



**NOAA**  
**FISHERIES**

# Application of WHAM to Black Sea Bass Black sea bass Research Track

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# Outline

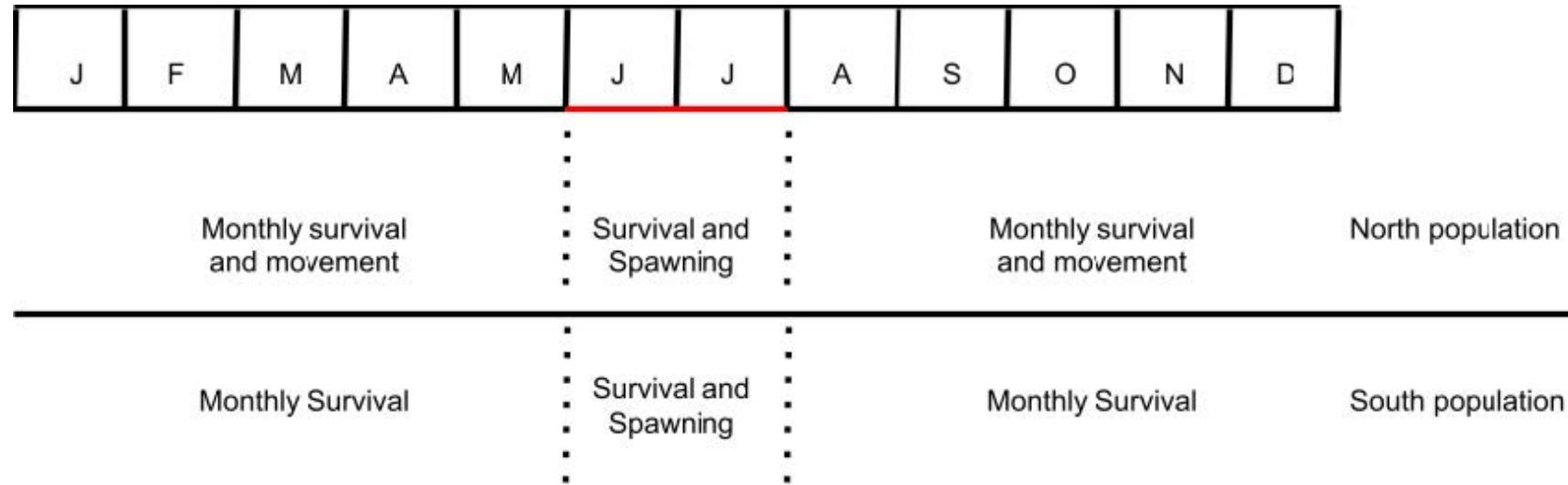
- Description of proposed base model
- Diagnostics
- Results
- Path to the base model
  - Initial bridge building
  - Progression of model development

# Description of proposed base model

# General attributes

- 2 regions
  - North
  - South
- 2 stock components:
  - North
  - South
- Model years: 1989 - 2021
- Ages: 1-8+
- 2 Environmental processes (1959-2022)
  - Bottom temperature in North
  - Bottom temperature in South
- Natural mortality = 0.4 all ages, components, regions

# Movement configuration:



- All Jan 1 recruitment for a given stock component only in respective regions
- North fish can only move from south to north in first 5 seasons
- North fish can only move from north to south in last 4 seasons
- Any remaining North fish that are in the south move back to their spawning region at end of season 5
- All North fish remain in North spawning region until end of season 7
- Spawning season is only time when whole North population is in spawning region
- South population stays in South.

# Movement configuration:

- The monthly/seasonal movement matrix after spawning:

$$\mathbf{p}_1 = \begin{bmatrix} 1 - p_1 & p_1 \\ 0 & 1 \end{bmatrix}$$

- Before spawning:

$$\mathbf{p}_2 = \begin{bmatrix} 1 & 0 \\ p_2 & 1 - p_2 \end{bmatrix}$$

# Movement rates from Stock Synthesis

- The Stock Synthesis model has 2 seasons (6 months each)
- proportion  $P_1$  of the northern component moves to the south in one season and some proportion  $P_2$  move back to the south in the second season.
- The movement matrices for each season are

$$\mathbf{P}_1 = \begin{bmatrix} 1 - P_1 & P_1 \\ 0 & 1 \end{bmatrix}$$

and

$$\mathbf{P}_2 = \begin{bmatrix} 1 & 0 \\ P_2 & 1 - P_2 \end{bmatrix}$$

# Transforming to shorter seasons in WHAM

- Approximate the monthly movement matrices as the roots of  $\mathbf{P}_1$  and  $\mathbf{P}_2$  defined by the number of months of movement for each season (5 and 4, respectively):
  - Given the proportion parameter, the eigen decomposition of the matrices can be used to define the roots

$$\mathbf{P}_1^{\frac{1}{5}} = \mathbf{V}_1 \mathbf{D}_1^{\frac{1}{5}} \mathbf{V}_1^{-1}$$

$$\mathbf{P}_2^{\frac{1}{4}} = \mathbf{V}_2 \mathbf{D}_2^{\frac{1}{4}} \mathbf{V}_2^{-1}$$

where  $\mathbf{V}_i$  and  $\mathbf{D}_i$  are the matrix of eigenvectors (columnwise) and the diagonal matrix of corresponding eigenvalues of  $\mathbf{P}_i$  for parameter  $P_i$ .

# Parameterizing the prior distribution

- The actual SS parameter estimates  $x_1 = -1.44$  and  $x_2 = 1.94$  are transformations of  $P_1 = 0.11$  and  $P_2 = 0.78$  such that

$$P_i = \frac{1}{1 + 2e^{-x_i}}$$

- Multi-WHAM uses an additive logit transformation (simply a logit transformation when there are only two regions):

$$p_i = \frac{1}{1 + e^{-y_i}}$$

# Parameterizing the movement prior distributions

Used a parametric bootstrap approach:

- Simulate 1000 values from a normal distribution with mean and standard deviation defined by the SS parameter estimate and standard error  $\tilde{x}_i \sim N(x_i, SE(x_i))$ .
- For each simulated value
  - construct  $\mathbf{P}_i$ ,
  - take the appropriate root,
  - calculate inverse logit for  $\tilde{y}_i$ .
  - calculate the mean and SD of the simulated values  $\tilde{y}_i$ .
  - mean values did not differ meaningfully from the transformation of the original estimates:  $y_1 = -3.79$  and  $y_2 = -0.79$
  - SD was approximately 0.2 for both parameters.
- distributions for random effects defining the movement parameters configured using the mean and SD from the bootstraps.

# Initial abundance at age

- With the movement configuration, northern origin fish (ages 2+) can occur in the southern region on January 1.
- Estimating initial numbers at age as separate parameters can be challenging even in single-stock models.
- To avoid difficulties, we used the equilibrium assumption described previously.
- Two parameters are estimated for each regional stock component: an initial recruitment and an equilibrium full F across all fleets.

# Recruitment and Survival/movement transitions

- 2DAR1 (age and year) correlated random effects for both the northern and southern components.
- Variance and correlation parameters are different for the northern and southern components.
- Northern component:
  - abundance at age 1 on January 1 (recruitment) is only allowed in the northern region,
  - older individuals may occur in either region on Jan 1 (based on movement description)
  - survival random effects will occur for abundances at age in both regions.
  - Base model assumes very small variance for the transitions in the southern region (approximately SCAA)
  - 2DAR1 models with estimated variance for this region would not converge (correlation could not be estimated).

# Observations

- Aggregate catch: 2 fleets in each region:
  - Commercial (1989-2021)
  - Recreational (1989-2021)
- Aggregate indices: 2 in each region:
  - Spring VAST (1989-2021)
  - Recreational CPA (1989-2021)
- Age composition for all fleets and indices (1989-2021)
- Model-based Bottom temperature observation in each region (1959-2022)

# Selectivity

Data component	Mean Selectivity model	Random effects configuration
North Commercial	age-specific (flat-topped at ages > 3)	2D-AR1 (age and year)
North Recreational	age-specific (flat-topped at ages > 6)	2D-AR1 (age and year)
South Commercial	logistic	None
South Recreational	logistic	None
North Recreational CPA	age-specific (flat-topped at ages > 1)	AR1 (year)
North VAST	age-specific (flat-topped at ages > 4)	2D-AR1 (age and year)
South Recreational CPA	age-specific (flat-topped at ages > 2)	None
South VAST	age-specific (flat-topped at ages > 1)	None

# Age composition models

Data component	Age Composition Likelihood
North Commercial	Dirichlet-Multinomial
North Recreational	Logistic-normal (0s as missing)
South Commercial	Logistic-normal (AR1, 0s as missing)
South Recreational	Logistic-normal (AR1, 0s as missing)
North Recreational CPA	Logistic-normal (0s as missing)
North VAST	Dirichlet-Multinomial
South Recreational CPA	Logistic-normal (AR1, 0s as missing)
South VAST	Logistic-normal (AR1, 0s as missing)

# Uncertainty in Rec CPA indices

- CVs provided by analyses that generated Rec CPA indices were deemed implausibly small (CVs: 0.02 to 0.06).
- In many early runs and proposed base model we estimated a scalar of the SD of the log-aggregate Rec CPA indices.
  - Estimates of the scalar were usually approximately 5 for the north and the south Rec CPA indices.
- Estimation included in the proposed base model allow more realistic estimates of uncertainty in model output.

# Bottom Temperature effects on recruitment

- Included model-based bottom temperature observations in the BSB model.
- Very small uncertainty in observations (SEs: 0.03 to 0.09).
- State-space treatment:
  - Modeled latent covariate as AR1 process.

$$X_y \sim N(\mu_X(1 - \rho_X) + \rho_X X_{y-1}, \sigma_X^2)$$

- Observations of the latent covariate:
$$x_y \sim N(X_y, \sigma_x^2)$$
- Fit models with and without effects on northern and southern recruitment

$$\log R_y = \mu_R + \beta X_y + \epsilon_y.$$

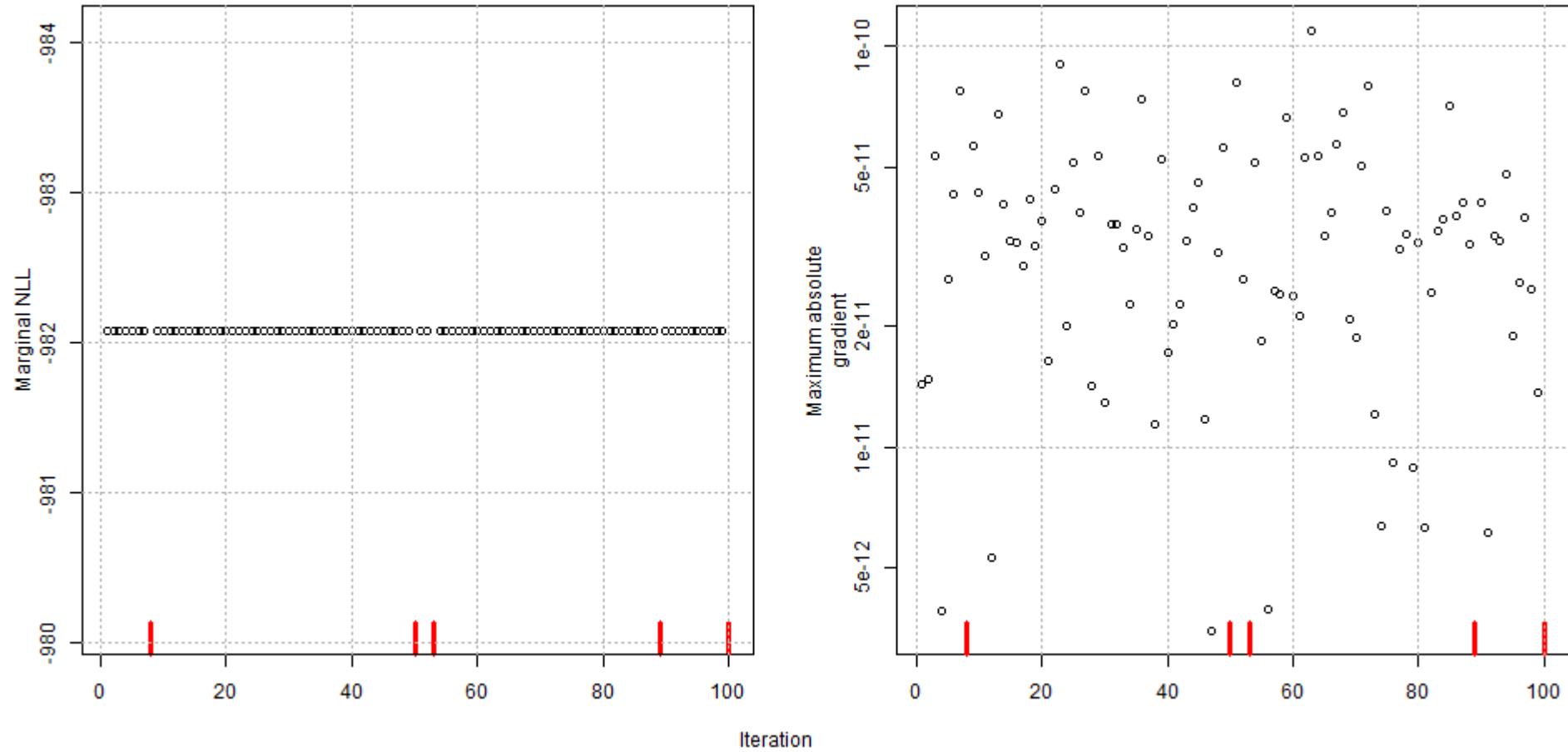
- Examined AIC for full model and all retrospective peels.
- Might be worth exploring an alternative effect on  $M$  for age 1.
  - Would also affect reference points and projections differently.

# Diagnostics for base model

# Jitter analysis

- Simulated 100 fixed effects parameter vectors from a normal distribution with mean equal to the optimized values and covariance equal to the hessian-based covariance matrix of the optimized model.
- All of the re-fits of the model resulted in the same marginal negative log-likelihood.
- The gradients at these optimized values were all satisfactory with maximum absolute values less than  $10^{-9}$ .

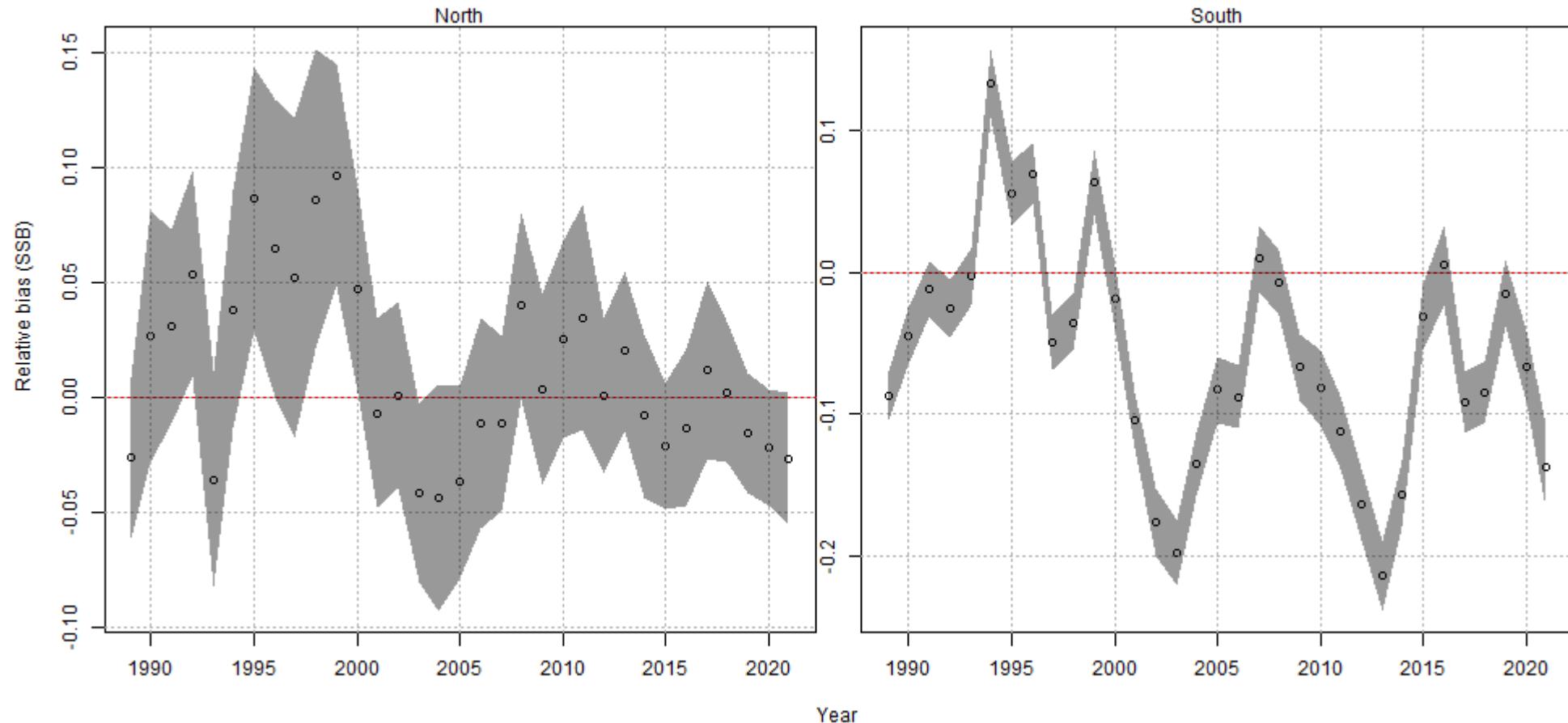
# Jitter analysis



# Self-test

- Simulated new observations conditional on all random effects estimated in the proposed base model
- Fitted the same model configuration each of the simulated data sets.
- For 7 of the the simulated data sets the model failed to optimize.
- The maximum absolute gradient was  $< 10^{-6}$  for only 9 and  $< 10^{-4}$  for 52 of the 93 successfully fitted models.
- The poor convergence appeared to be attributable to the estimation of the scalar for the standard errors of the log-transformed northern Recreational CPA index
  - Estimates tended to 0 for nearly all of the fits ( $\$ < 0.01 \$$  for 83 fits).
- Even across all fits including those with poor convergence, the SSB estimates appeared to be reliable.

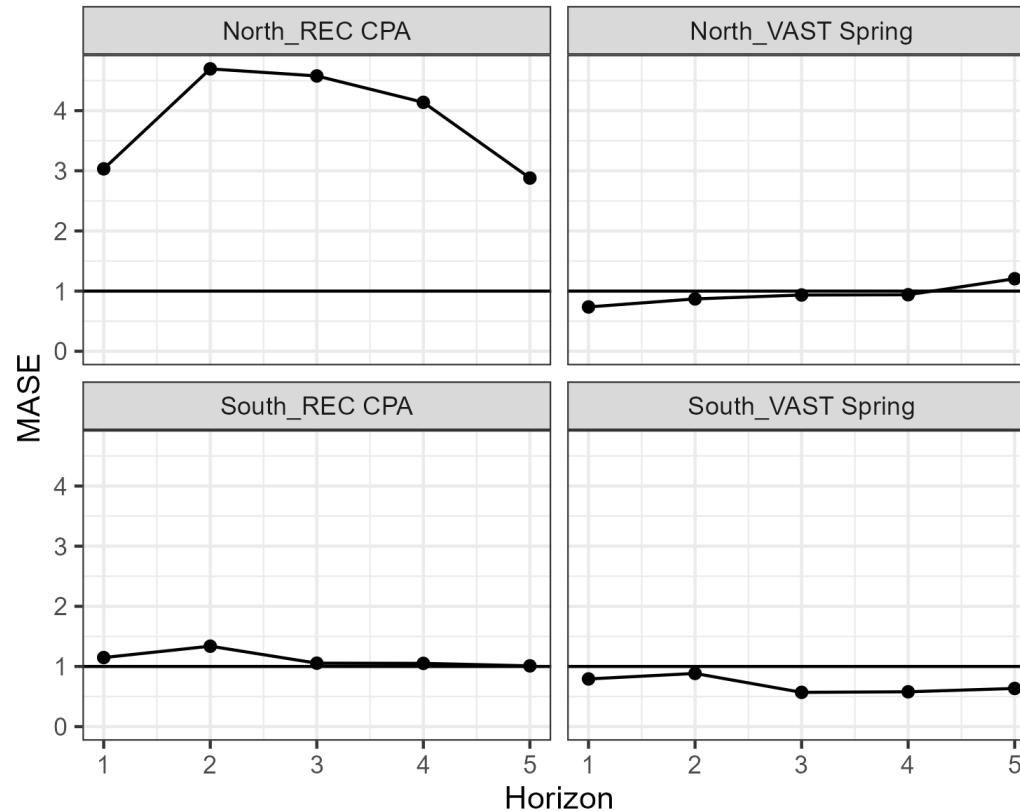
# Self-test



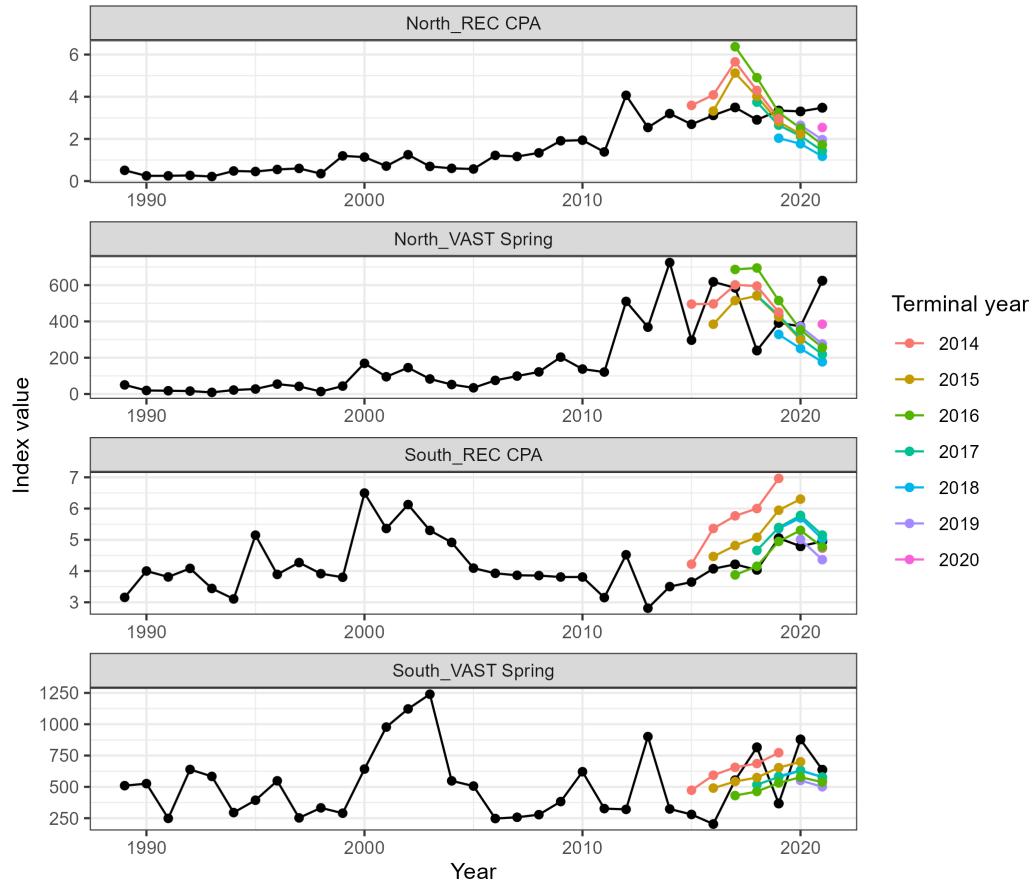
# MASE

- We fit 7 configurations of the model where the last 1 to 7 years of aggregate index and age composition observations were removed sequentially (peels).
- Calculate the mean absolute scaled error (MASE) of the predictions at 1 to 5 years beyond the final year of index observations (horizons).
  - The mean absolute errors are scaled by the mean absolute errors of so-called naïve predictions using the aggregate index observation from the final year of each peel.
- A MASE < 1 results when the mean absolute error is greater using the model than the naïve forecast.
- For the proposed base model, predictions for 3 of the 4 surveys performed similarly to naïve predictions across all horizons,
- BUT MASE scores were much greater than 1 for the northern region recreational CPA index at all horizons.
  - The large MASE values occur because the index has no trend and low variability over the years used for the calculation whereas the model predictions vary much more.

