# State-space age-structured assessment models provide reliable inferences(?)

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## Abstract

### Keywords

# 1 Introduction

Much is known about the reliabiltiy of state-space models that are linear or Gaussian, but applications in fisheris 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 Gaussain Reliability of hidden process models

# 2 Methods

Used the WHAM package commit = XXXXXXX (Stock and Miller 2021, Miller and Stock 2020). This packages has also been used to configure operating and estimating models for closed loop simulations evaluating index-based asssessment methods (Legault et al. In press).

We completed a simulation study with 24 NAA re operating models, 16 M re operating models, 16 Sel re operating models and 16 q re operating models. We simulated N 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 ## Operating models

common to all:

ages, M maturity waa observation error assumptions 2.5 Fmsy -> Fmsy after 20 years Fmsy througout

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

NAA_oms process error assumtions

Population - Initial population, ages, M maturity waa

Fishing history All operating models assumed one of two different fishing histories. One : Fishing mortality is equal to Fmsy 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.

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

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 $= e^{1}0$ and $F_{\mathrm{MSY}} = F_{40}$ equated to a steepness of 0.68 and a and b parameters X and X?

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 Fhistory as other operating models which corresposds to Fmsy at the mean selectivity parameters.

Initial population starts at equilibium population structure associated with F= x*Fmsy where x = 1 or 2.5.

surveys, selectivity

fleets, selectivity

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

## 2.1 Estimating models

32 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 Massachussetts 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 XXXXX).

# 3 Results

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

AIC performance

SR estimation? M estimation?

Bias, Mean Square error

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

## 3.1 Numbers at age operating models

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

Table 1. NAA operating models, estimating models all assume a B-H stock recruit relationship and M is fixed at the true value.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | NAA | M | Sel | q |
|---|---|---|---|---|---|---|---|---|
| 0.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 1.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 0.5 | 0.25 | H-MSY | L | 0 | 100 | 0 | 0 | 0 |
| 1.5 | 0.25 | H-MSY | L | 0 | 100 | 0 | 0 | 0 |
| 0.5 | 0.50 | H-MSY | L | 0 | 96 | 4 | 0 | 0 |
| 1.5 | 0.50 | H-MSY | L | 0 | 100 | 0 | 0 | 0 |
| 0.5 | | MSY | L | 97 | 0 | 0 | 0 | 3 |
| 1.5 | | MSY | L | 96 | 0 | 0 | 0 | 4 |
| 0.5 | 0.25 | MSY | L | 0 | 99 | 1 | 0 | 0 |
| 1.5 | 0.25 | MSY | L | 0 | 99 | 1 | 0 | 0 |
| 0.5 | 0.50 | MSY | L | 0 | 100 | 0 | 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 | 94 | 0 | 0 | 0 | 6 |
| 0.5 | 0.25 | H-MSY | H | 46 | 50 | 0 | 0 | 4 |
| 1.5 | 0.25 | H-MSY | H | 65 | 30 | 0 | 0 | 5 |
| 0.5 | 0.50 | H-MSY | H | 1 | 99 | 0 | 0 | 0 |
| 1.5 | 0.50 | H-MSY | H | 0 | 98 | 0 | 0 | 2 |
| 0.5 | | MSY | H | 94 | 0 | 0 | 0 | 6 |
| 1.5 | | MSY | H | 95 | 0 | 0 | 0 | 5 |
| 0.5 | 0.25 | MSY | H | 45 | 52 | 0 | 0 | 3 |
| 1.5 | 0.25 | MSY | H | 63 | 28 | 0 | 0 | 9 |
| 0.5 | 0.50 | MSY | H | 0 | 100 | 0 | 0 | 0 |
| 1.5 | 0.50 | MSY | H | 0 | 98 | 1 | 0 | 1 |

