

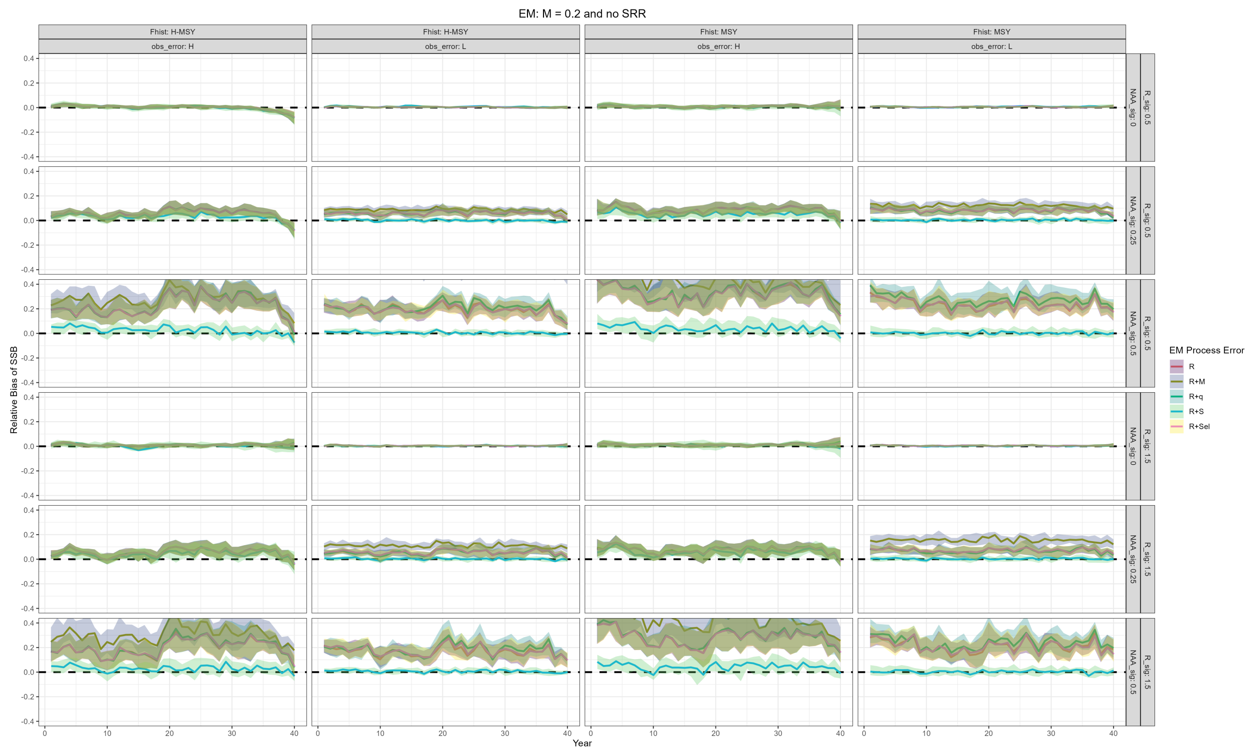


Fig. 26. Median relative bias of for SSB for estimating models that estimate mean recruitment and M is estimated.