# MASE



# MASE

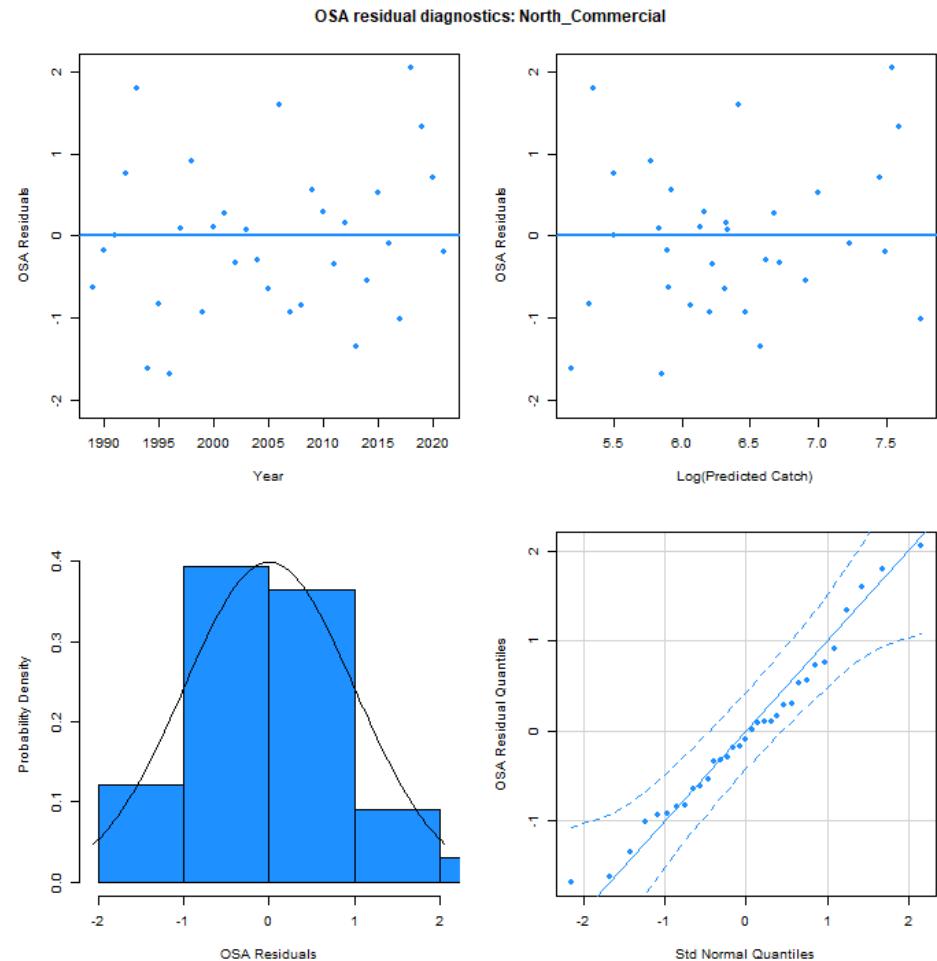


# One-step-ahead residuals

- For composition observations and for aggregate observations in state-space models, Pearson residuals do not have the appropriate properties:
  - independent standard normal for a correctly specified model
- Due to lack of independence of observations.
- One-step-ahead (OSA) residuals have this property
- However, understanding causes of mis-specification can be difficult.

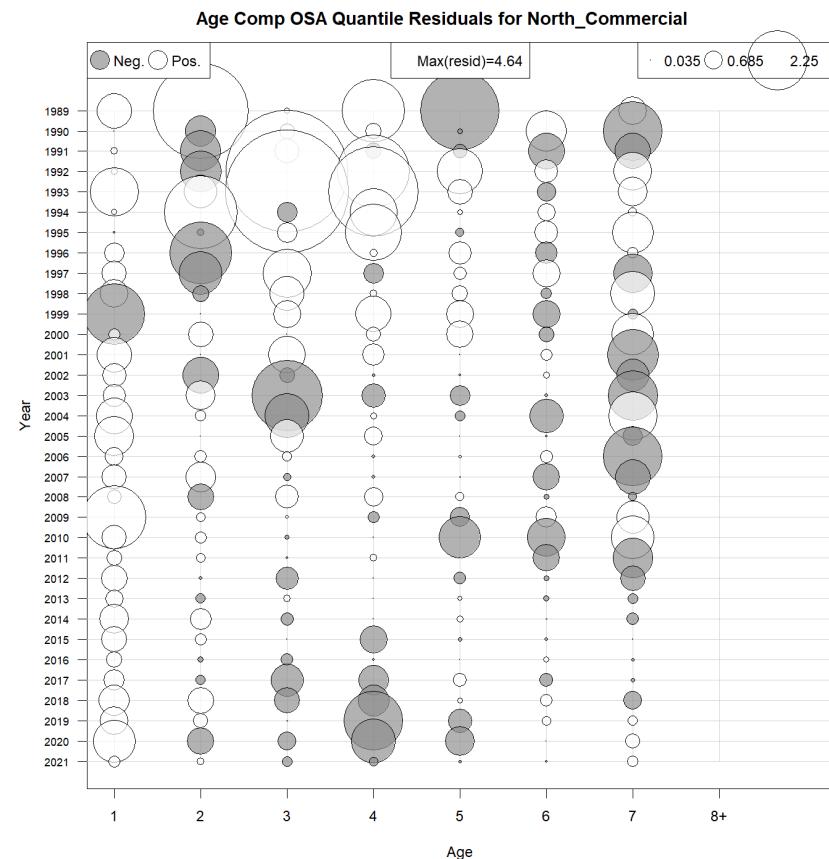
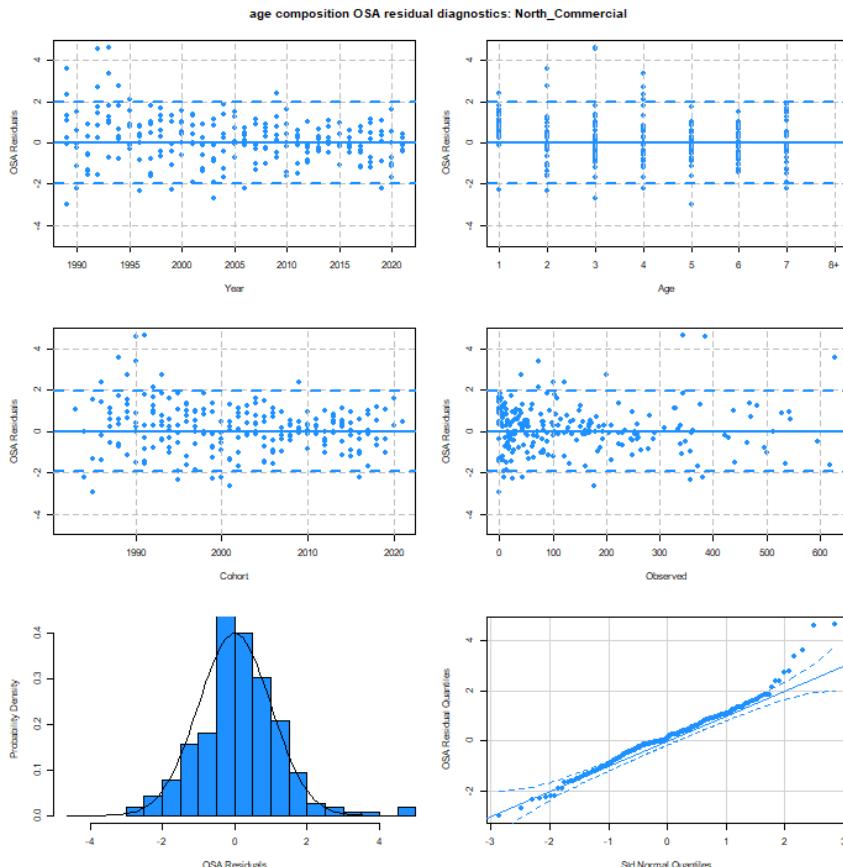
# OSA: North commercial fleet

- no evidence of mis-specification aggregate catch.



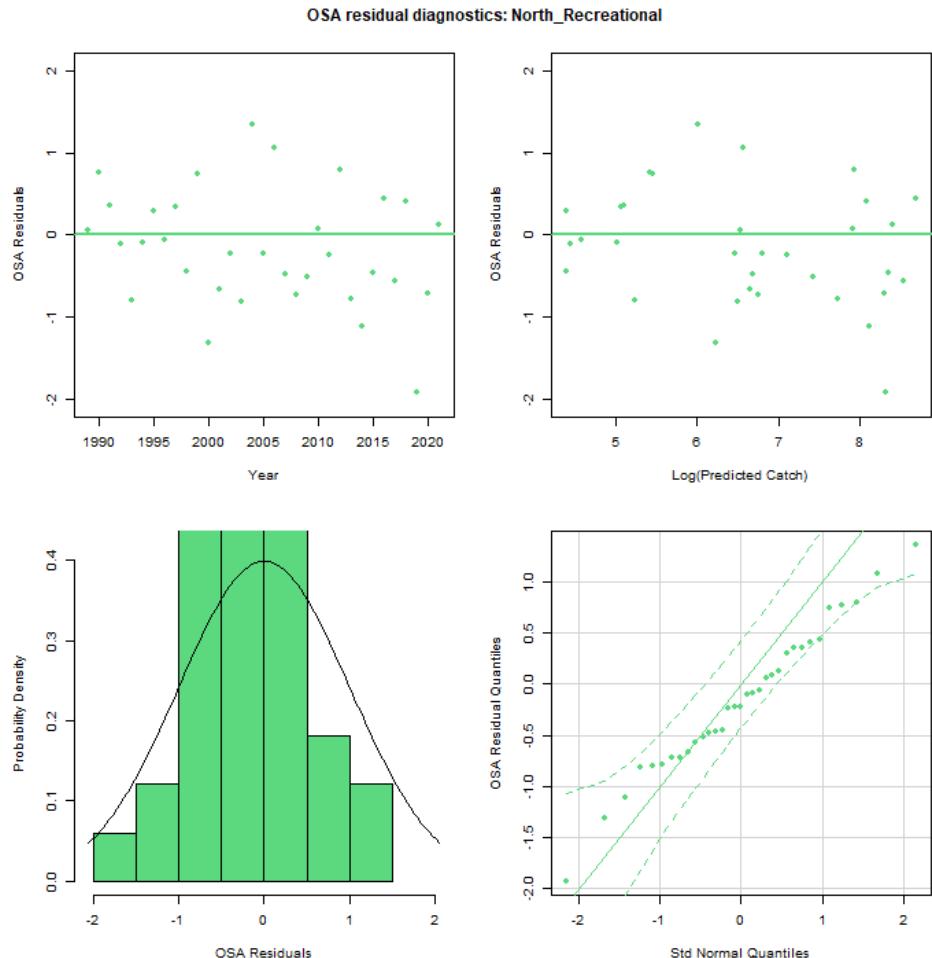
# OSA: North commercial fleet

- some indication of trends in residuals of some of the age composition observations early in the time series and for the first age class.



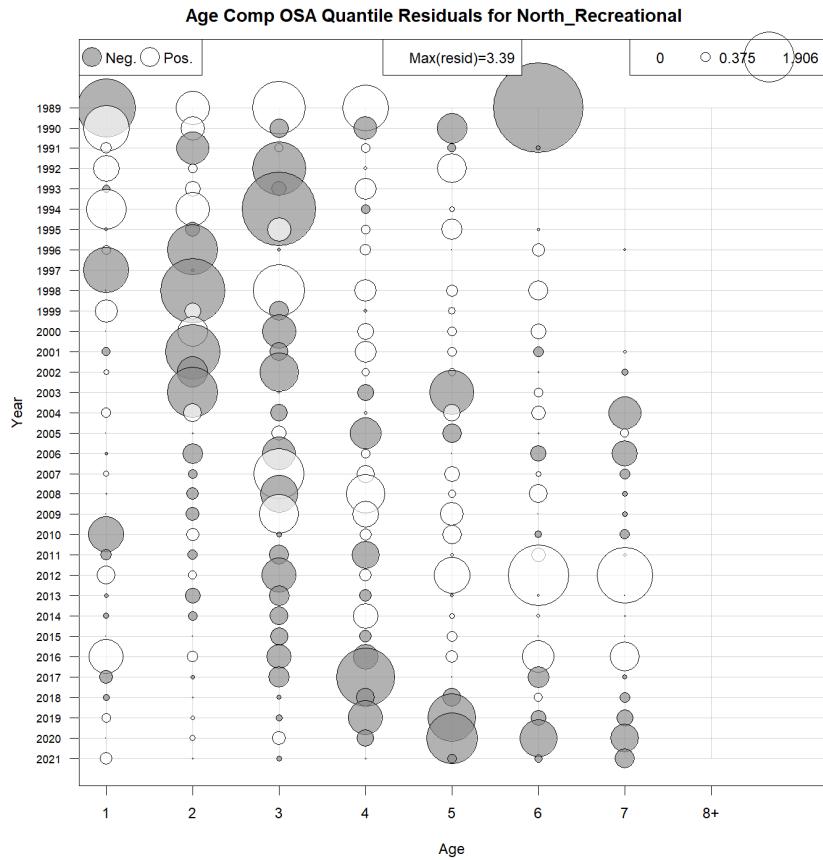
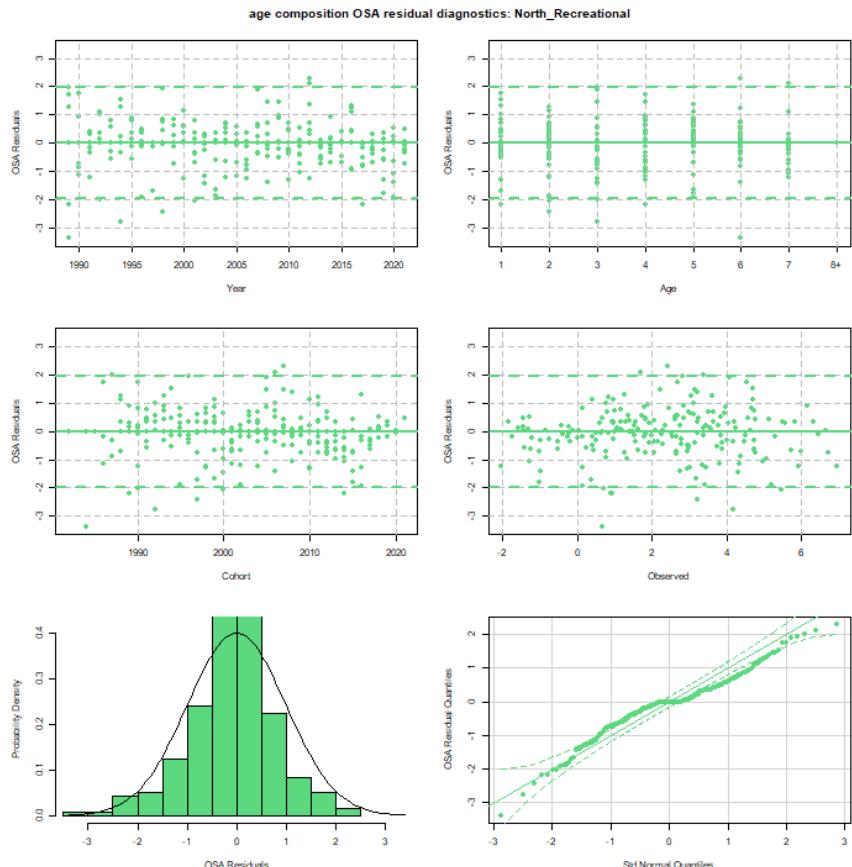
# OSA: North recreational fleet

- residuals appeared satisfactory.



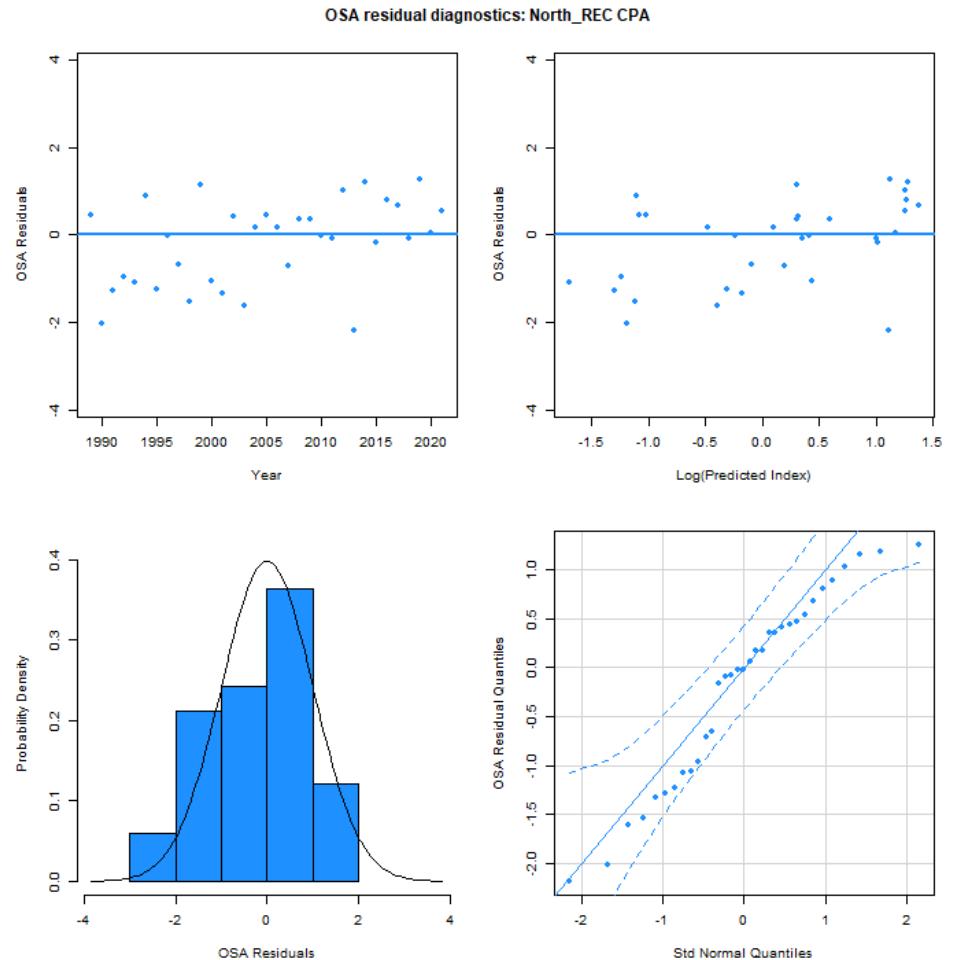
# OSA: North recreational fleet

- residuals showed some tendency of underdispersion



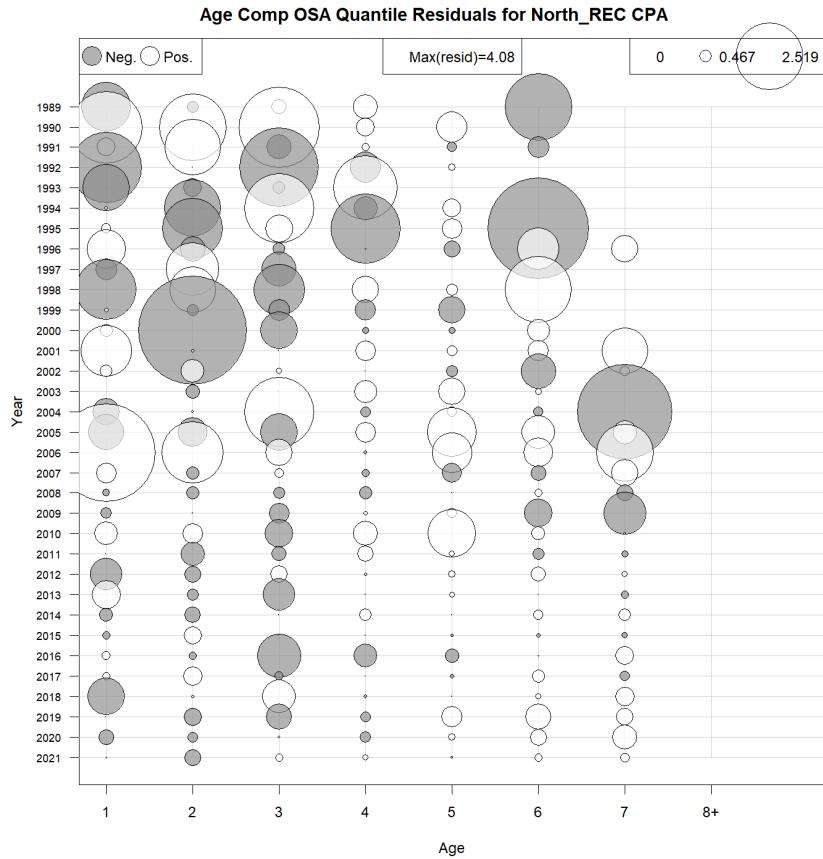
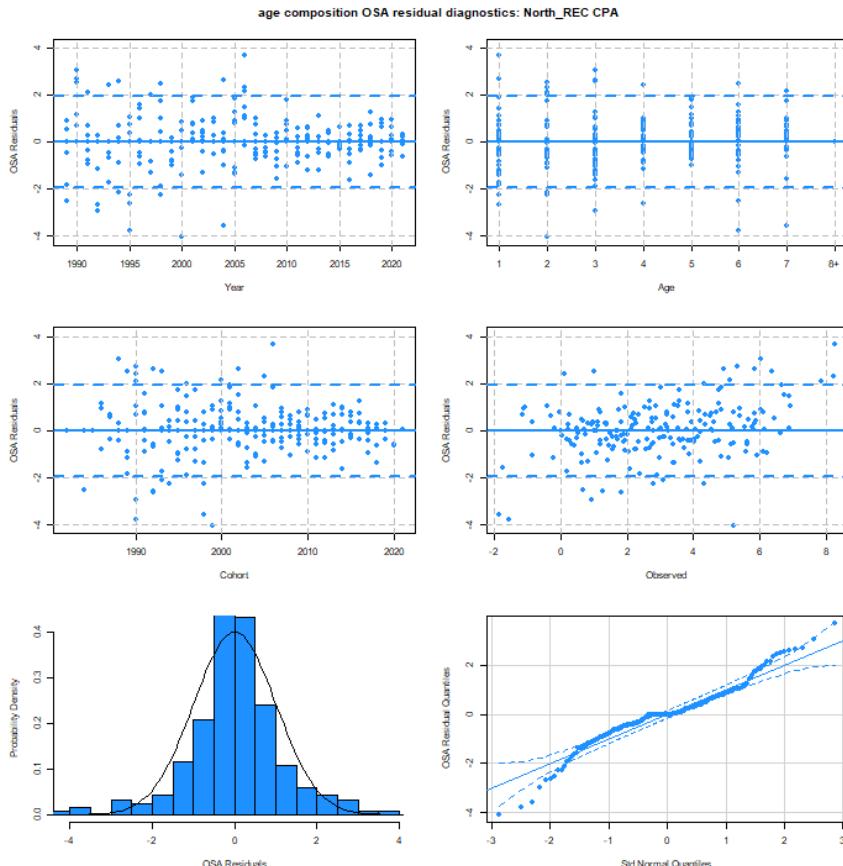
# OSA: North Rec CPA index