Table 2. NAA operating models, estimating models all assume a B-H stock recruit relationship and M is estimated.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | NAA | M | Sel | q |
|---|---|---|---|---|---|---|---|---|
| 0.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 1.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 0.5 | 0.25 | H-MSY | L | 0 | 98 | 1 | 1 | 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 | 96 | 2 | 2 | 0 |
| 0.5 | | MSY | L | 95 | 1 | 0 | 0 | 4 |
| 1.5 | | MSY | L | 93 | 3 | 0 | 0 | 4 |
| 0.5 | 0.25 | MSY | L | 0 | 94 | 1 | 5 | 0 |
| 1.5 | 0.25 | MSY | L | 0 | 85 | 5 | 3 | 0 |
| 0.5 | 0.50 | MSY | L | 0 | 91 | 7 | 1 | 1 |
| 1.5 | 0.50 | MSY | L | 0 | 77 | 20 | 0 | 1 |
| 0.5 | | H-MSY | H | 94 | 0 | 0 | 0 | 6 |
| 1.5 | | H-MSY | H | 96 | 0 | 0 | 0 | 4 |
| 0.5 | 0.25 | H-MSY | H | 50 | 47 | 0 | 0 | 3 |
| 1.5 | 0.25 | H-MSY | H | 68 | 28 | 0 | 0 | 4 |
| 0.5 | 0.50 | H-MSY | H | 1 | 99 | 0 | 0 | 0 |
| 1.5 | 0.50 | H-MSY | H | 0 | 97 | 1 | 0 | 2 |
| 0.5 | | MSY | H | 78 | 15 | 0 | 1 | 4 |
| 1.5 | | MSY | H | 69 | 21 | 0 | 2 | 6 |
| 0.5 | 0.25 | MSY | H | 45 | 41 | 0 | 0 | 6 |
| 1.5 | 0.25 | MSY | H | 37 | 44 | 1 | 0 | 8 |
| 0.5 | 0.50 | MSY | H | 3 | 79 | 0 | 0 | 11 |
| 1.5 | 0.50 | MSY | H | 4 | 69 | 7 | 1 | 13 |

Table 3. NAA operating models, estimating models all estimate a mean recruitment and M is fixed at the true value.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | NAA | M | Sel | q |
|---|---|---|---|---|---|---|---|---|
| 0.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 1.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 0.5 | 0.25 | H-MSY | L | 0 | 99 | 0 | 1 | 0 |
| 1.5 | 0.25 | H-MSY | L | 0 | 100 | 0 | 0 | 0 |
| 0.5 | 0.50 | H-MSY | L | 0 | 99 | 1 | 0 | 0 |
| 1.5 | 0.50 | H-MSY | L | 0 | 97 | 3 | 0 | 0 |
| 0.5 | | MSY | L | 97 | 0 | 0 | 0 | 3 |
| 1.5 | | MSY | L | 96 | 0 | 0 | 0 | 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 | 0 | 6 |
| 0.5 | 0.25 | H-MSY | H | 48 | 48 | 0 | 0 | 4 |
| 1.5 | 0.25 | H-MSY | H | 65 | 30 | 0 | 0 | 5 |
| 0.5 | 0.50 | H-MSY | H | 0 | 99 | 1 | 0 | 0 |
| 1.5 | 0.50 | H-MSY | H | 0 | 99 | 0 | 0 | 1 |
| 0.5 | | MSY | H | 94 | 0 | 0 | 0 | 6 |
| 1.5 | | MSY | H | 95 | 0 | 0 | 0 | 5 |
| 0.5 | 0.25 | MSY | H | 46 | 51 | 0 | 0 | 3 |
| 1.5 | 0.25 | MSY | H | 63 | 28 | 0 | 0 | 9 |
| 0.5 | 0.50 | MSY | H | 0 | 100 | 0 | 0 | 0 |
| 1.5 | 0.50 | MSY | H | 0 | 98 | 1 | 0 | 1 |