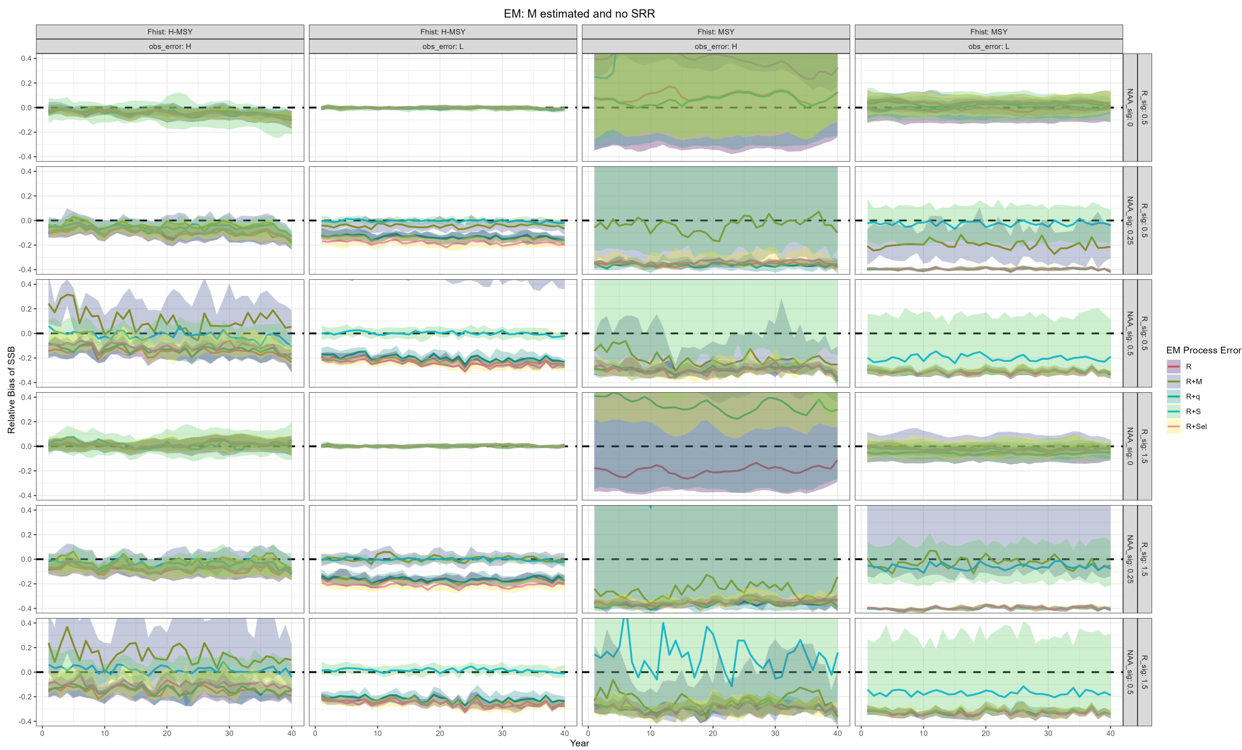


Fig. 27. Median relative bias of for SSB for estimating models that estimates a BH stock-recruitment function and M is fixed at the true value.