- no signs of mis-specification



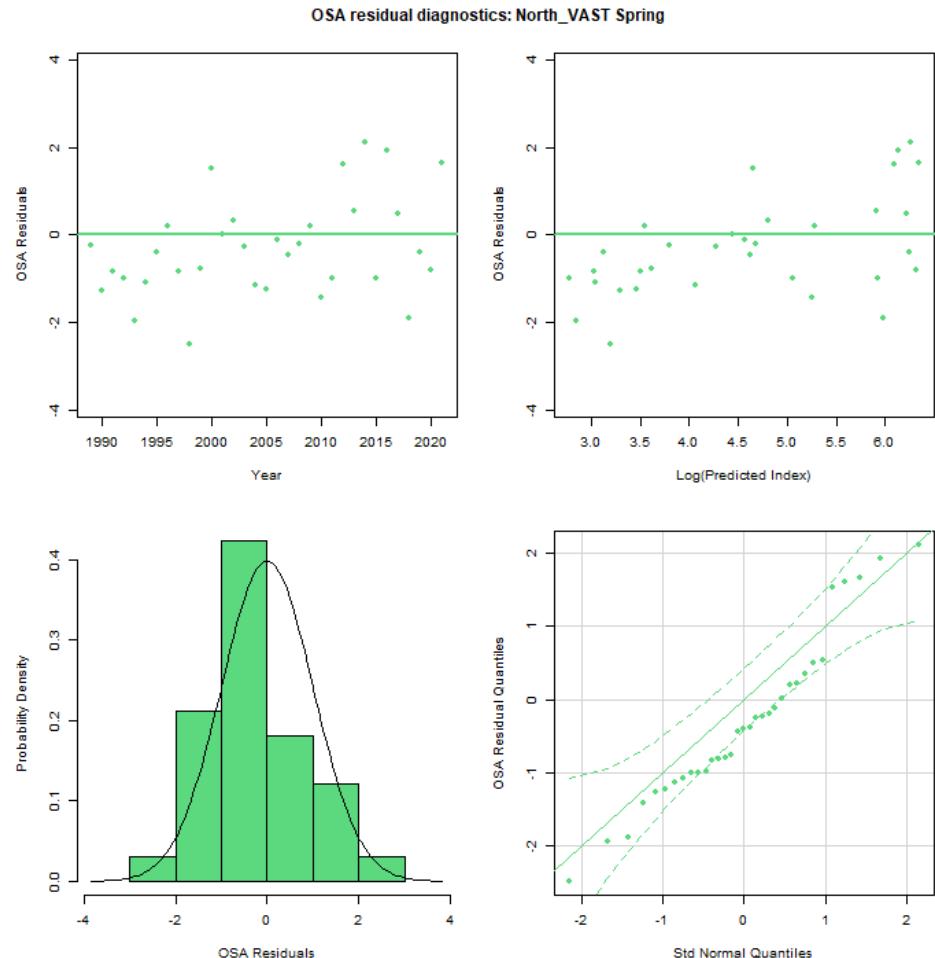
# OSA: North Rec CPA index

- no signs of mis-specification



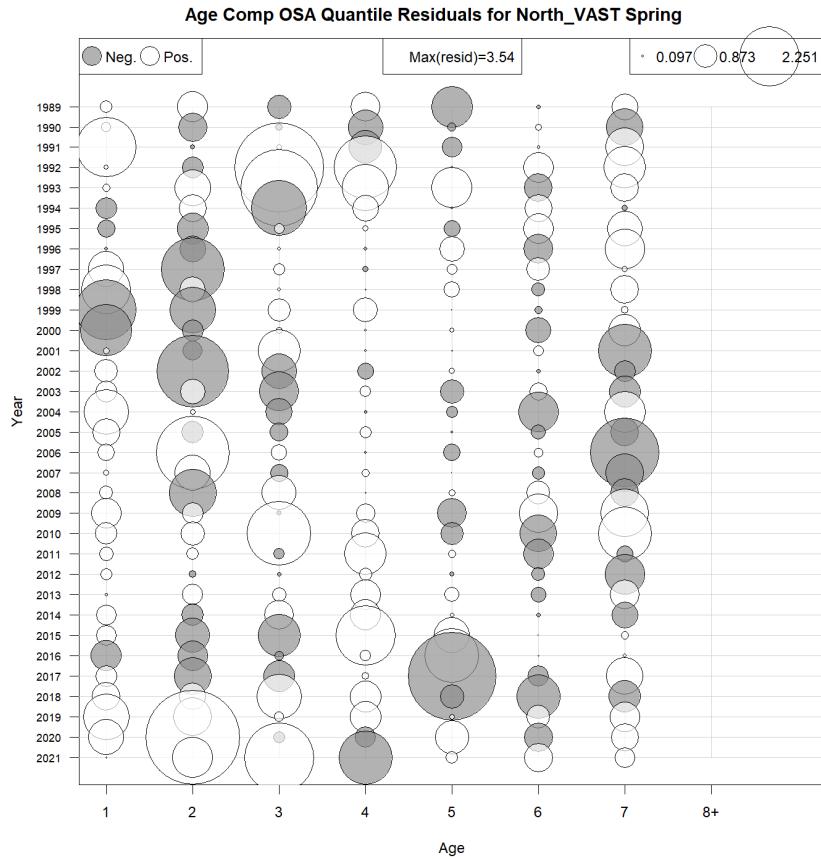
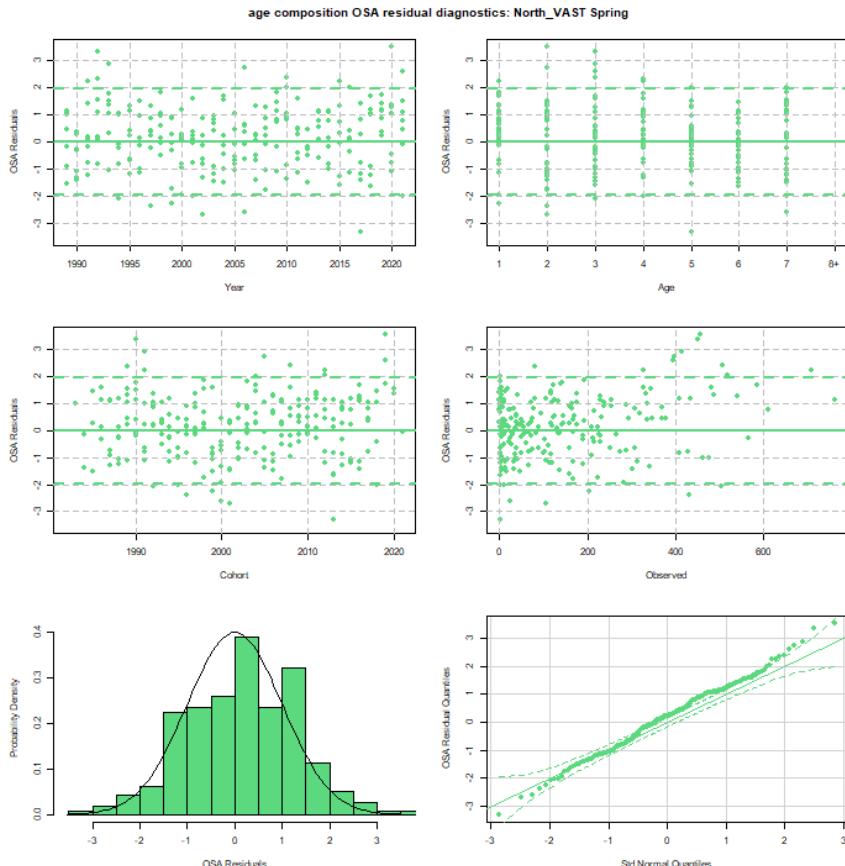
# OSA: North VAST index

- some evidence of tendency toward negative residuals



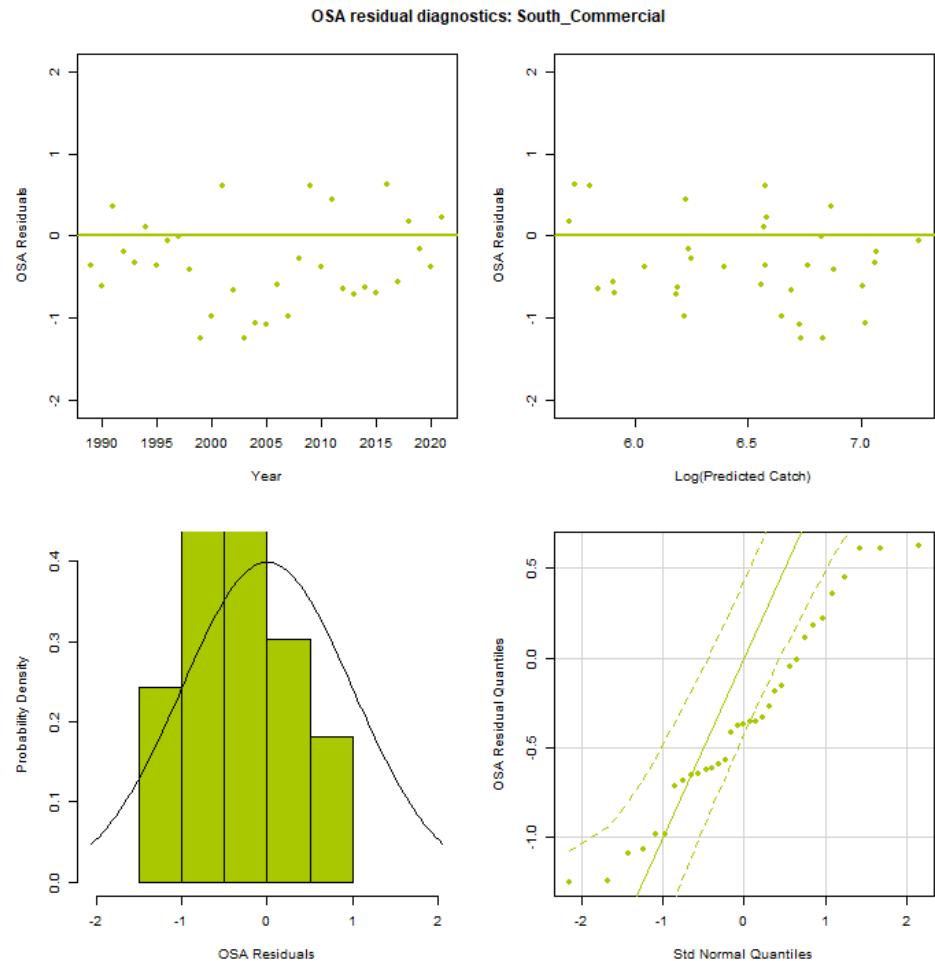
# OSA: North VAST index

- some indication of positive residuals, particularly at age 1



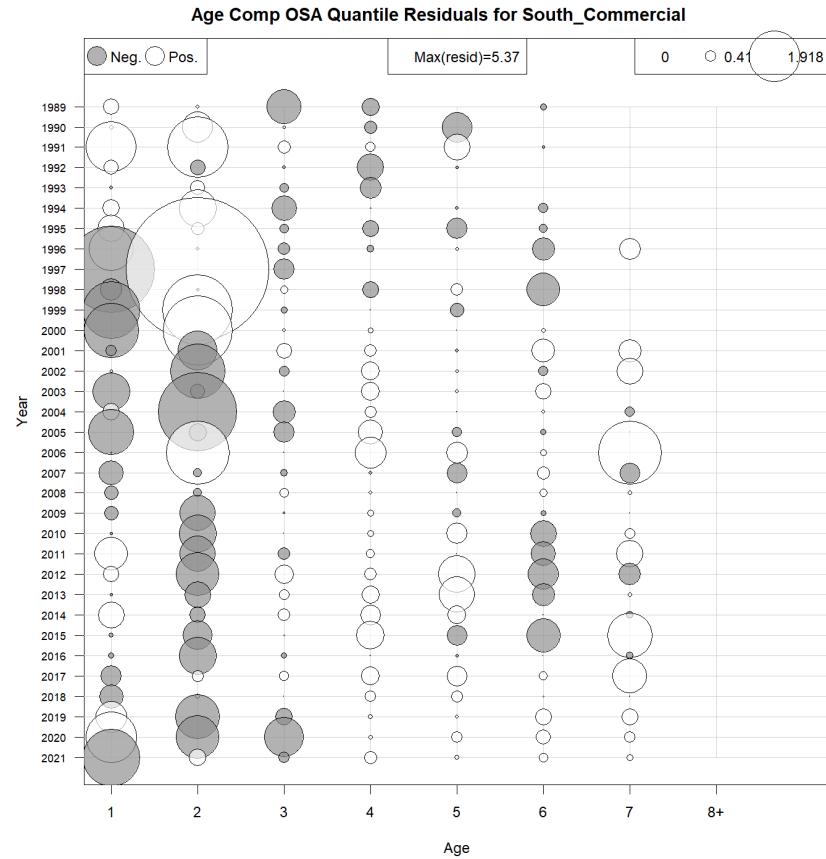
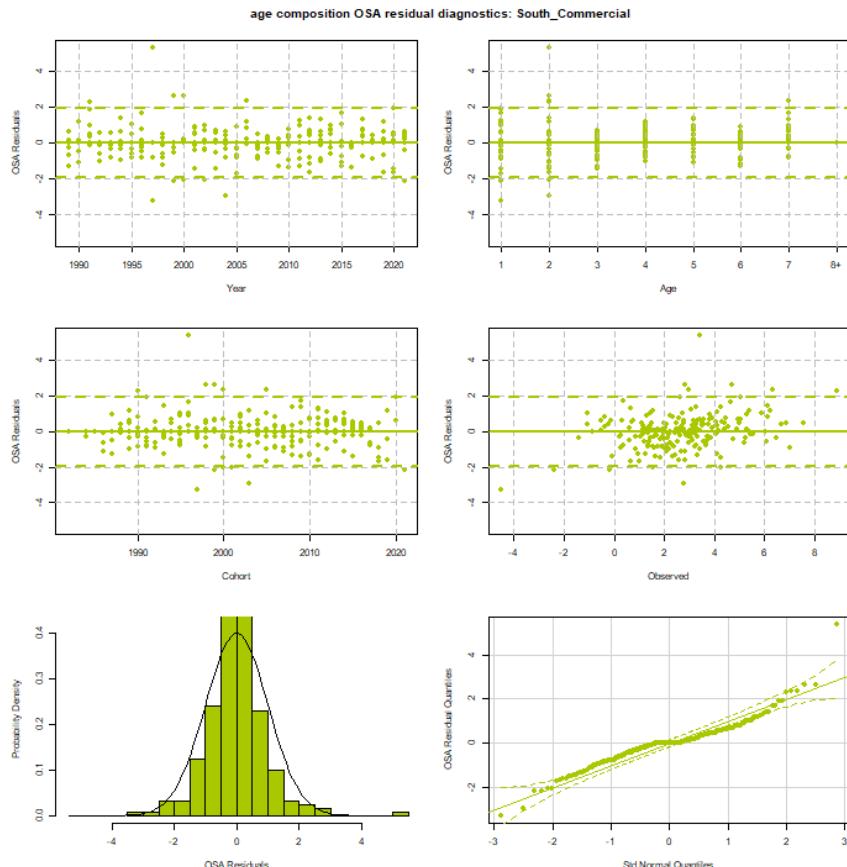
# OSA: South commercial fleet

- residuals tended to be negative



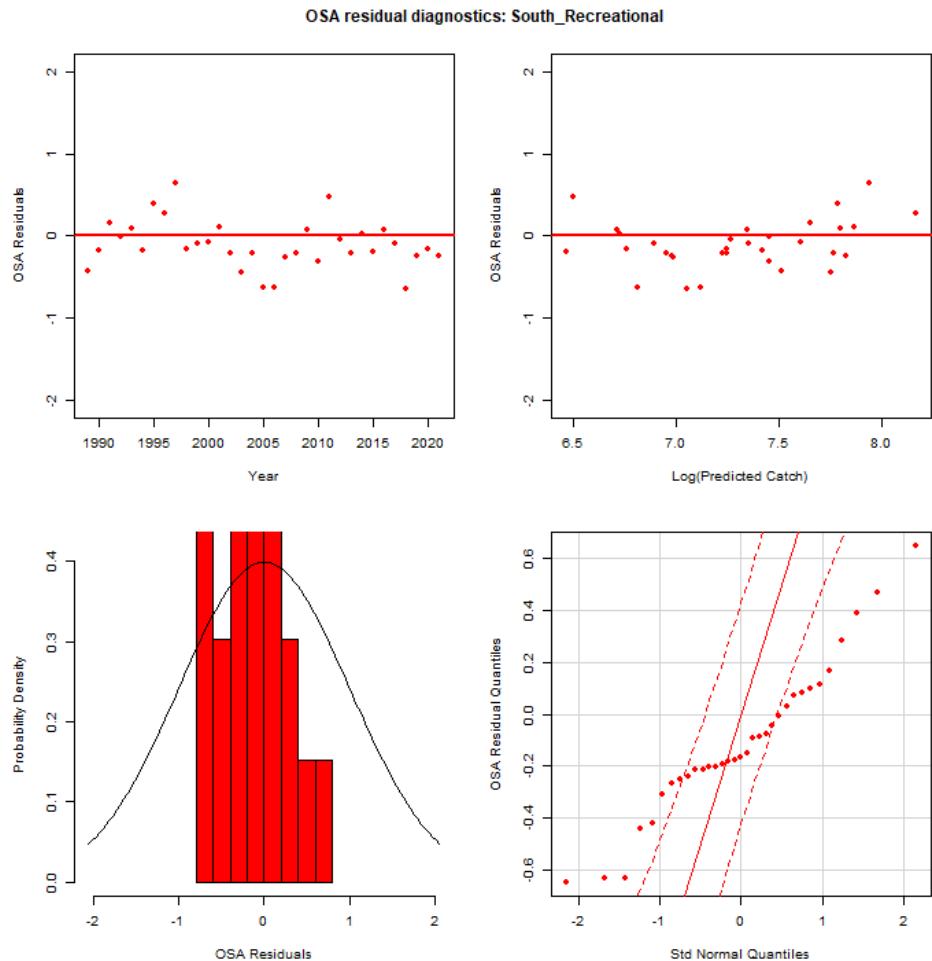
# OSA: South commercial fleet

- no evidence of mis-specification



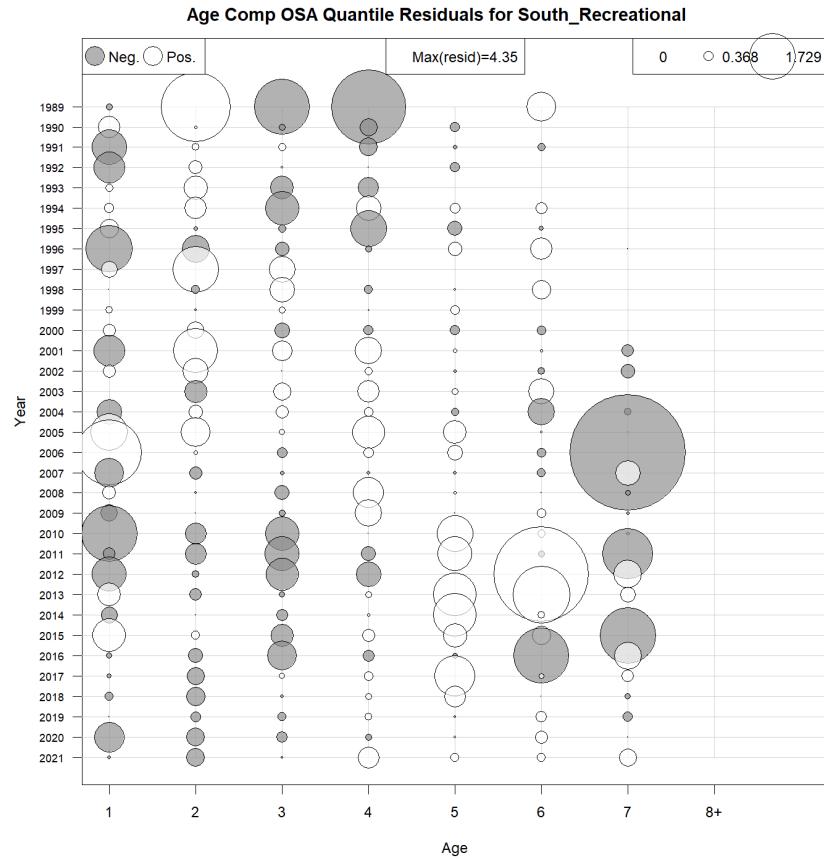
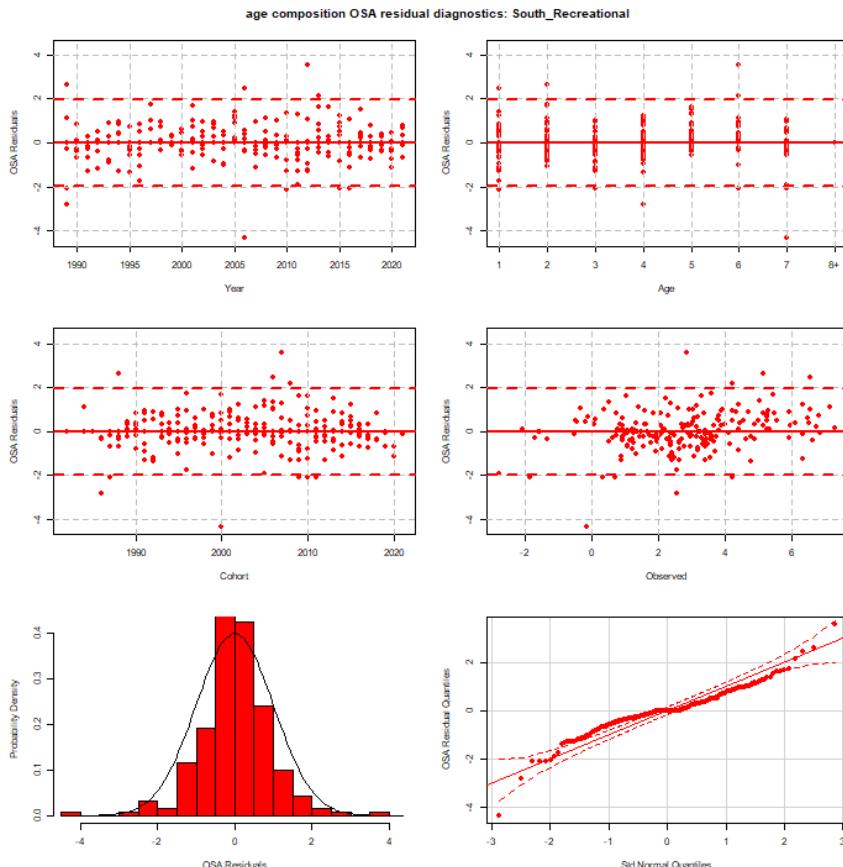
# OSA: South recreational fleet

- residuals were under-dispersed but no trends.