Table 4. NAA operating models, estimating models all estimate a mean recruitment and M estimated.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | NAA | M | Sel | q |
|---|---|---|---|---|---|---|---|---|
| 0.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 1.5 | | H-MSY | L | 96 | 0 | 0 | 0 | 4 |
| 0.5 | 0.25 | H-MSY | L | 0 | 99 | 0 | 1 | 0 |
| 1.5 | 0.25 | H-MSY | L | 0 | 100 | 0 | 0 | 0 |
| 0.5 | 0.50 | H-MSY | L | 0 | 99 | 1 | 0 | 0 |
| 1.5 | 0.50 | H-MSY | L | 0 | 97 | 3 | 0 | 0 |
| 0.5 | | MSY | L | 97 | 0 | 0 | 0 | 3 |
| 1.5 | | MSY | L | 96 | 0 | 0 | 0 | 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 | 0 | 6 |
| 0.5 | 0.25 | H-MSY | H | 48 | 48 | 0 | 0 | 4 |
| 1.5 | 0.25 | H-MSY | H | 65 | 30 | 0 | 0 | 5 |
| 0.5 | 0.50 | H-MSY | H | 0 | 99 | 1 | 0 | 0 |
| 1.5 | 0.50 | H-MSY | H | 0 | 99 | 0 | 0 | 1 |
| 0.5 | | MSY | H | 94 | 0 | 0 | 0 | 6 |
| 1.5 | | MSY | H | 95 | 0 | 0 | 0 | 5 |
| 0.5 | 0.25 | MSY | H | 46 | 51 | 0 | 0 | 3 |
| 1.5 | 0.25 | MSY | H | 63 | 28 | 0 | 0 | 9 |
| 0.5 | 0.50 | MSY | H | 0 | 100 | 0 | 0 | 0 |
| 1.5 | 0.50 | MSY | H | 0 | 98 | 1 | 0 | 1 |

Fig. 1. Median relative bias of for SSB for estimating models that estimate mean recruitment and M is fixed at the true value.