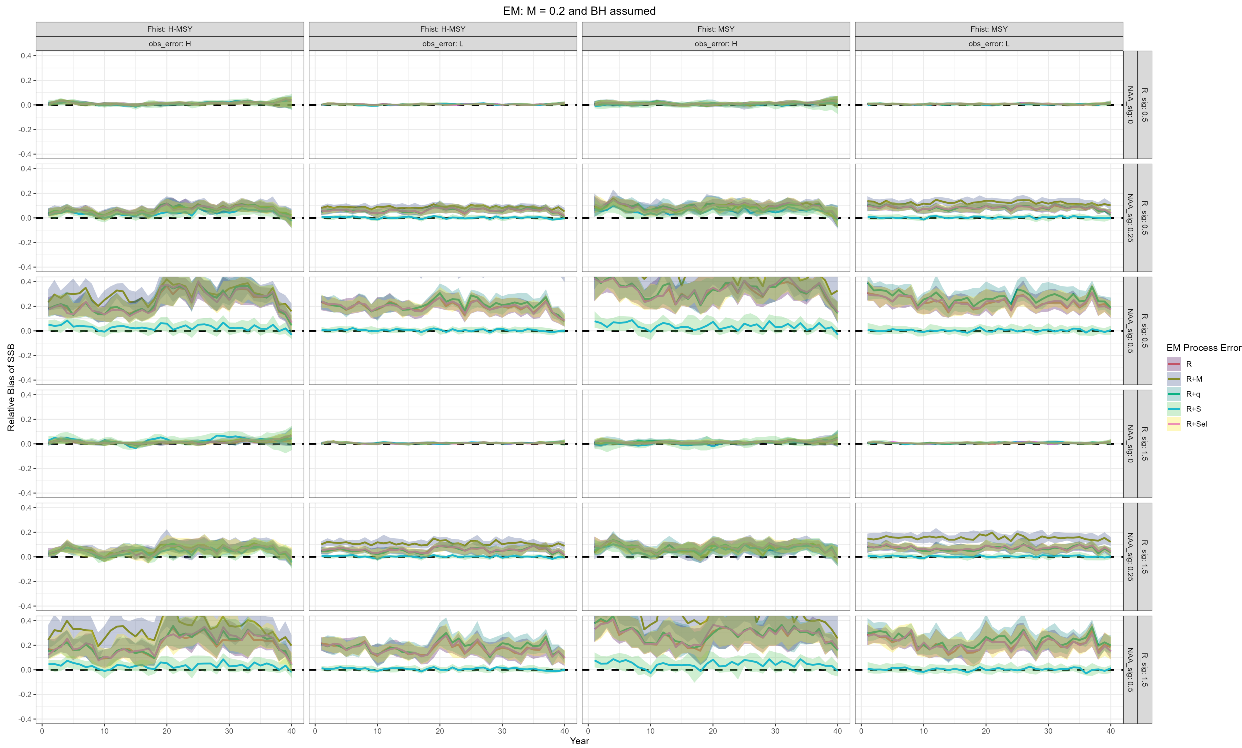
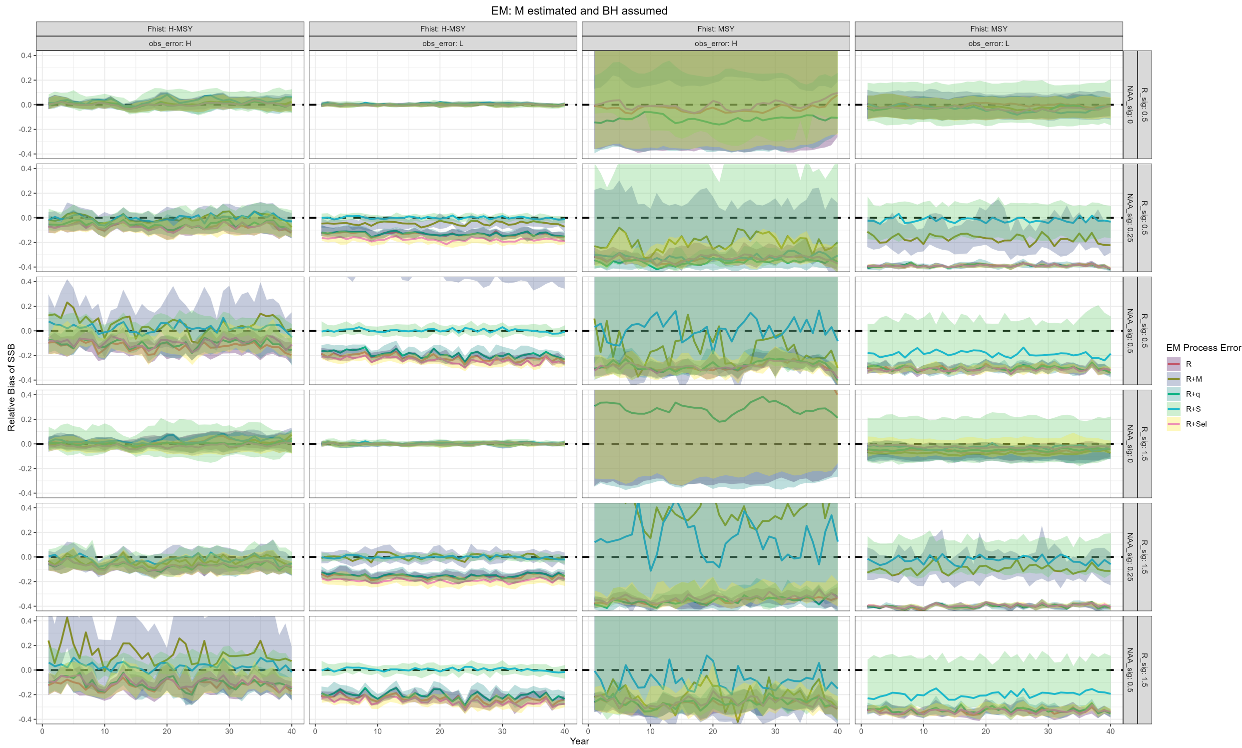


Fig. 28. Median relative bias of for SSB for estimating models that estimates a BH stock-recruitment function and M is estimated.



4 Discussion

The estimating models assumed variances of aggregate catch and index observations was known. This approximation may be appropriate for indices where we have a reliable estimate of uncertainty based on the survey design (), but there may be better approaches for the aggregate catch such as an informed prior on the standard errors with realistic bounds.

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