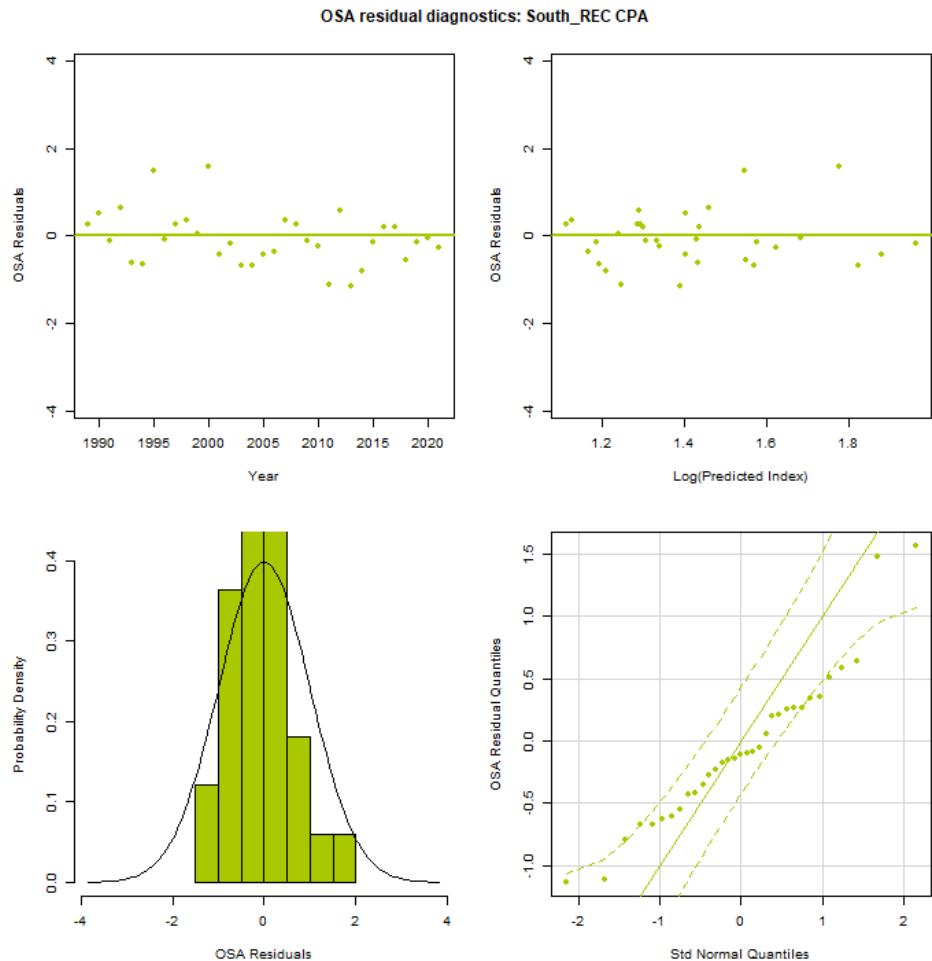
# OSA: South recreational fleet

- somewhat underdispersed, but no trends



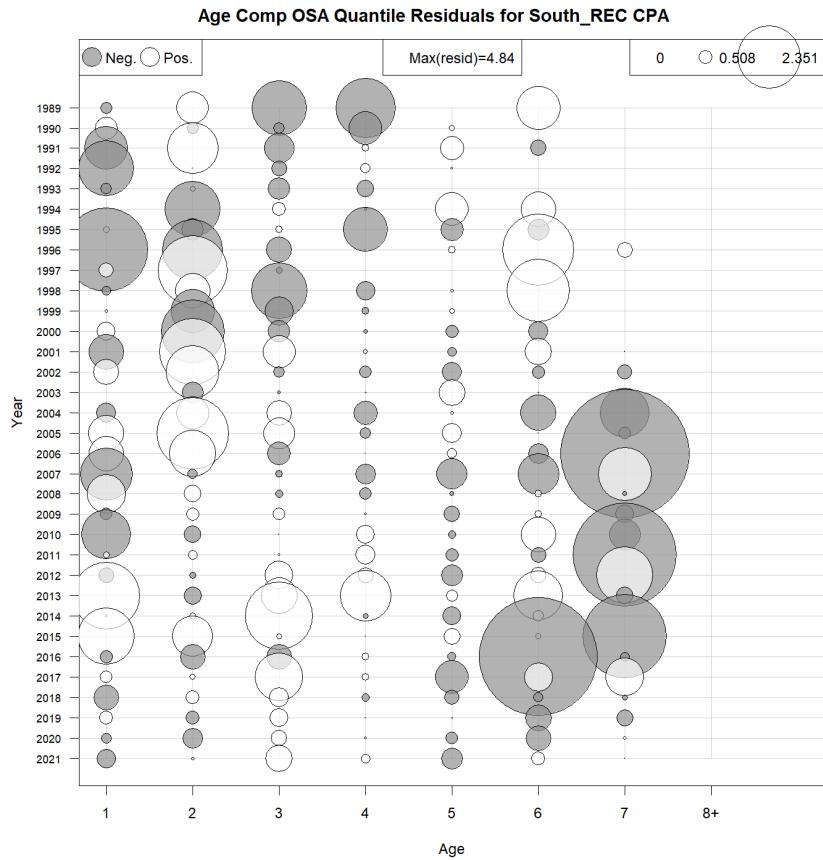
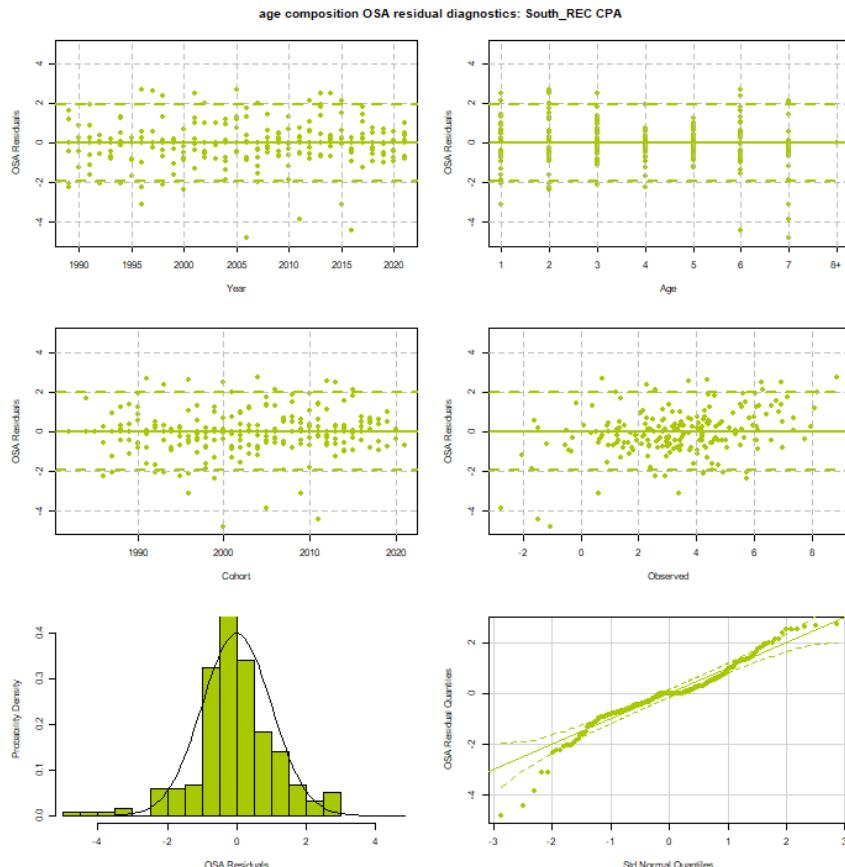
# OSA: South Rec CPA index

- somewhat under-dispersed



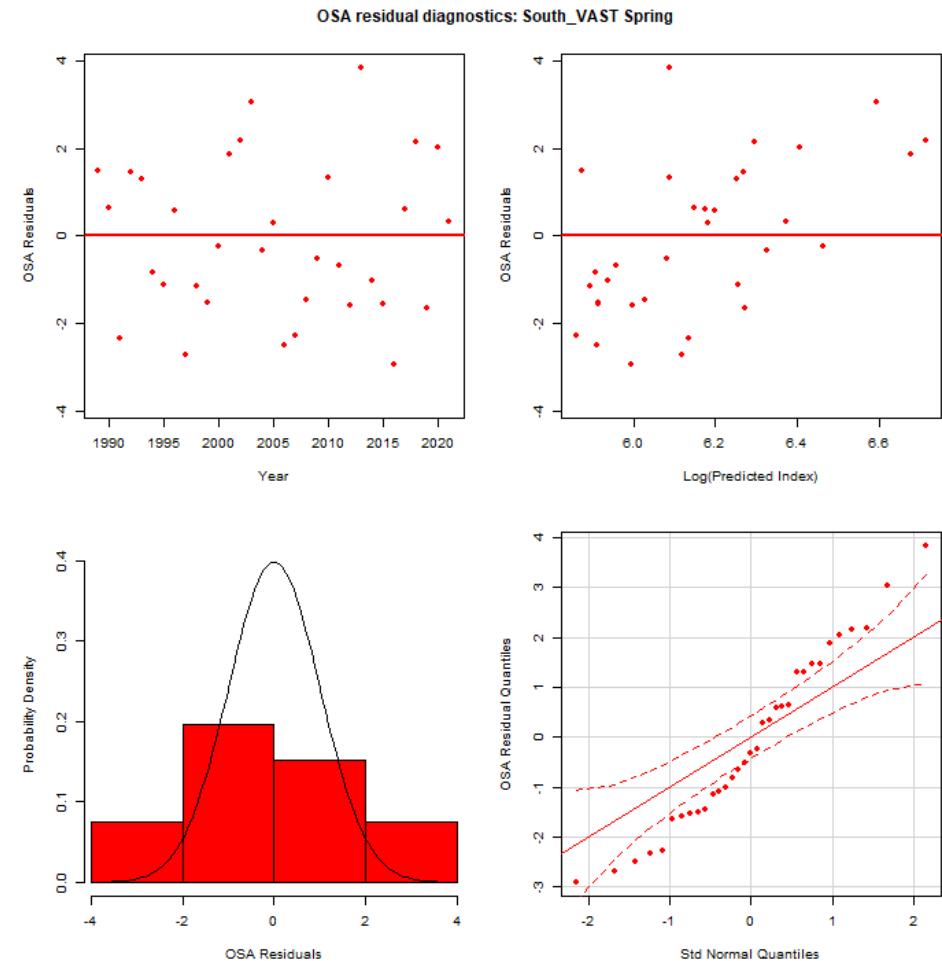
# OSA: South Rec CPA index

- a few large negative residuals at older ages, but otherwise no apparent trends



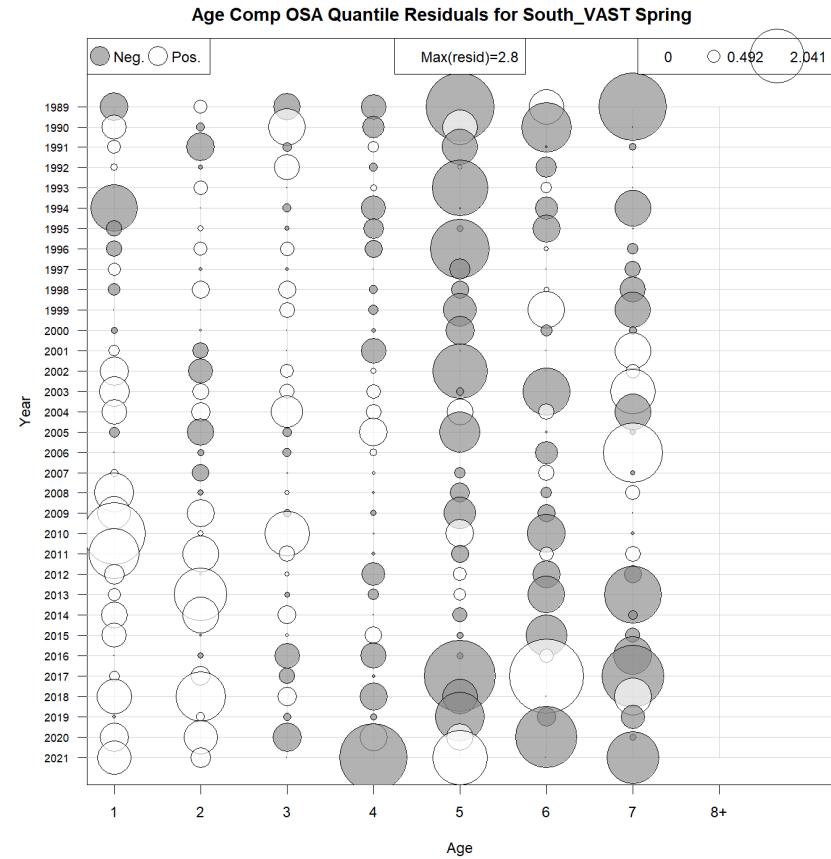
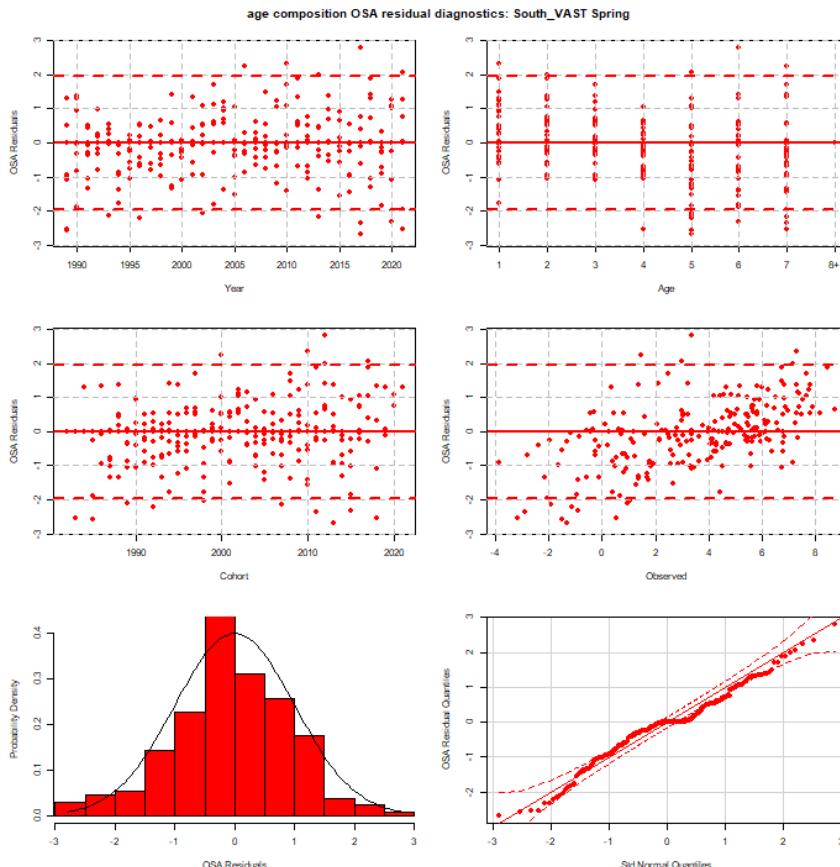
# OSA: South VAST index

- somewhat over-dispersed



# OSA: South VAST index

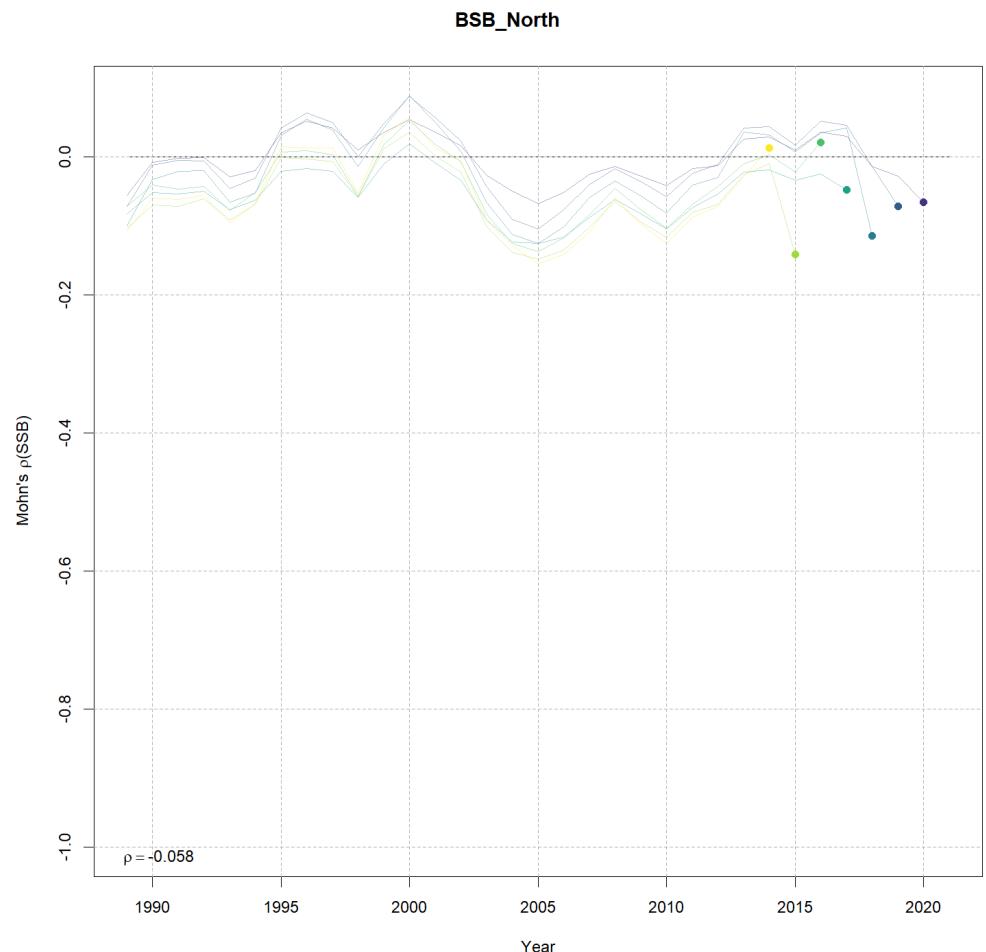
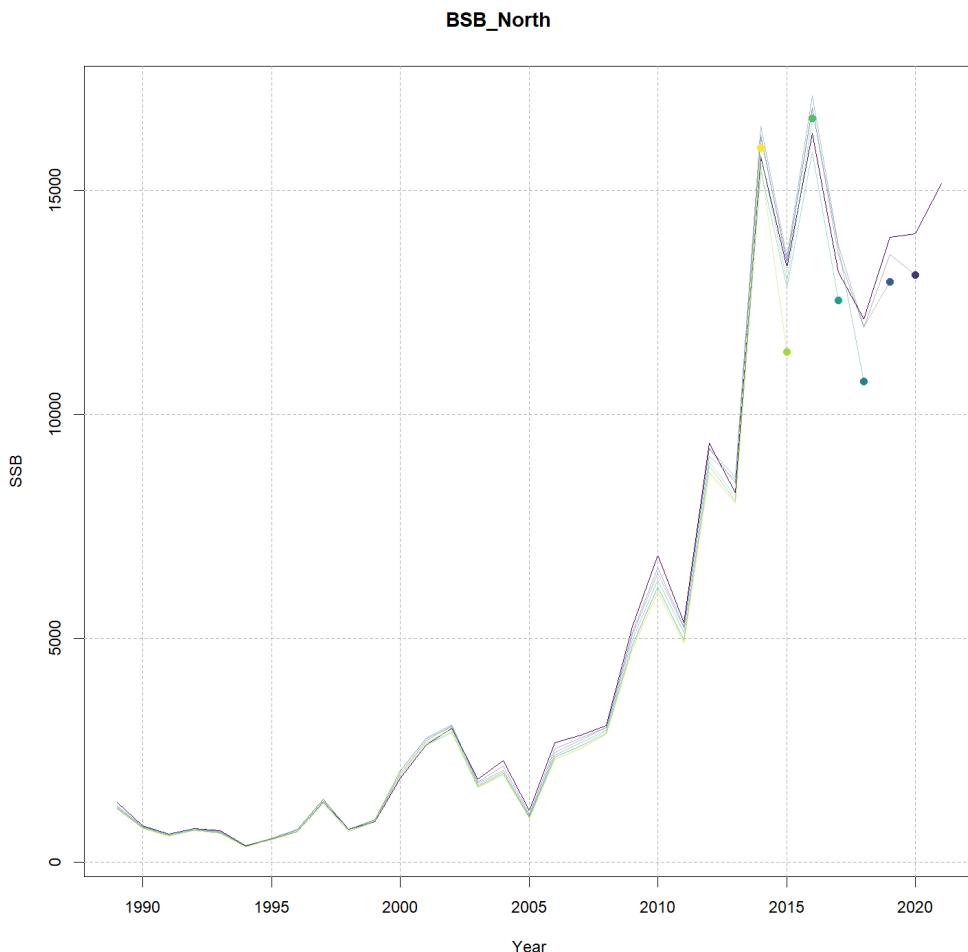
- some trend with observed proportion and age



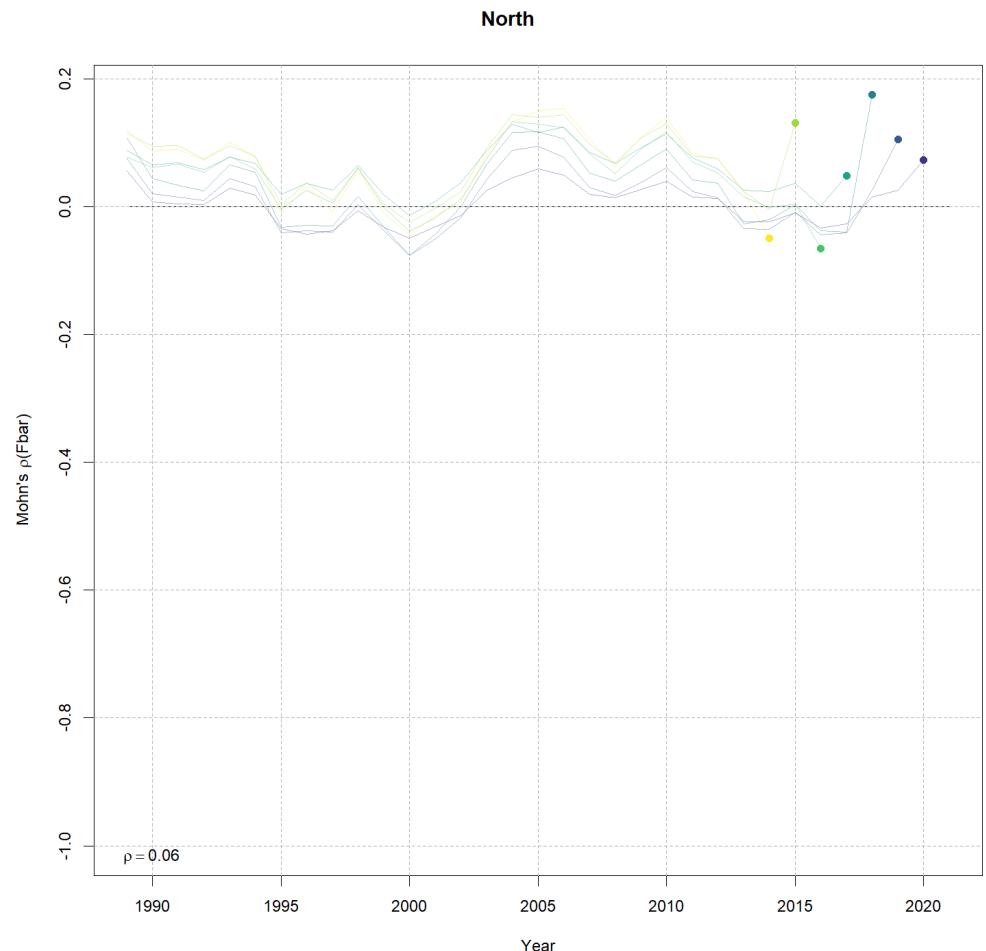
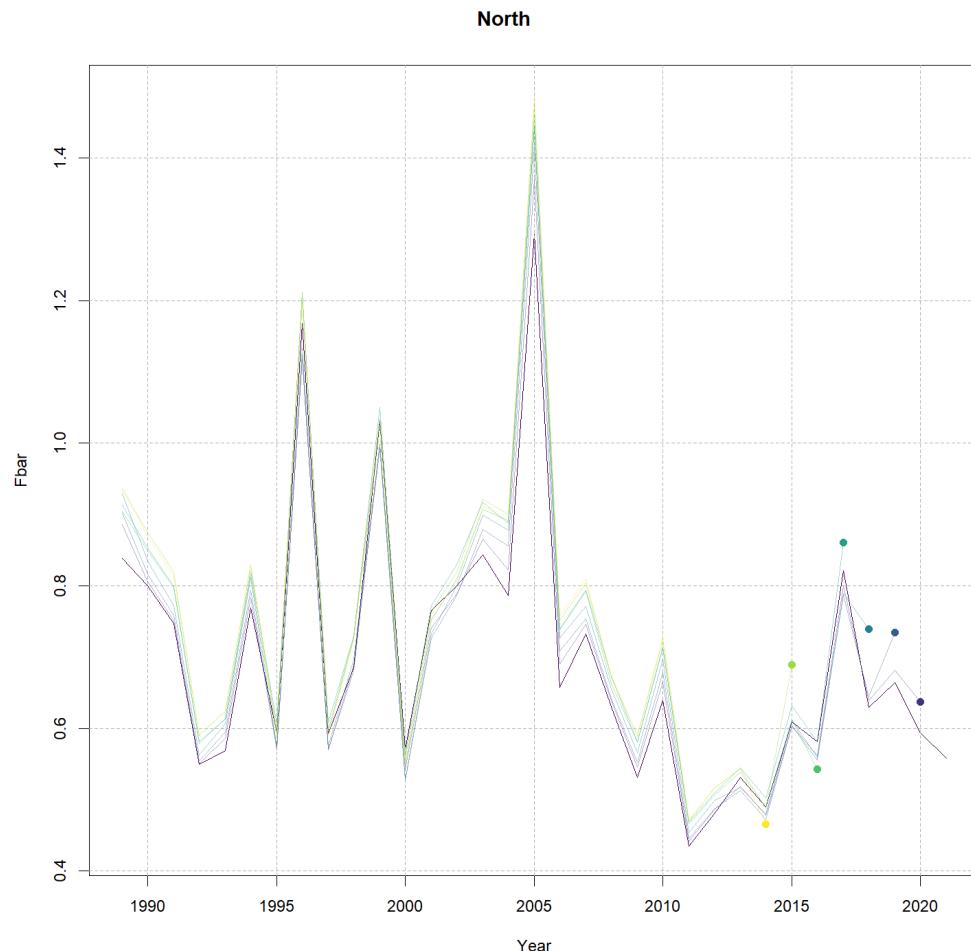
# Retrospective patterns

- Seven peels of the base model.
- Strong retrospective patterns in the most recent management track assessment for the northern component of the stock, do not occur in base model.