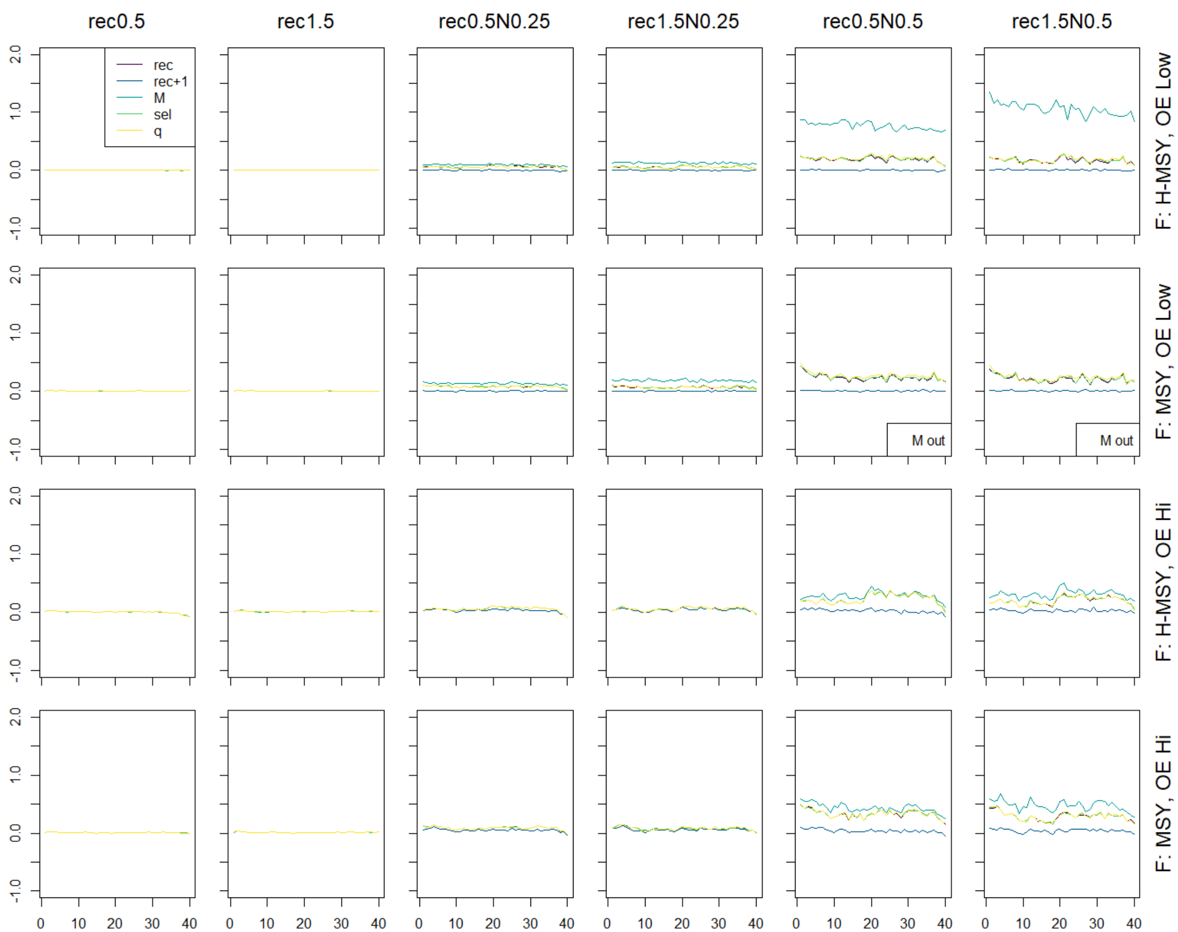


Fig. 2. Median relative bias of for SSB for estimating models that estimate mean recruitment and M is estimated.