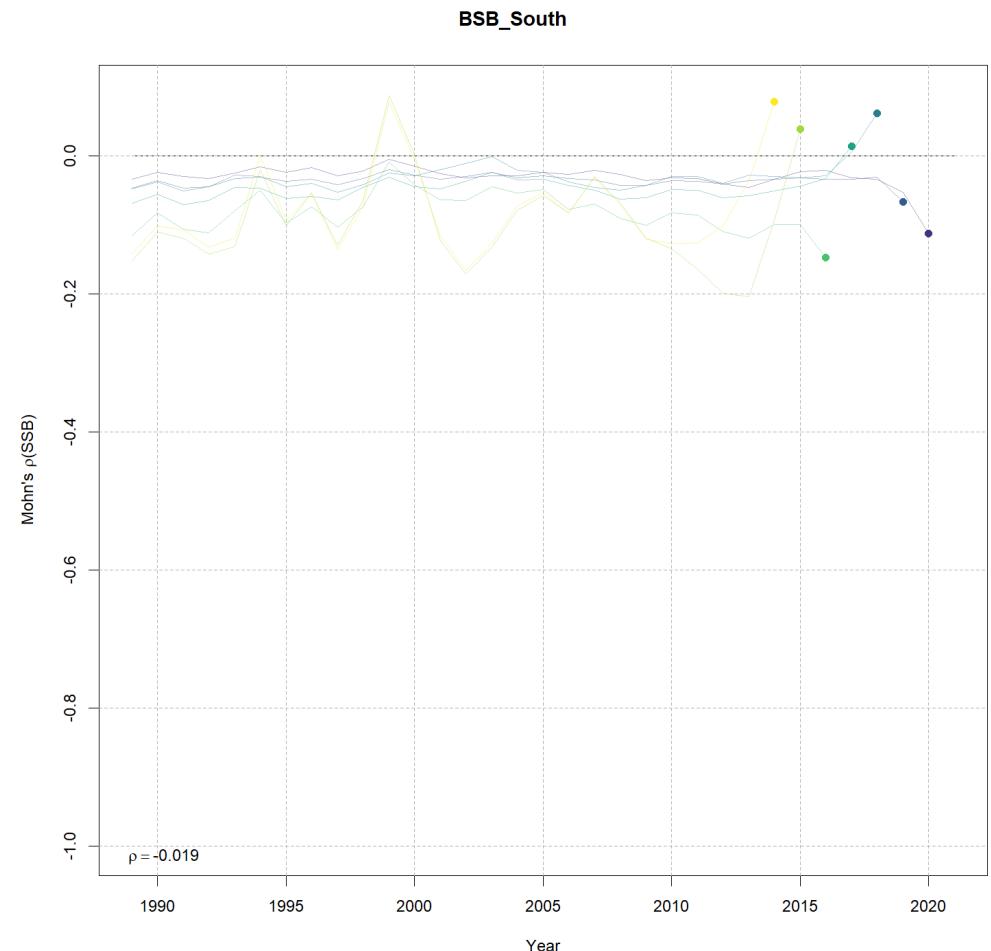
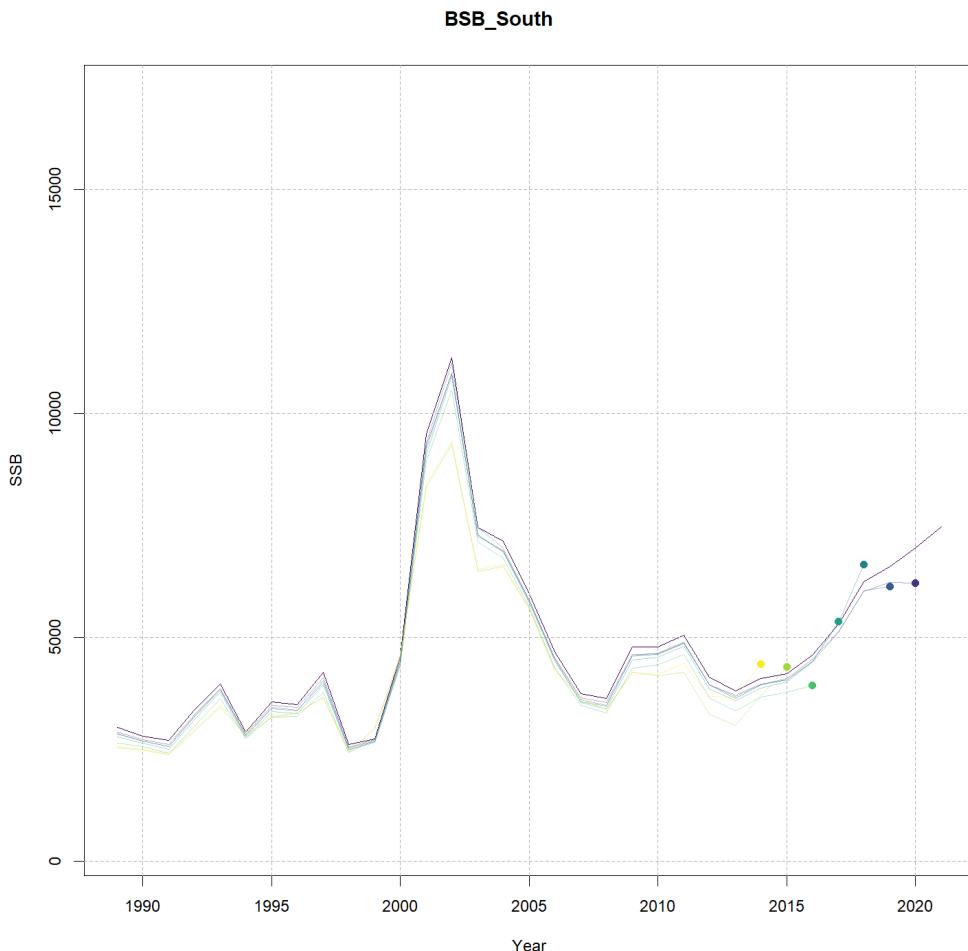
# Retrospective patterns: North SSB



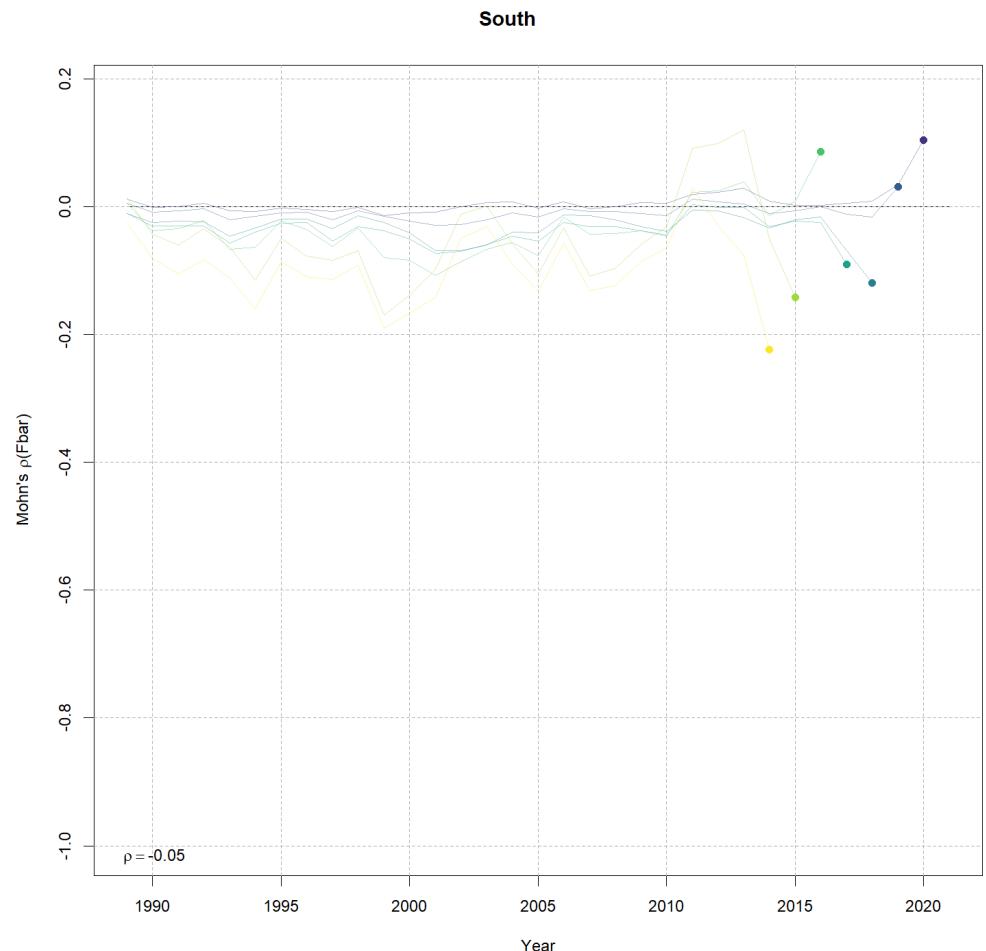
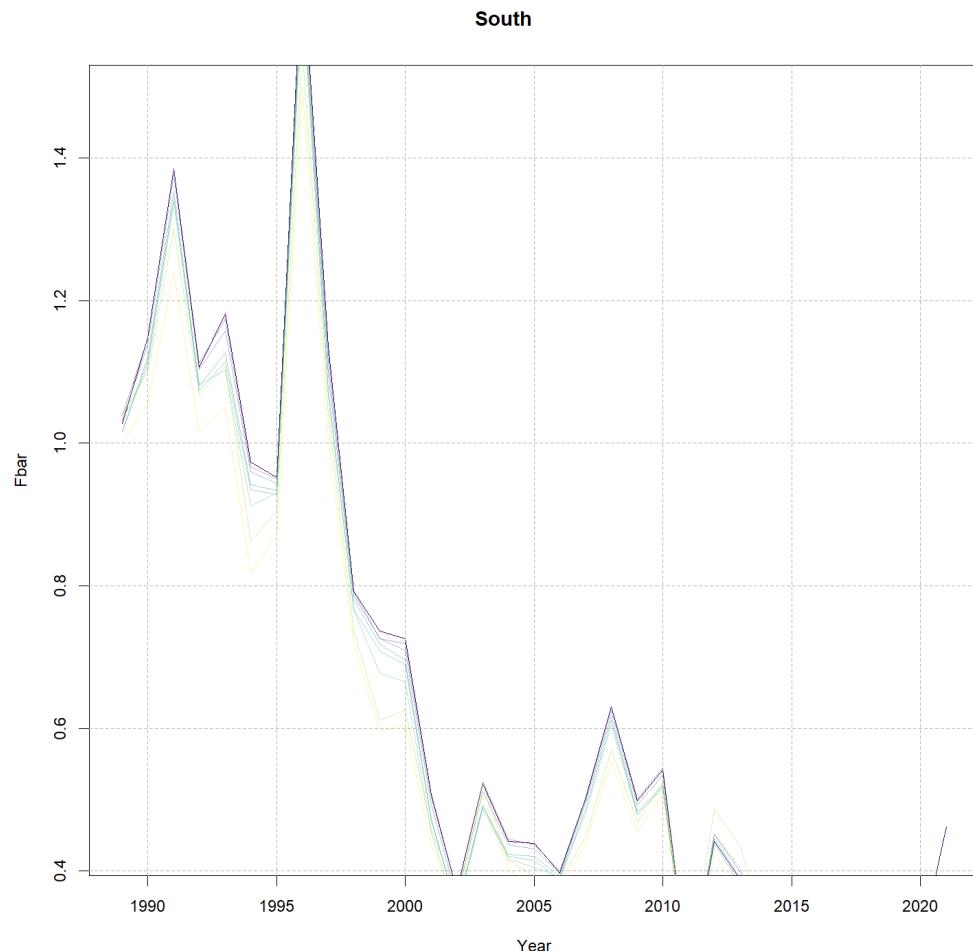
# Retrospective patterns: North F (average of ages 6-7)