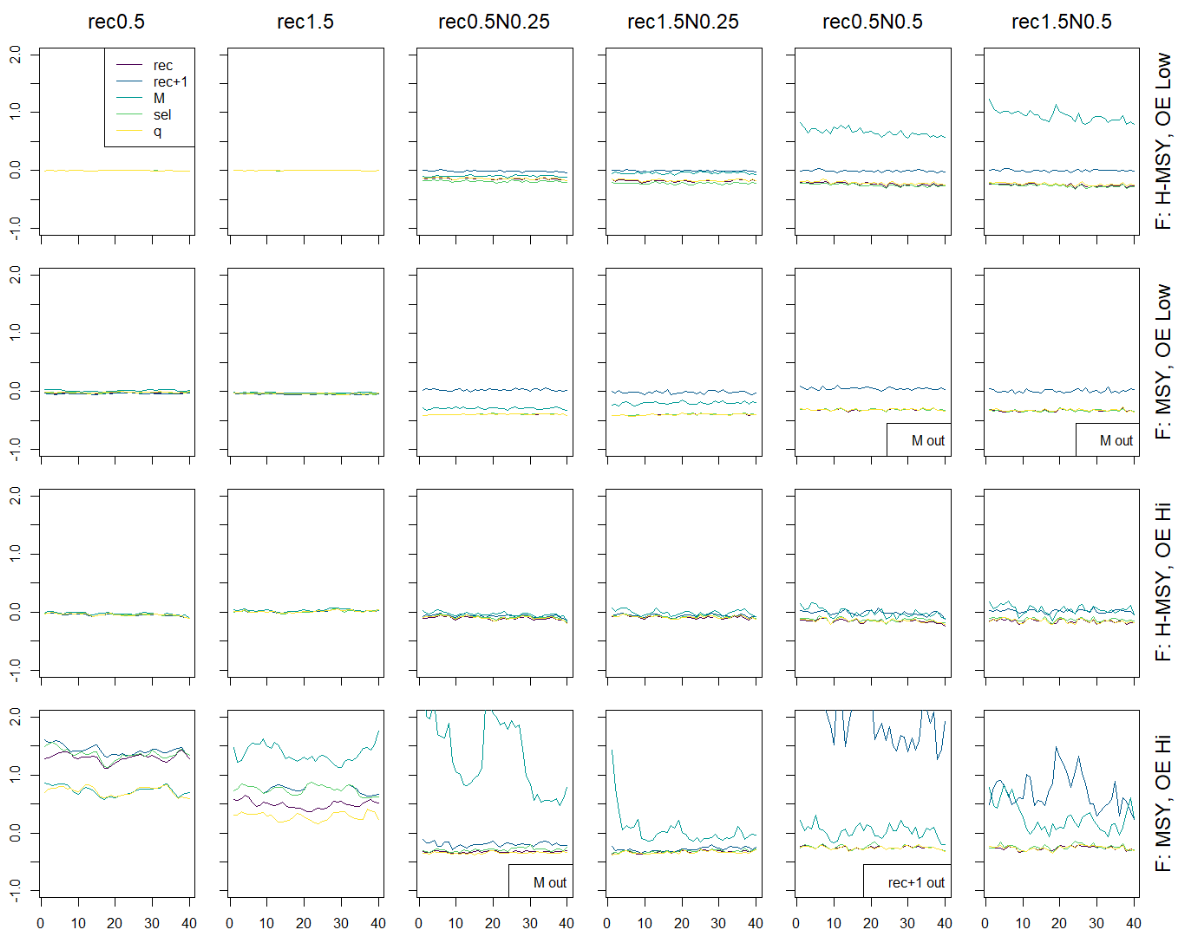


Fig. 3. Median relative bias of for SSB for estimating models that estimates a BH stock-recruitment function and M is fixed at the true value.