# Retrospective patterns: South SSB

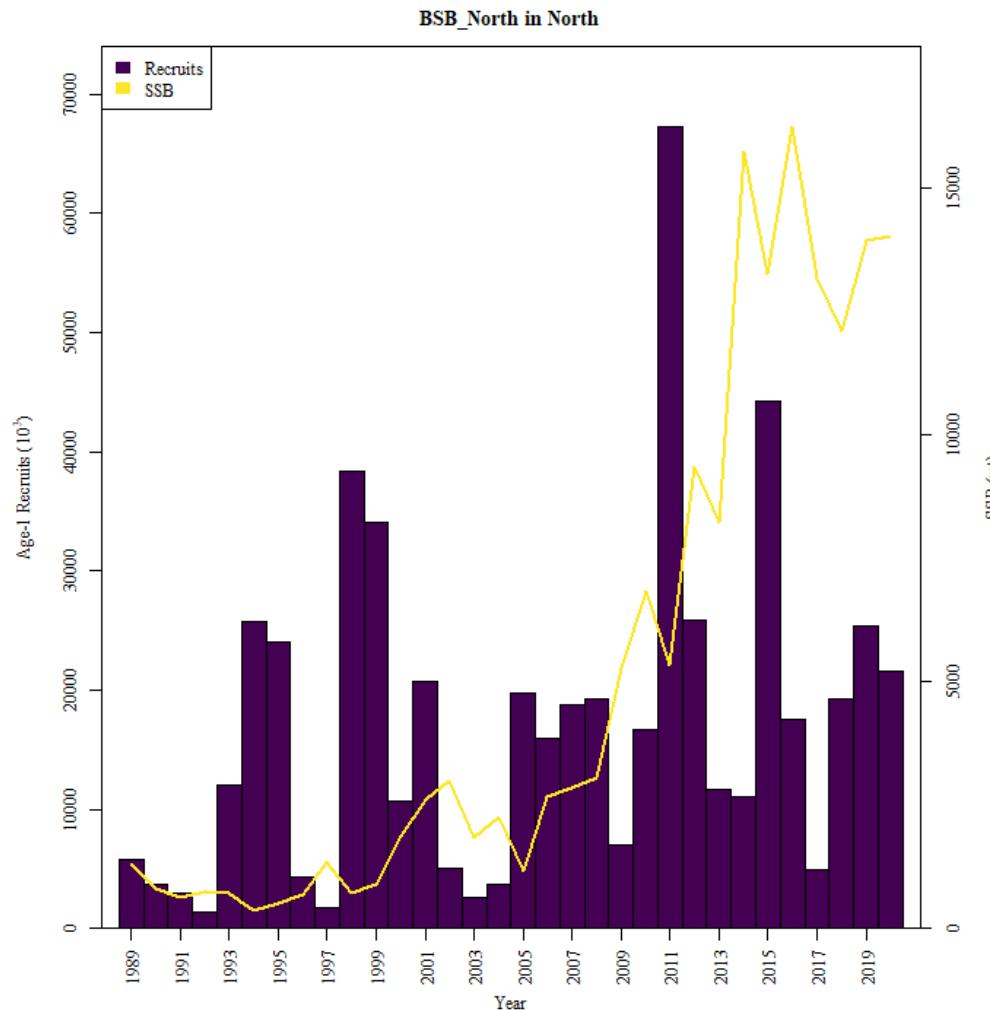


# Retrospective patterns: South F (average of ages 6-7)

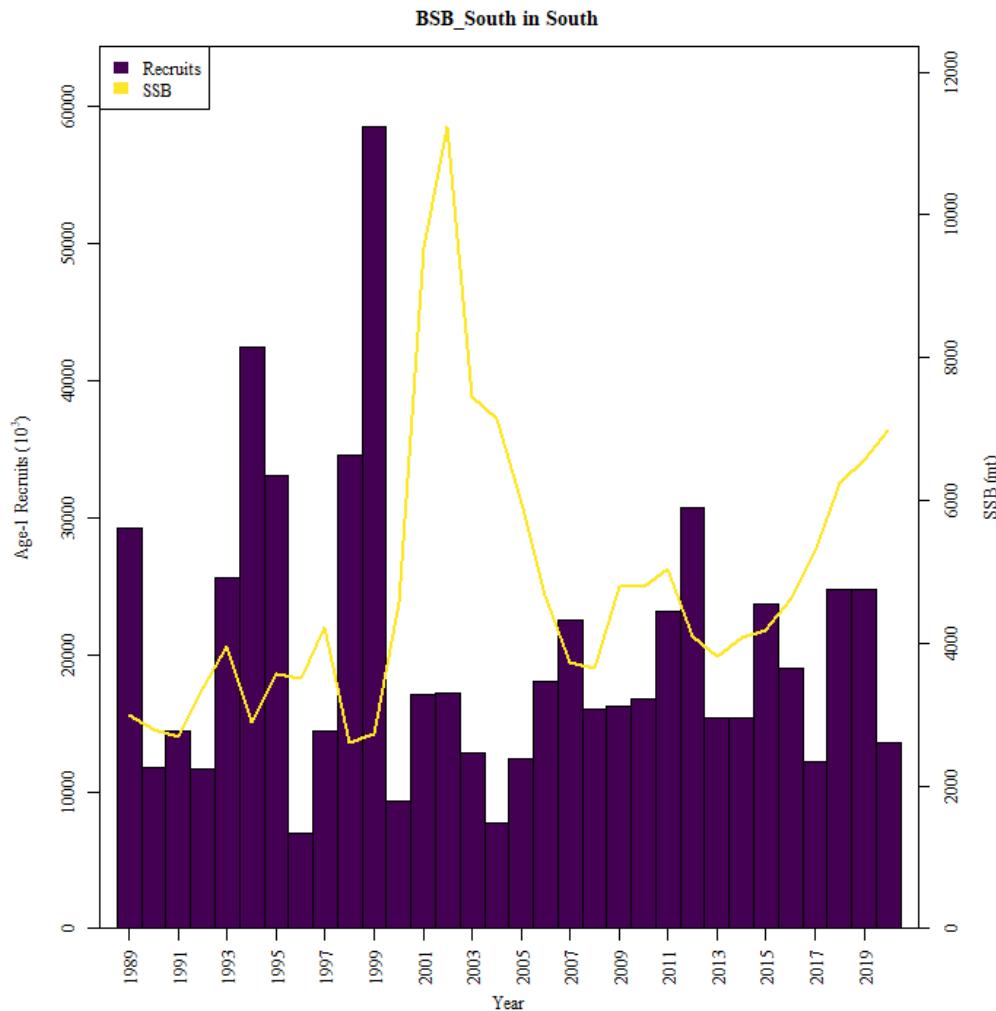


# Results

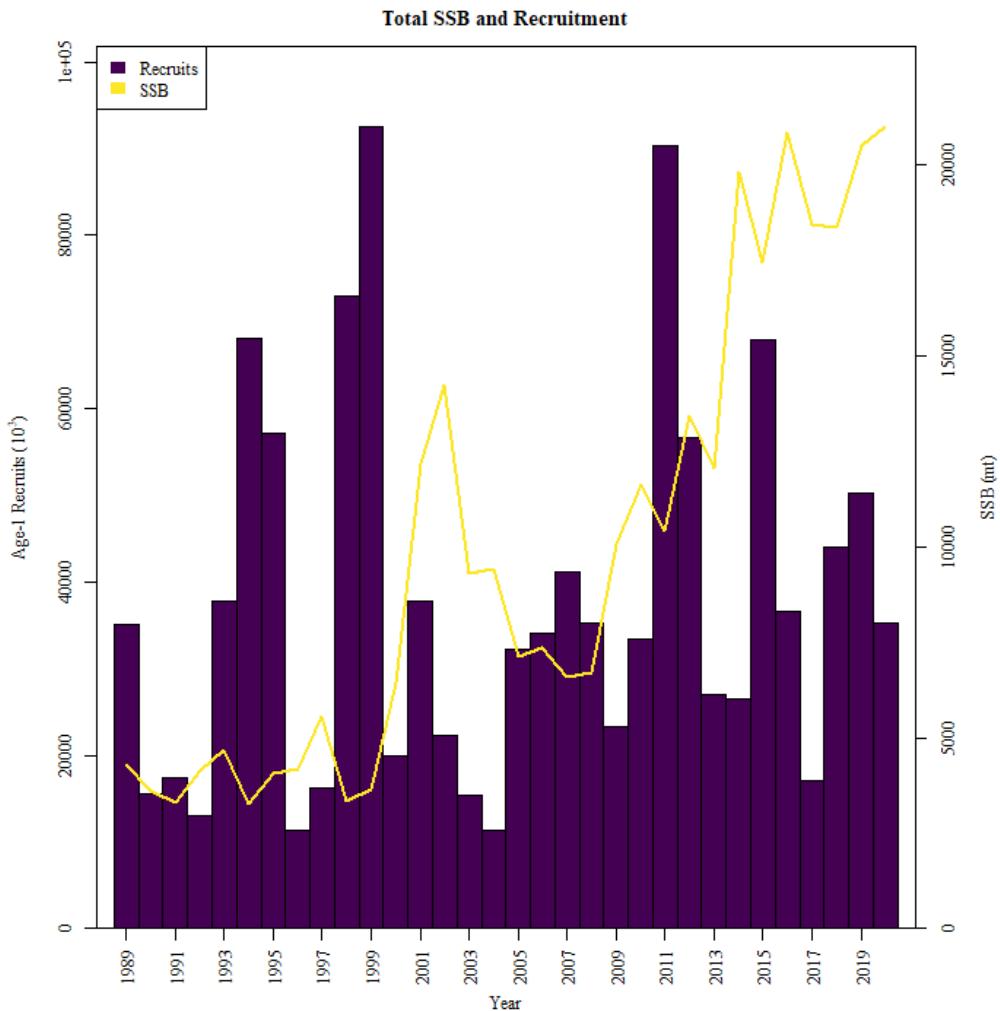
# SSB, R: North



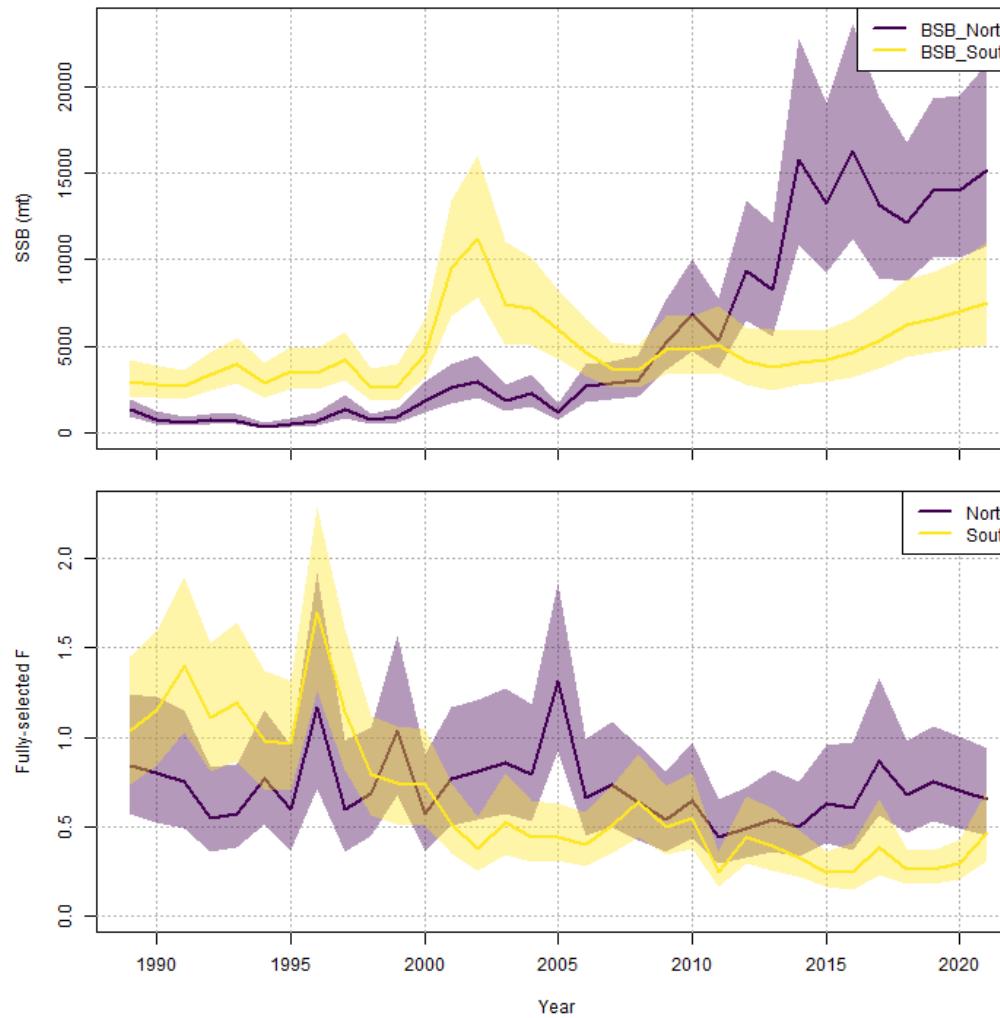
# SSB, R: South



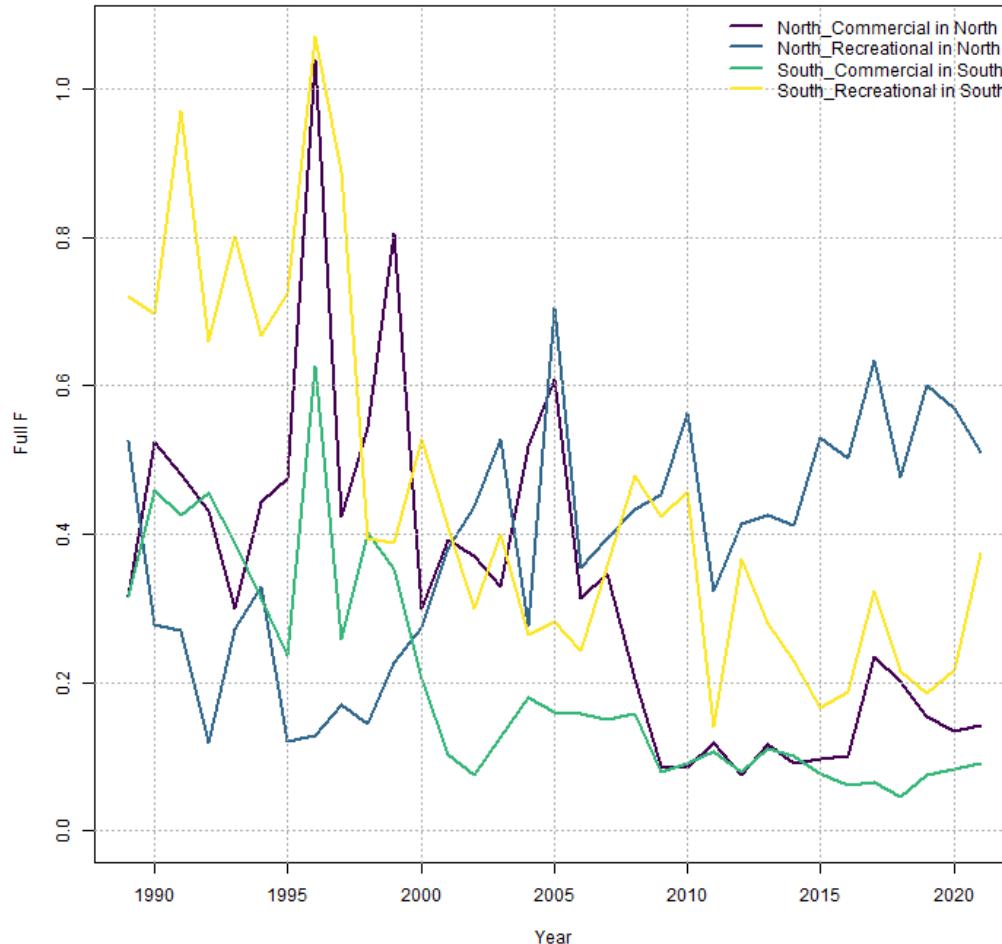
# SSB, R: Total



# SSB, F

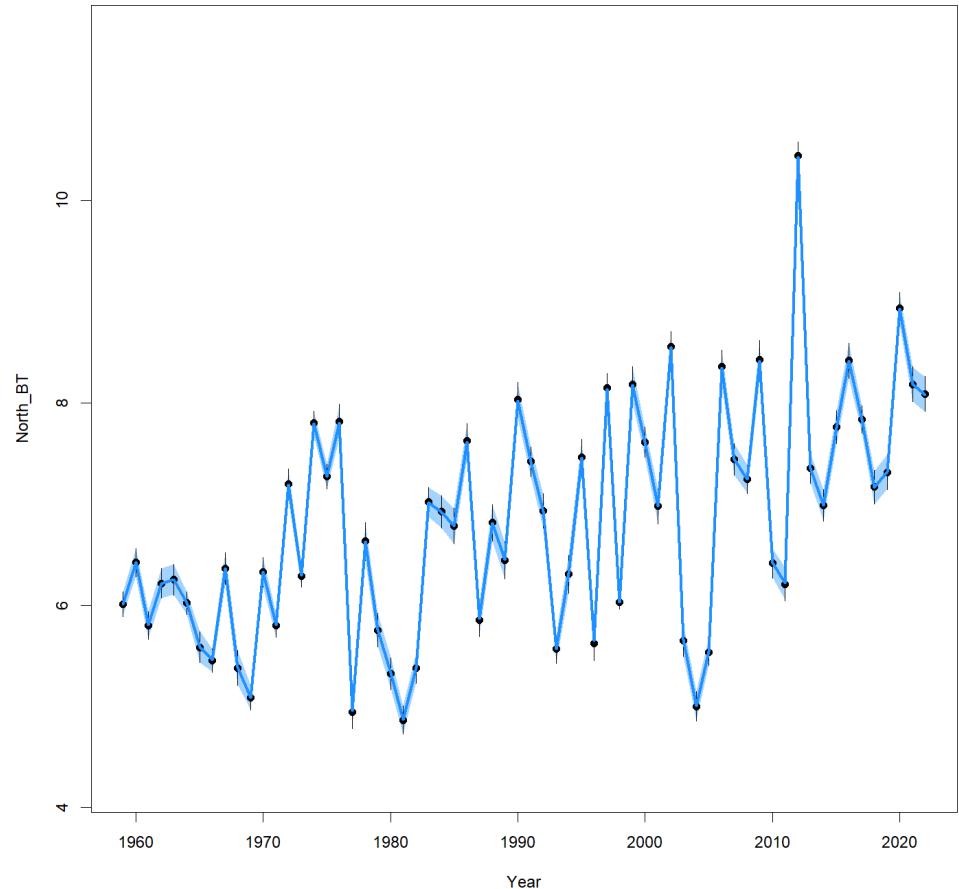


# F by fleet

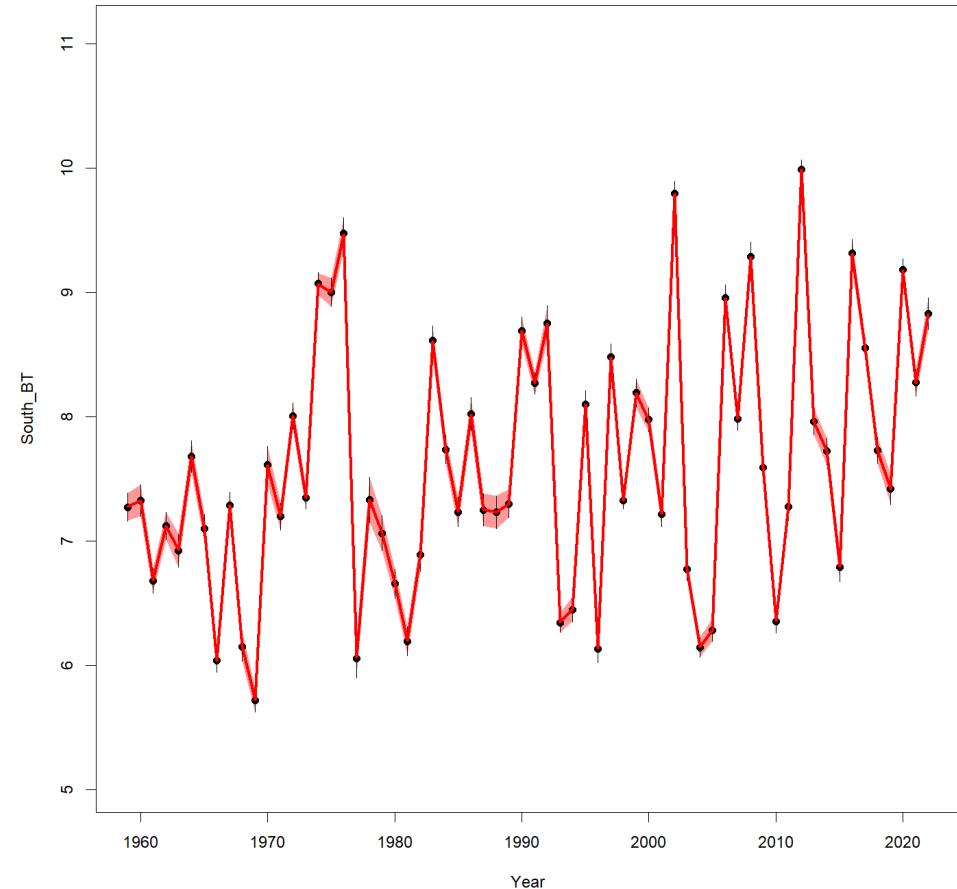


# Bottom temperature

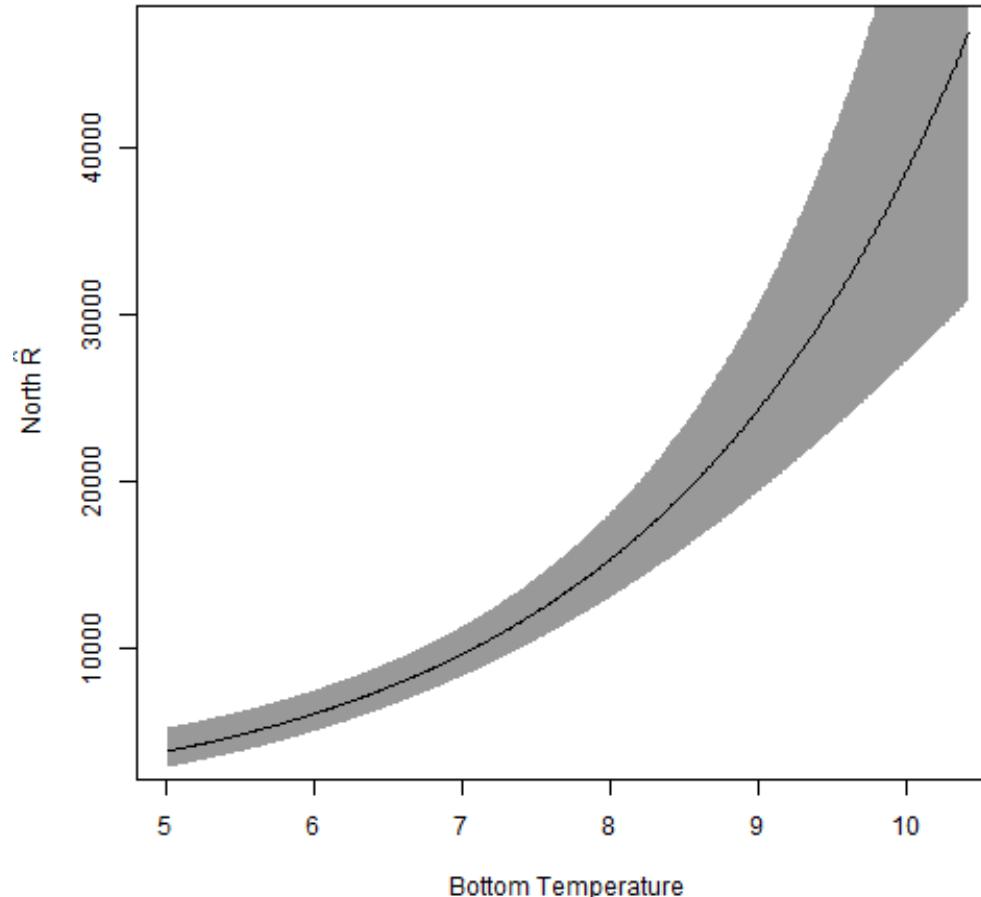
Ecov 1: North\_BT



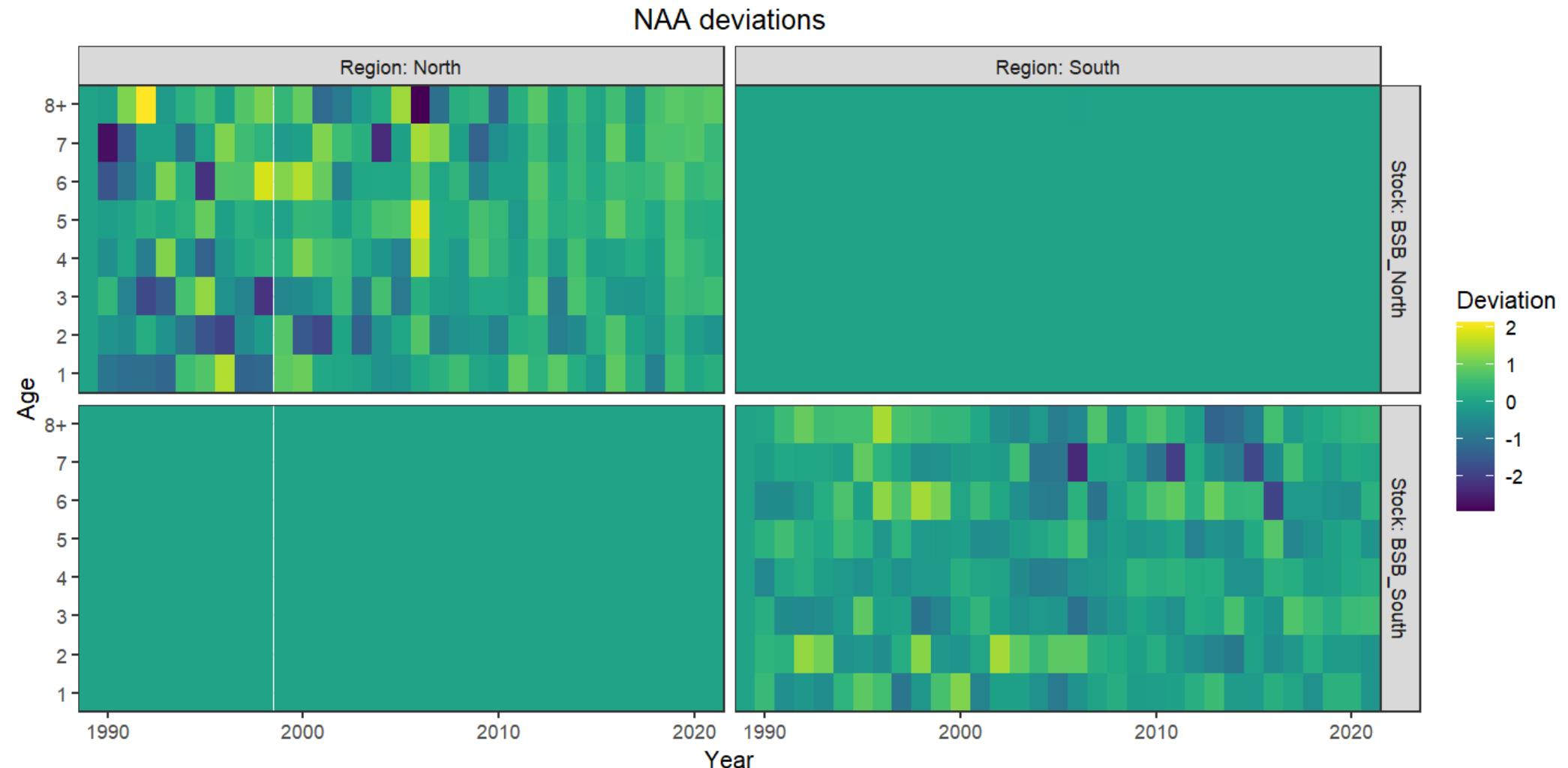
Ecov 2: South\_BT



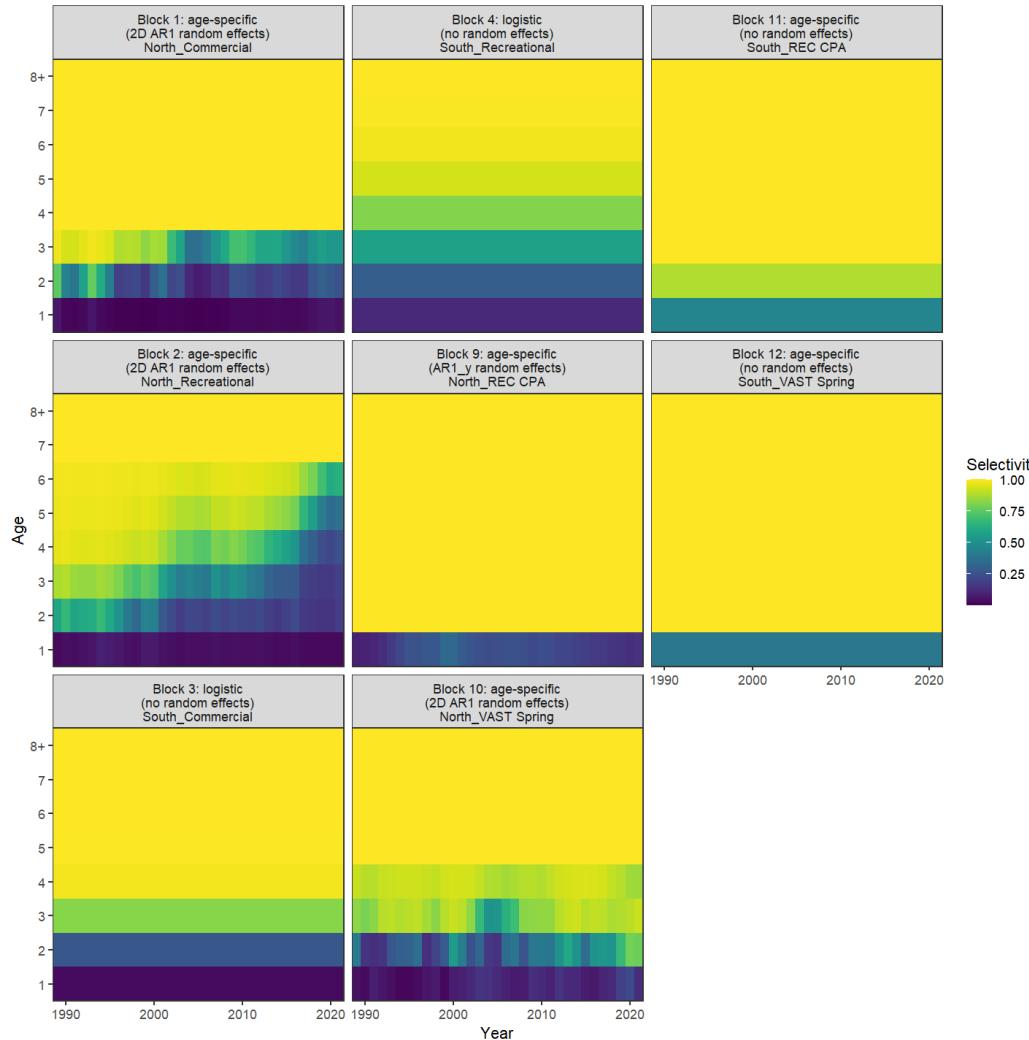
# Northern recruitment and bottom temperature



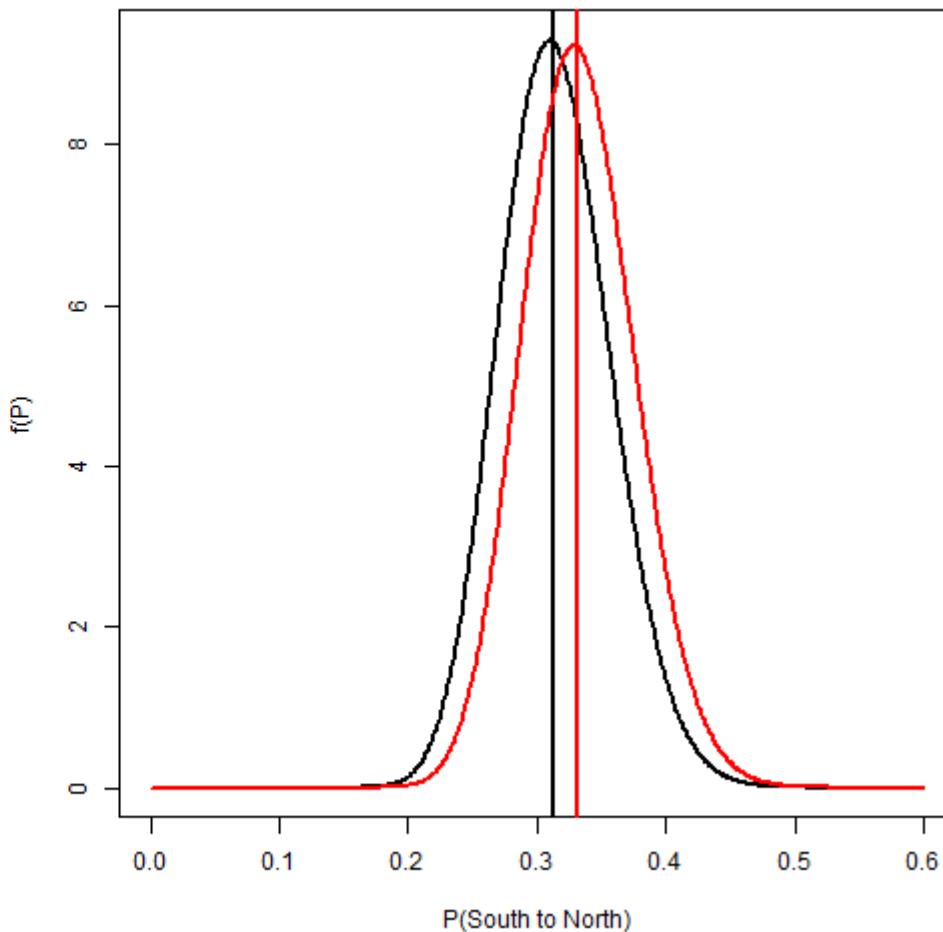
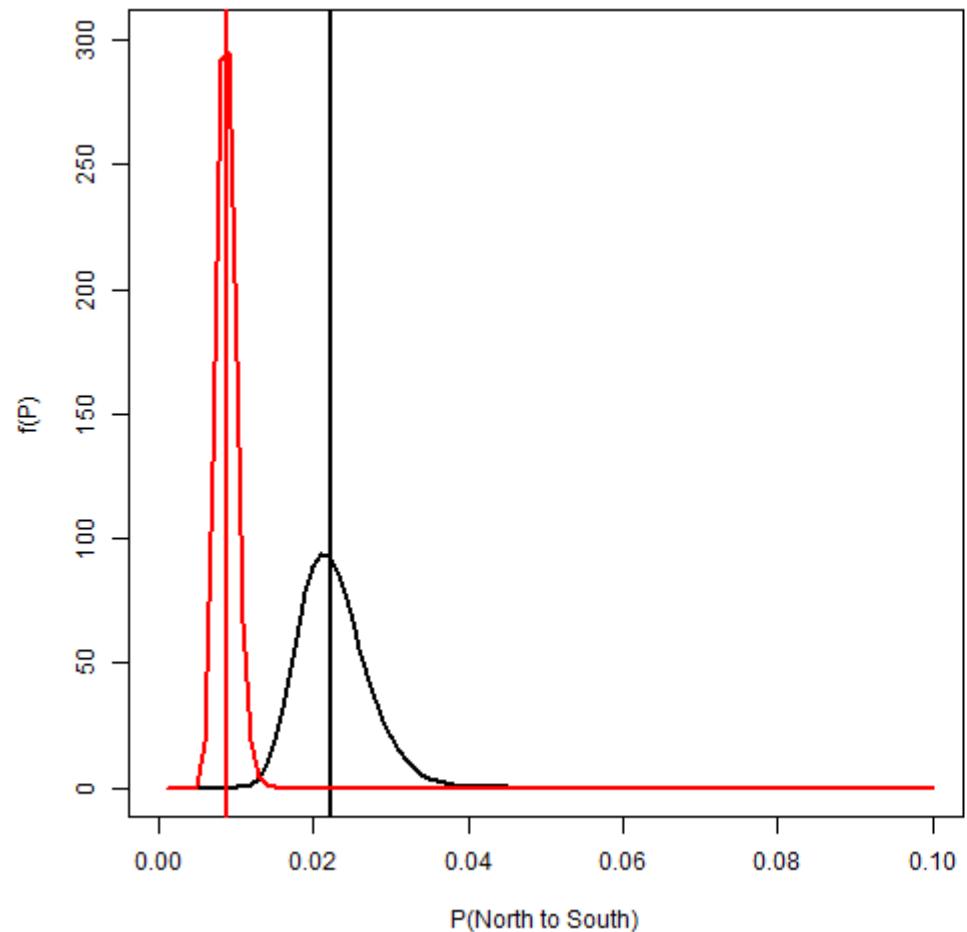
# NAA random effects deviations



# Selectivity



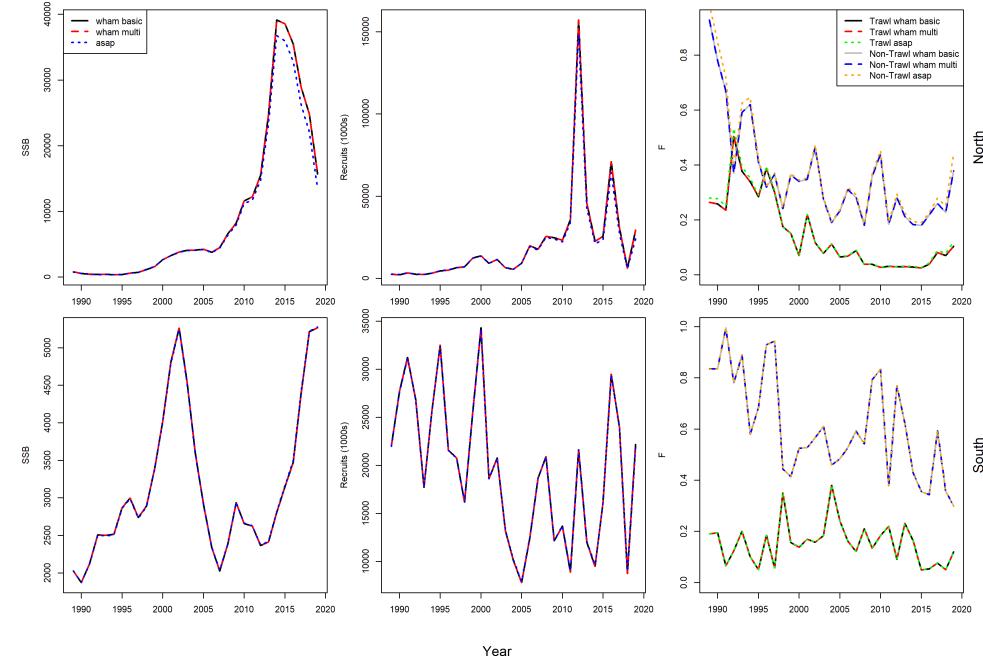
# Prior and posterior movement rates



# Path to the base model

# Comparing ASAP with standard WHAM and Multi-WHAM

- Based on data used in last management track
  - Time series of observations not updated
  - Use previous fleet definitions (Trawl and Non-Trawl).
- Compared
  - Management track ASAP
  - Separate fits in standard WHAM
  - Simultaneous (separate) fits in Multi-WHAM



# Bridge runs

Separate fits for north and south regions

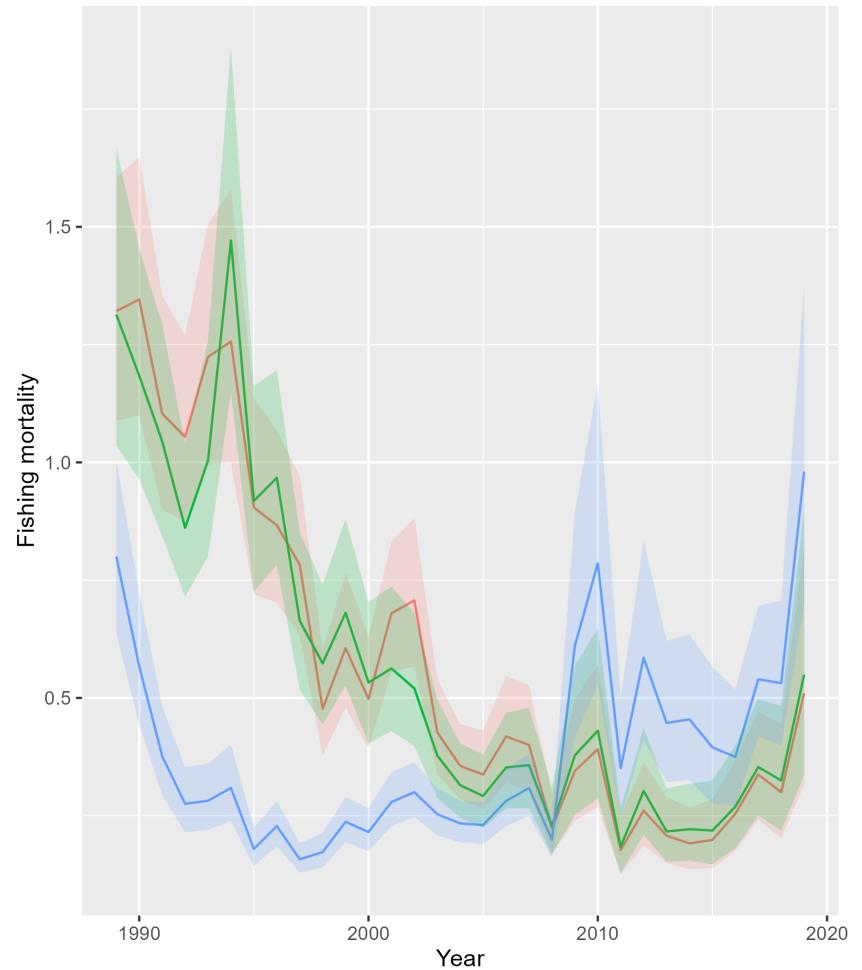
- 1: Turn off all indices but NEFSC Spring BTS and Rec CPA
- 2: Update fishery catches, fishing fleets and catch WAA estimates to comm/rec fleets
- 3: Update Spring BTS and Rec CPA
- 4: Add 2020-2021
- 5: Update maturity
- 6: Add NEAMAP
- 7: Update remaining spring state indices (added VAST as well but didn't turn them on)
- 8: Rec CPA and both spring and fall VAST
- 9: Rec CPA and VAST spring only (also a combined stock run that matches the single stock results. This combined run will be used for later runs.)

# Bridge runs

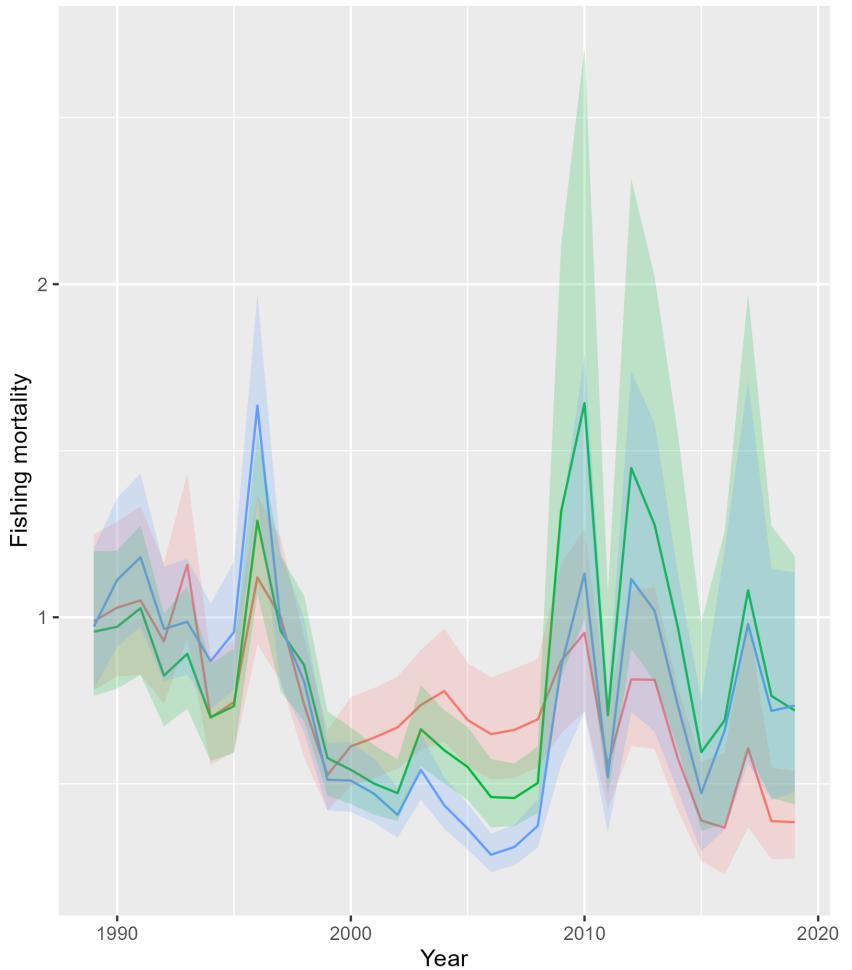
Separate fits for north and south regions

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- 9: Rec CPA and VAST spring only (also a combined stock run that matches the single stock results. This combined run will be used for later runs.)

# Bridge runs 1, 2, and 3

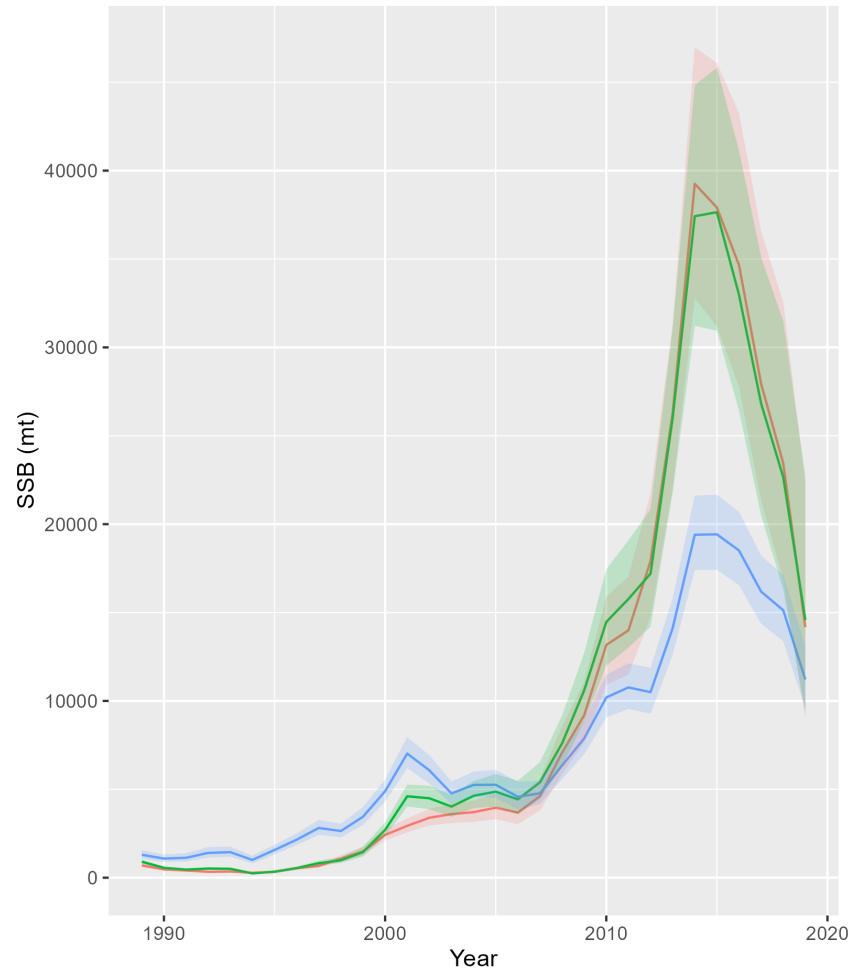


North

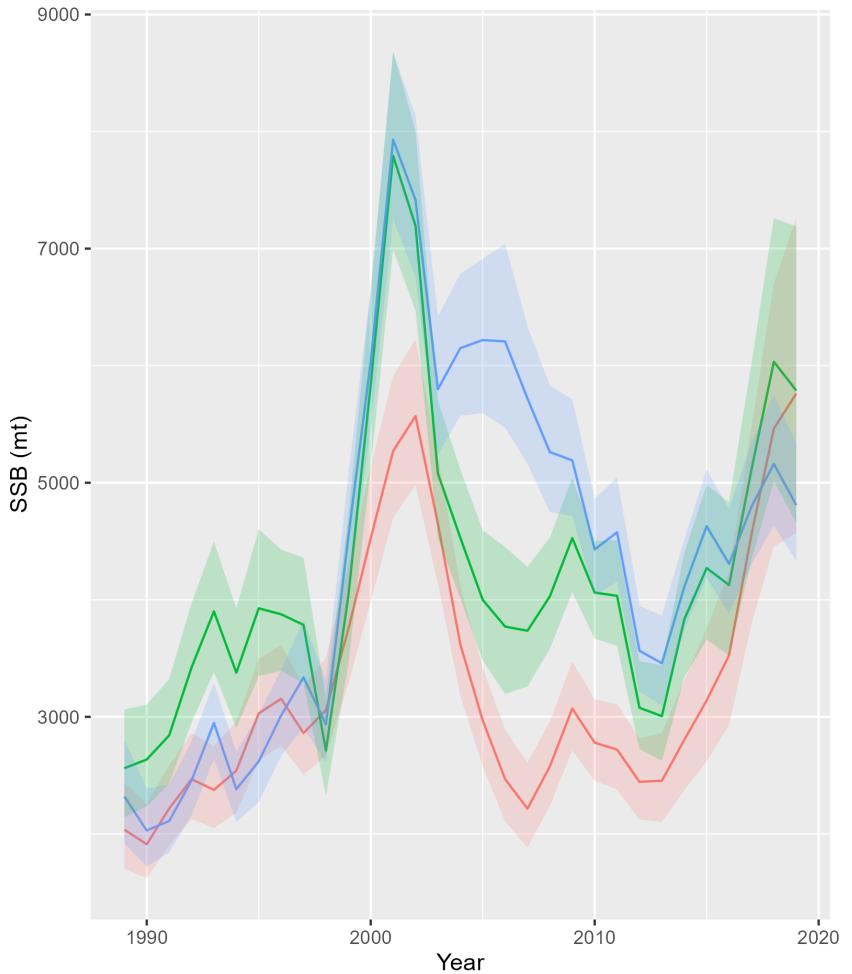


South

# Bridge runs 1, 2, and 3

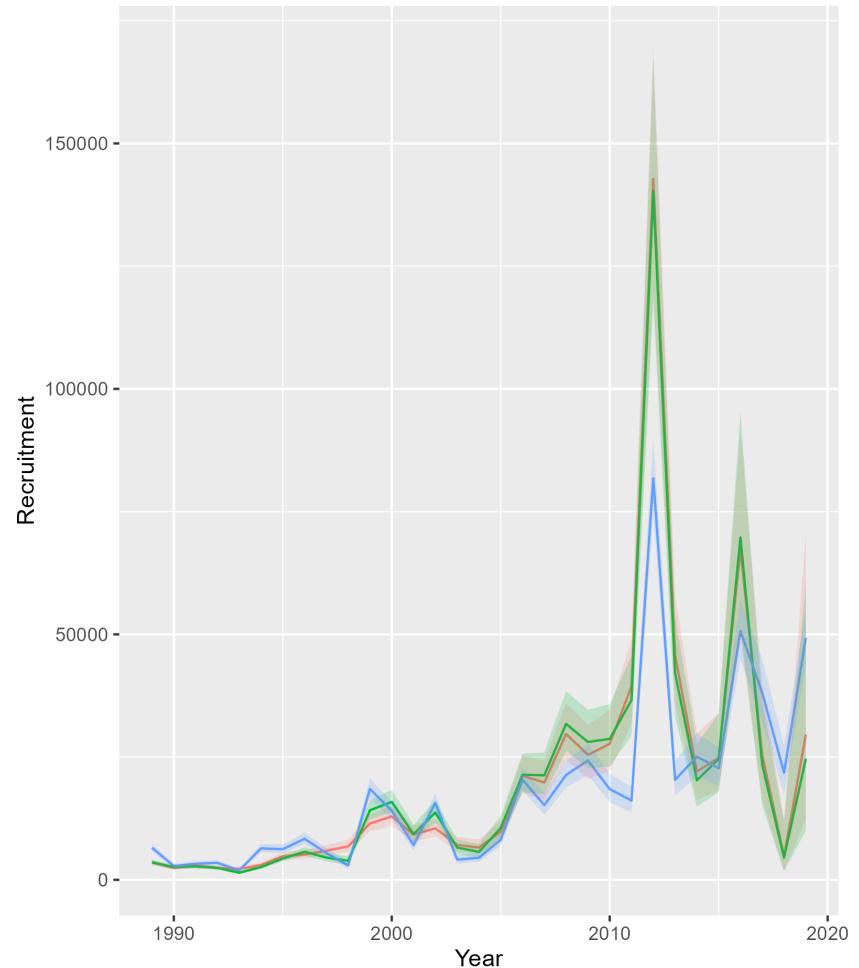


North

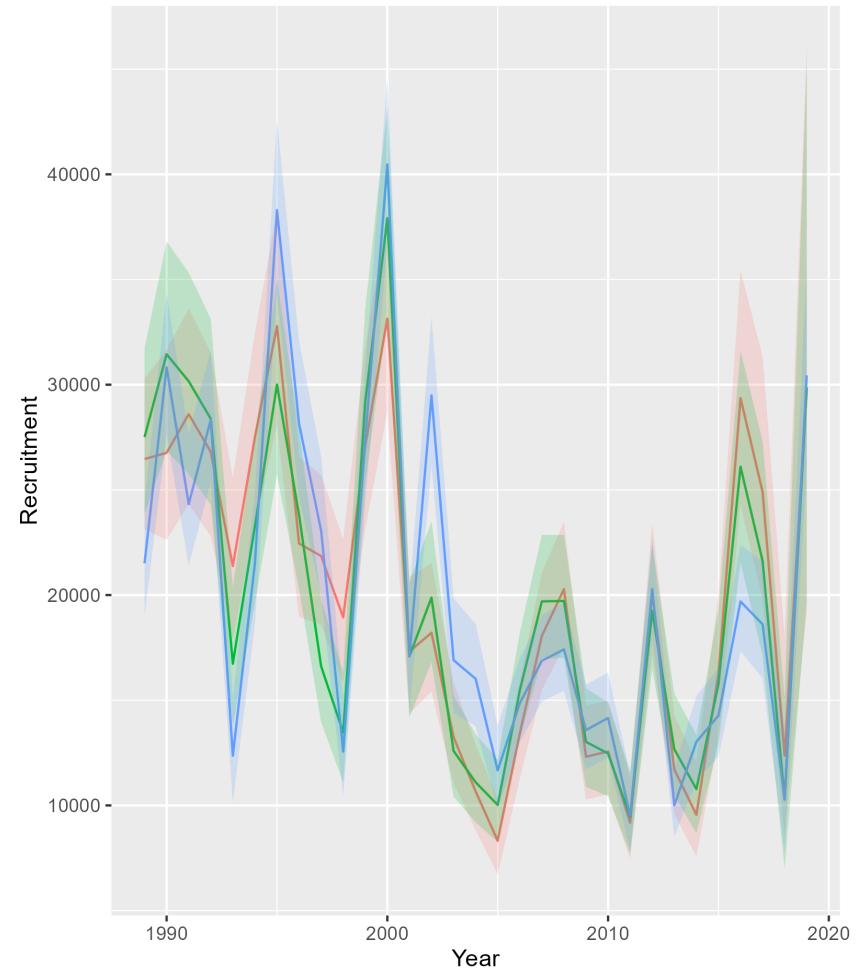


South

# Bridge runs 1, 2, and 3



North



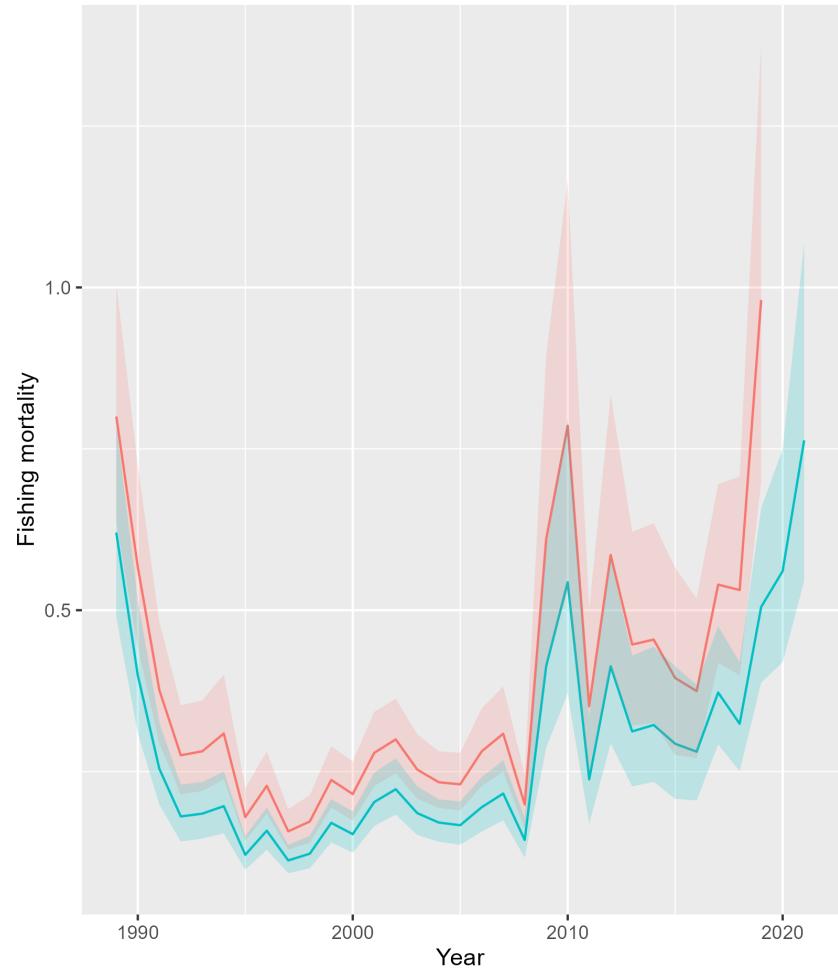
South

# Bridge runs

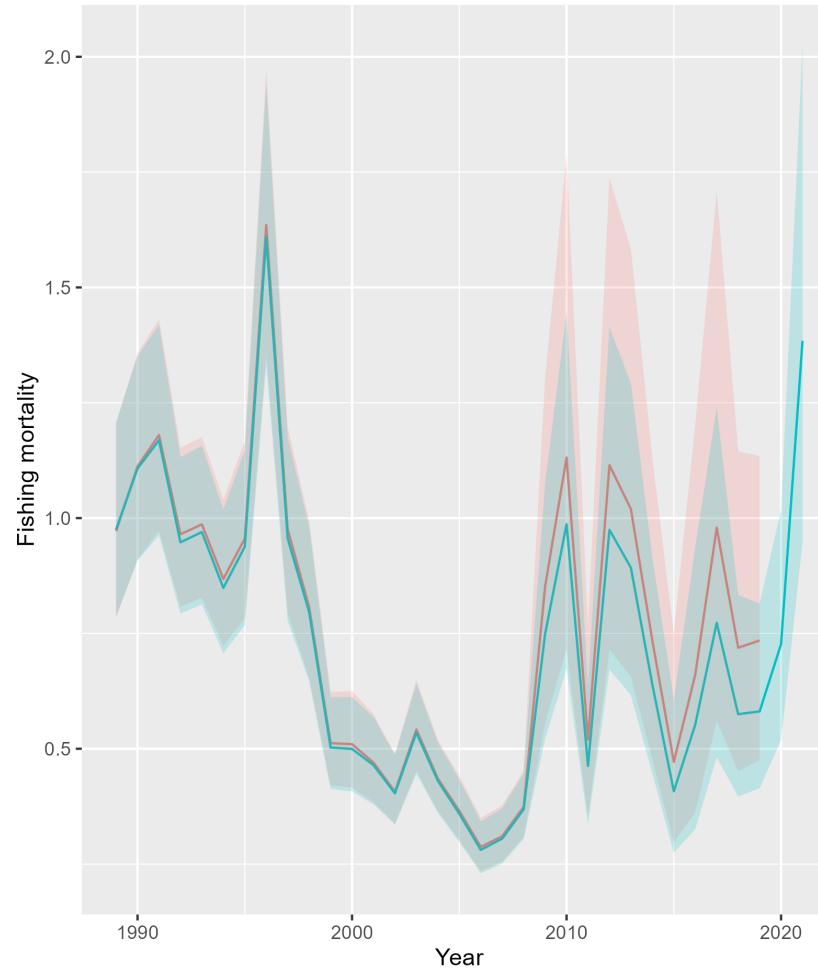
Separate fits for north and south regions

- 1: Turn off all indices but NEFSC Spring BTS and Rec CPA
- 2: Update fishery catches, fishing fleets and catch WAA estimates to comm/rec fleets
- 3: Update Spring BTS and Rec CPA
- 4: Add 2020-2021
- 5: Update maturity
- 6: Add NEAMAP
- 7: Update remaining spring state indices (added VAST as well but didn't turn them on)
- 8: Rec CPA and both spring and fall VAST
- 9: Rec CPA and VAST spring only (also a combined stock run that matches the single stock results. This combined run will be used for later runs.)