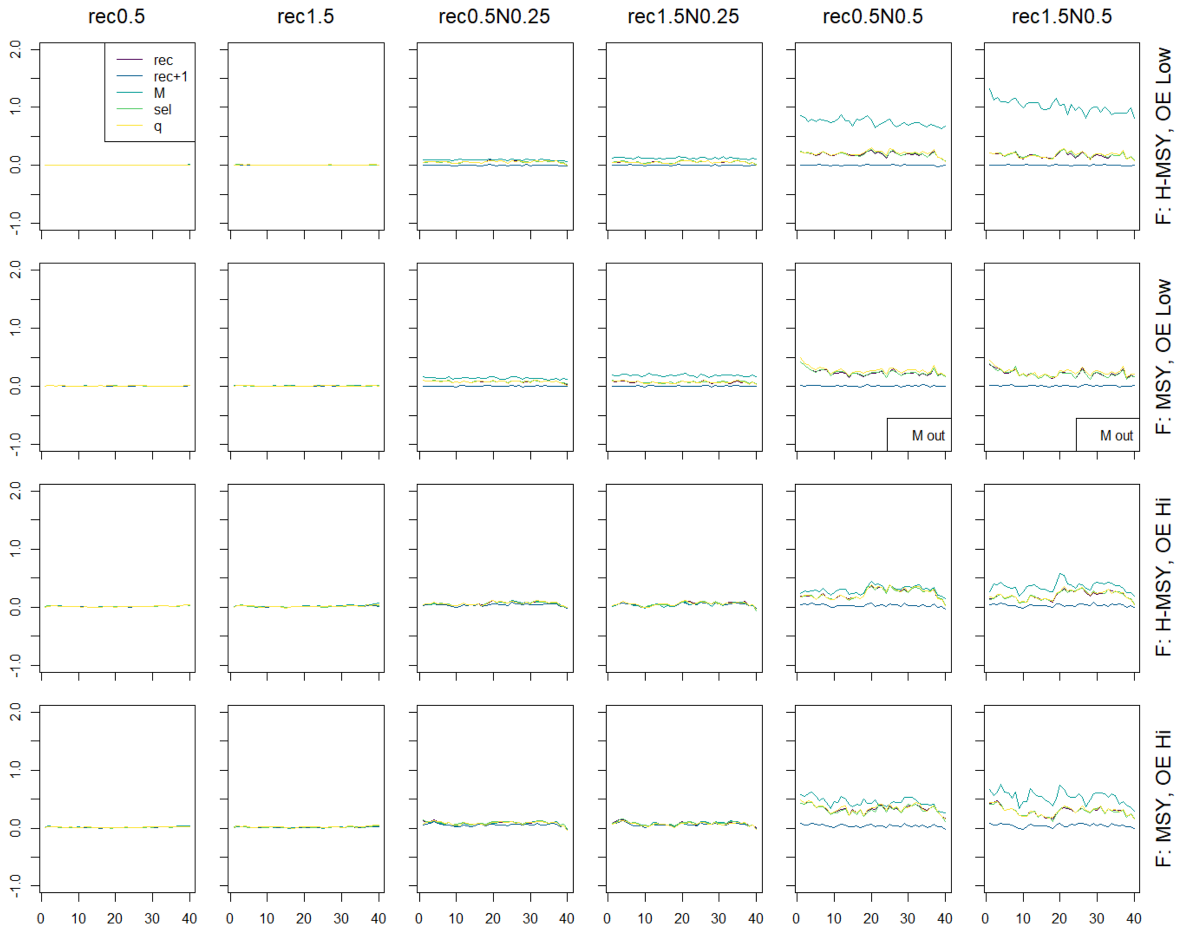
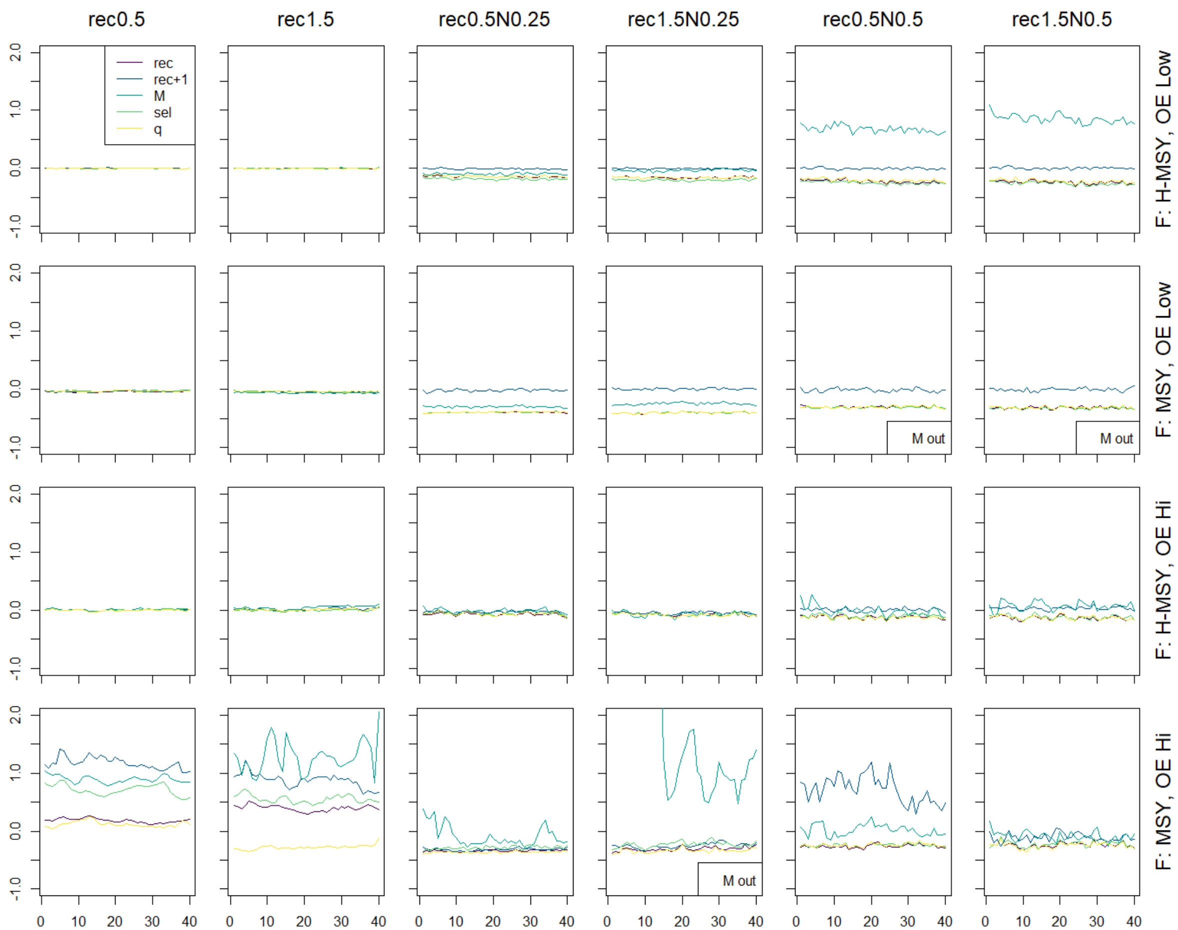


Fig. 4. Median relative bias of for SSB for estimating models that estimates a BH stock-recruitment function and M is estimated.



### 3.1.2 Estimating models include NAA random effects and estimation assumes mean R or BH SR

Table 5. Operating models and estimation models all assume RE on recruitment only, estimating models assume mean recruitment or a B-H stock recruit relationship and M is fixed at the true value.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | BH |
|---|---|---|---|---|---|
| 0.5 | | H-MSY | L | 46 | 54 |
| 1.5 | | H-MSY | L | 82 | 18 |
| 0.5 | | MSY | L | 71 | 29 |
| 1.5 | | MSY | L | 85 | 15 |
| 0.5 | | H-MSY | H | 51 | 49 |
| 1.5 | | H-MSY | H | 82 | 18 |
| 0.5 | | MSY | H | 72 | 28 |
| 1.5 | | MSY | H | 86 | 14 |

Table 6. Operating models and estimation models all assume RE on recruitment only, estimating models assume mean recruitment or a B-H stock recruit relationship and M is estimated.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | BH |
|---|---|---|---|---|---|
| 0.5 | | H-MSY | L | 45 | 55 |
| 1.5 | | H-MSY | L | 82 | 18 |
| 0.5 | | MSY | L | 70 | 30 |
| 1.5 | | MSY | L | 87 | 13 |
| 0.5 | | H-MSY | H | 56 | 44 |
| 1.5 | | H-MSY | H | 82 | 18 |
| 0.5 | | MSY | H | 75 | 25 |
| 1.5 | | MSY | H | 84 | 16 |

Table 7. Operating models and estimation models all assume RE on all abundances at age, estimating models assume mean recruitment or a B-H stock recruit relationship and M is fixed at the true value.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | BH |
|---|---|---|---|---|---|
| 0.5 | 0.25 | H-MSY | L | 43 | 57 |
| 1.5 | 0.25 | H-MSY | L | 84 | 16 |
| 0.5 | 0.50 | H-MSY | L | 33 | 67 |
| 1.5 | 0.50 | H-MSY | L | 77 | 23 |
| 0.5 | 0.25 | MSY | L | 69 | 31 |
| 1.5 | 0.25 | MSY | L | 88 | 12 |
| 0.5 | 0.50 | MSY | L | 55 | 45 |
| 1.5 | 0.50 | MSY | L | 87 | 13 |
| 0.5 | 0.25 | H-MSY | H | 57 | 43 |
| 1.5 | 0.25 | H-MSY | H | 84 | 16 |
| 0.5 | 0.50 | H-MSY | H | 66 | 34 |
| 1.5 | 0.50 | H-MSY | H | 79 | 21 |
| 0.5 | 0.25 | MSY | H | 78 | 22 |
| 1.5 | 0.25 | MSY | H | 88 | 12 |
| 0.5 | 0.50 | MSY | H | 73 | 27 |
| 1.5 | 0.50 | MSY | H | 83 | 17 |

Table 8. Operating models and estimation models all assume RE on all abundances at age, estimating models assume mean recruitment or a B-H stock recruit relationship and M is estimated.

| $\sigma_R$ | $\sigma_N$ | F-history | Obs Error | R only | BH |
|---|---|---|---|---|---|
| 0.5 | 0.25 | H-MSY | L | 44 | 56 |
| 1.5 | 0.25 | H-MSY | L | 84 | 16 |
| 0.5 | 0.50 | H-MSY | L | 31 | 69 |
| 1.5 | 0.50 | H-MSY | L | 80 | 20 |
| 0.5 | 0.25 | MSY | L | 68 | 32 |
| 1.5 | 0.25 | MSY | L | 88 | 12 |
| 0.5 | 0.50 | MSY | L | 55 | 45 |
| 1.5 | 0.50 | MSY | L | 86 | 14 |
| 0.5 | 0.25 | H-MSY | H | 59 | 41 |
| 1.5 | 0.25 | H-MSY | H | 81 | 19 |
| 0.5 | 0.50 | H-MSY | H | 67 | 33 |
| 1.5 | 0.50 | H-MSY | H | 80 | 20 |
| 0.5 | 0.25 | MSY | H | 66 | 34 |
| 1.5 | 0.25 | MSY | H | 74 | 26 |
| 0.5 | 0.50 | MSY | H | 74 | 26 |
| 1.5 | 0.50 | MSY | H | 87 | 13 |

# 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.

# Acknowledgements

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