# Bridge runs 3 and 4

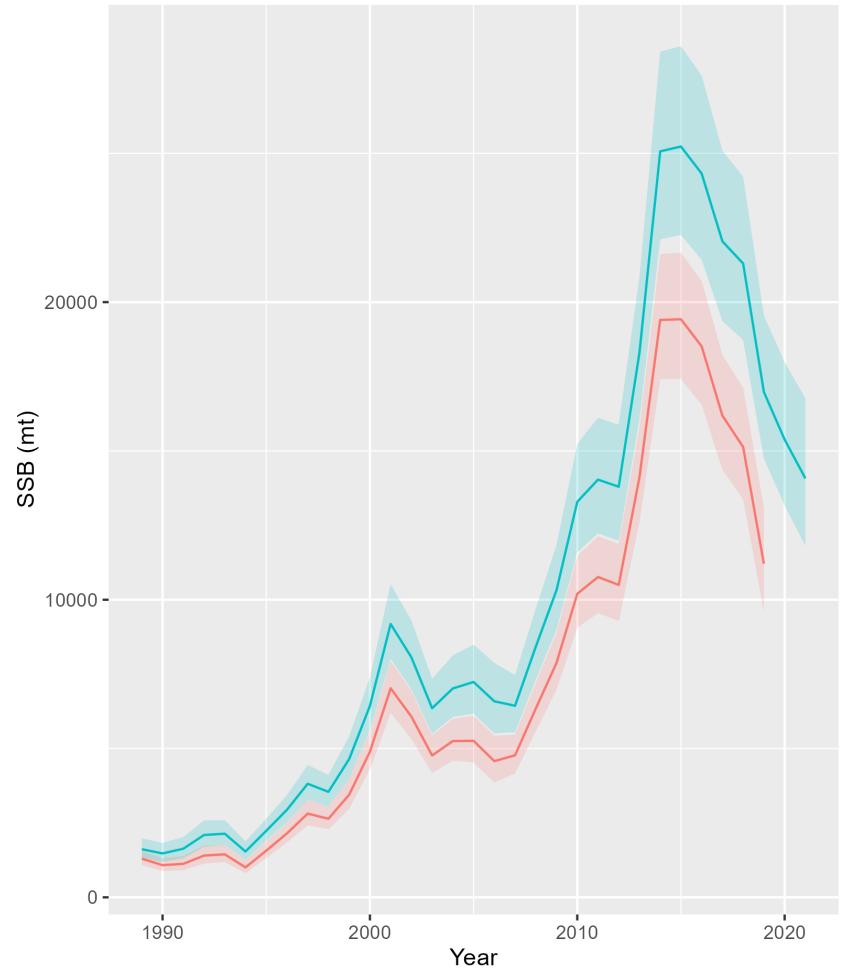


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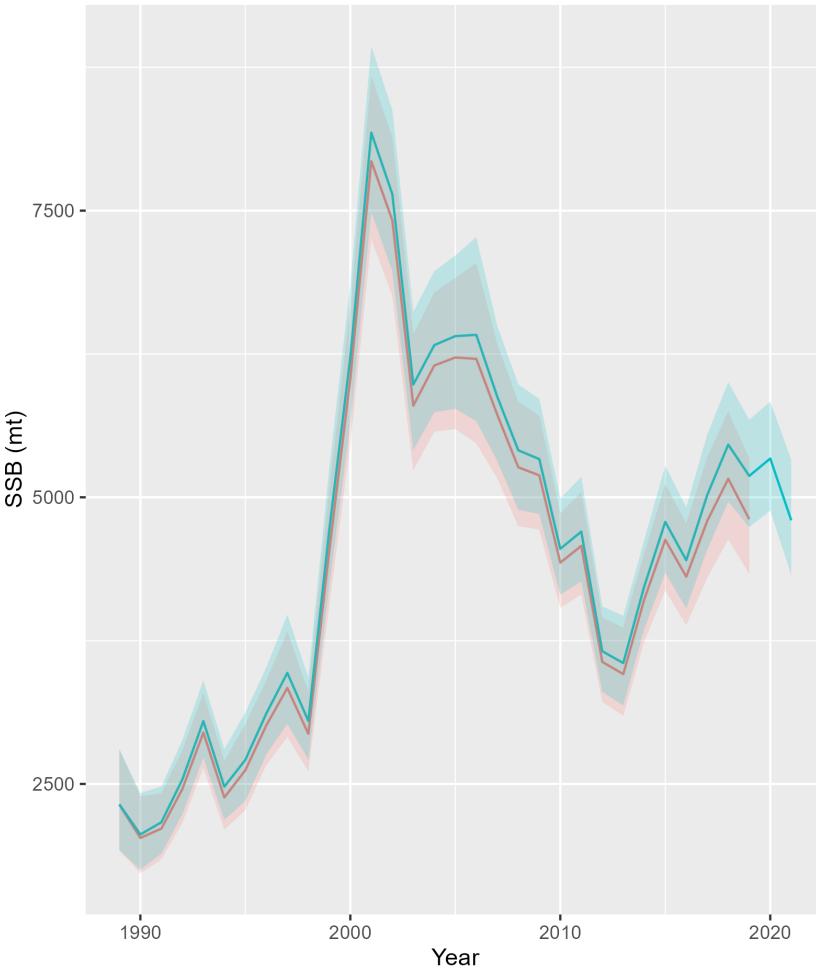


South

# Bridge runs 3 and 4

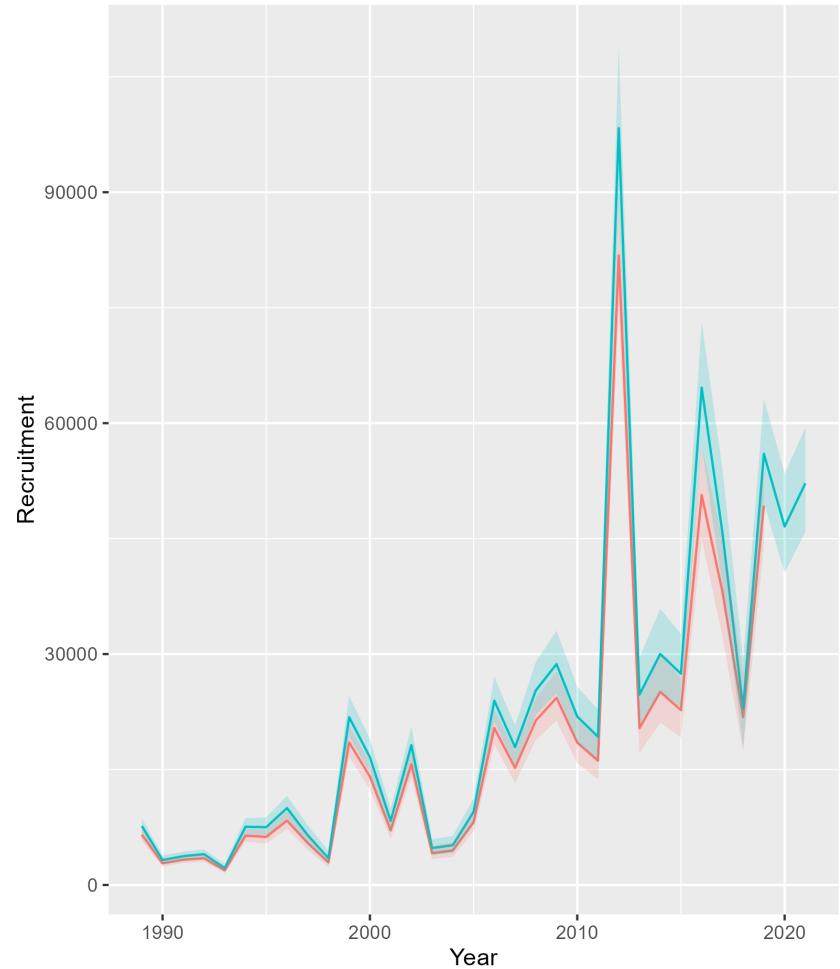


North

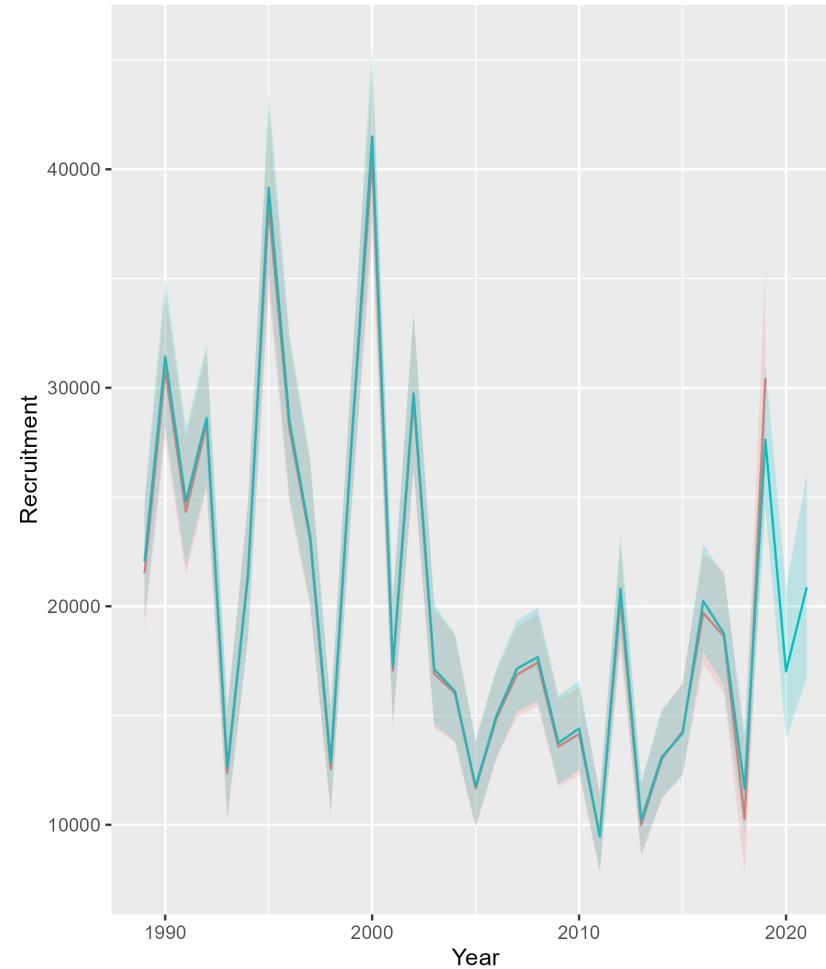


South

# Bridge runs 3 and 4



North



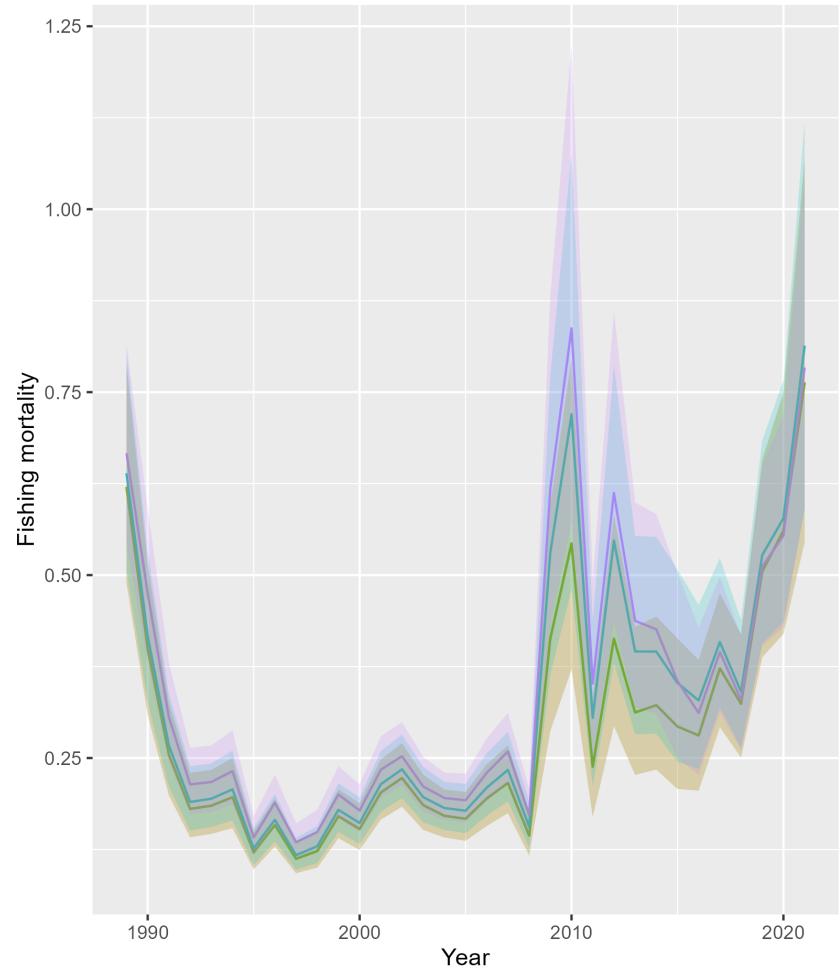
South

# Bridge runs

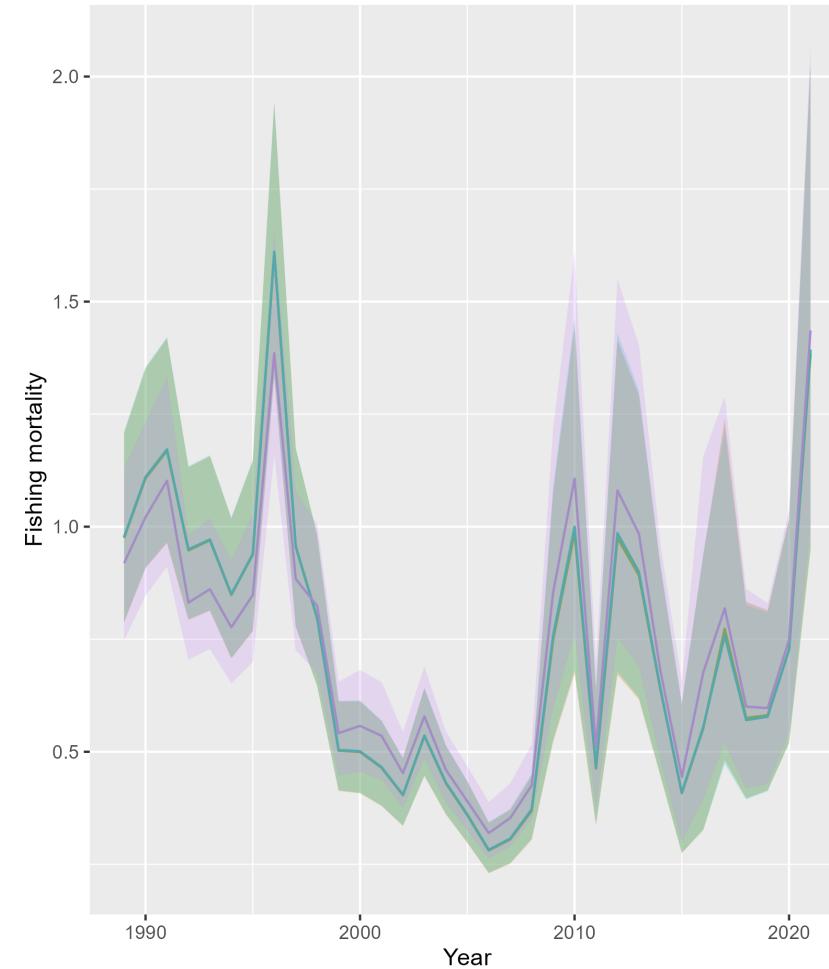
Separate fits for north and south regions

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- 3: Update Spring BTS and Rec CPA
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# Bridge runs 4, 5, 6, and 7

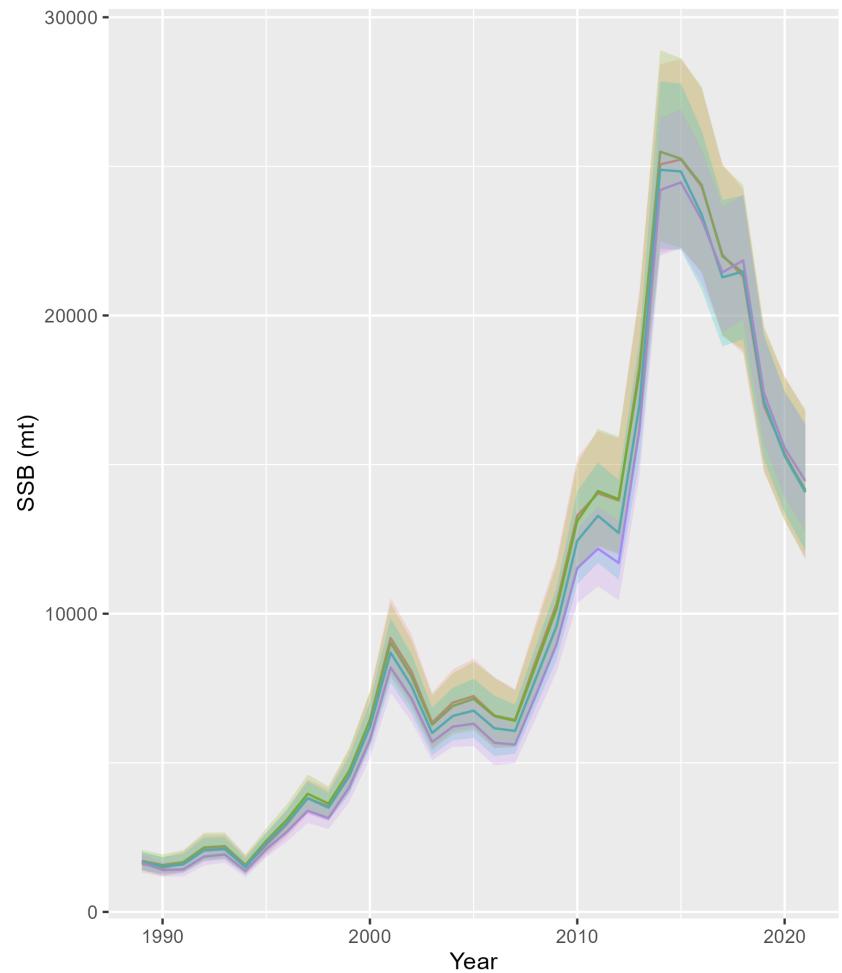


North

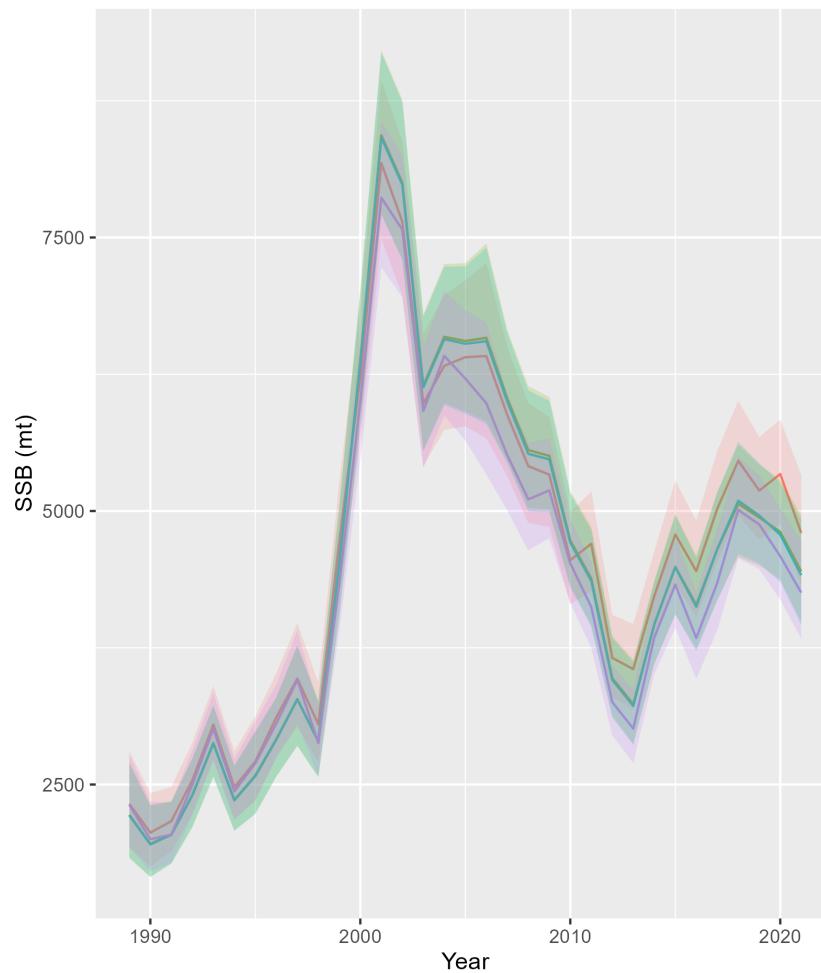


South

# Bridge runs 4, 5, 6, and 7

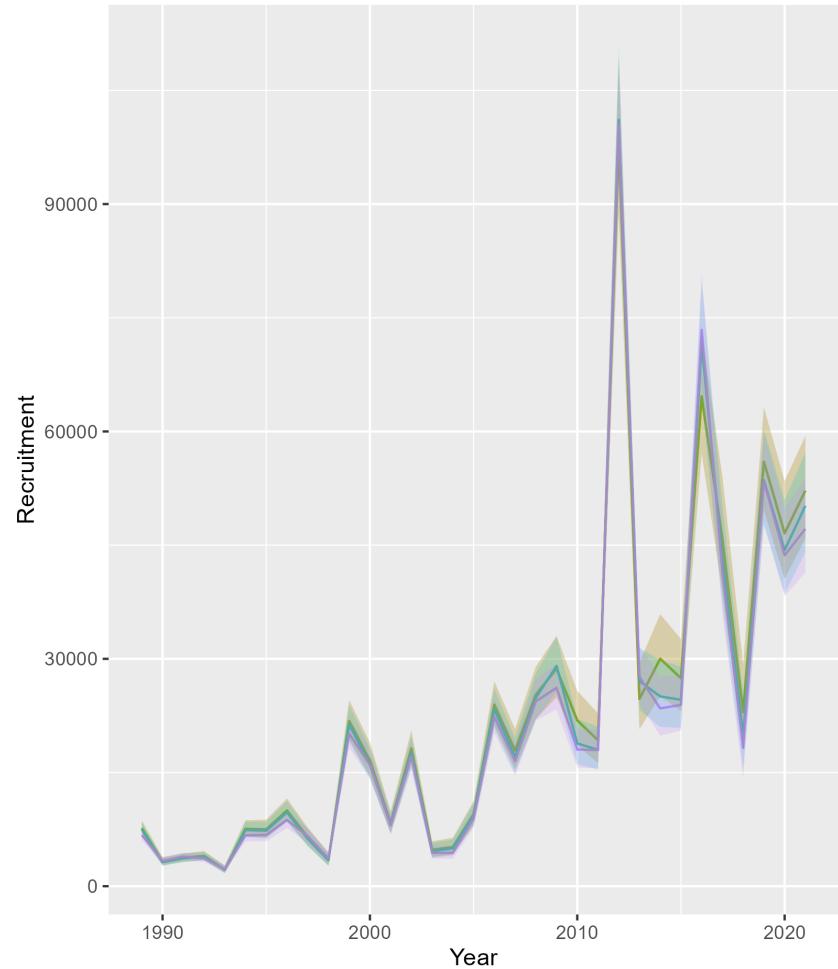


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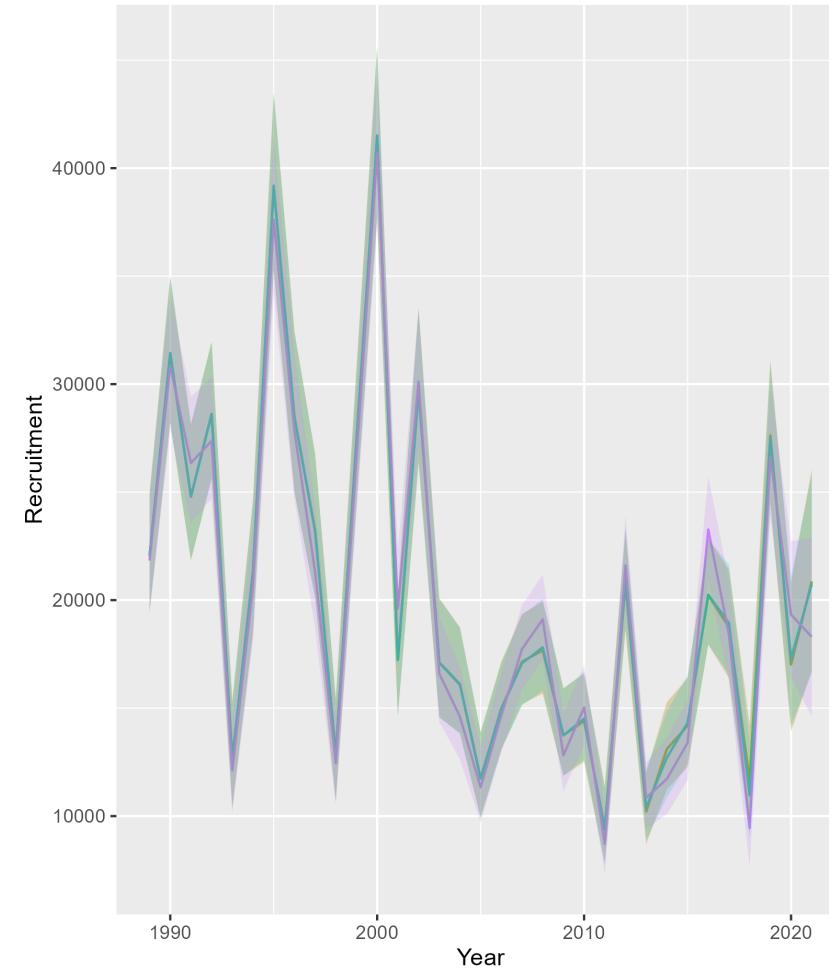


South

# Bridge runs 4, 5, 6, and 7



North



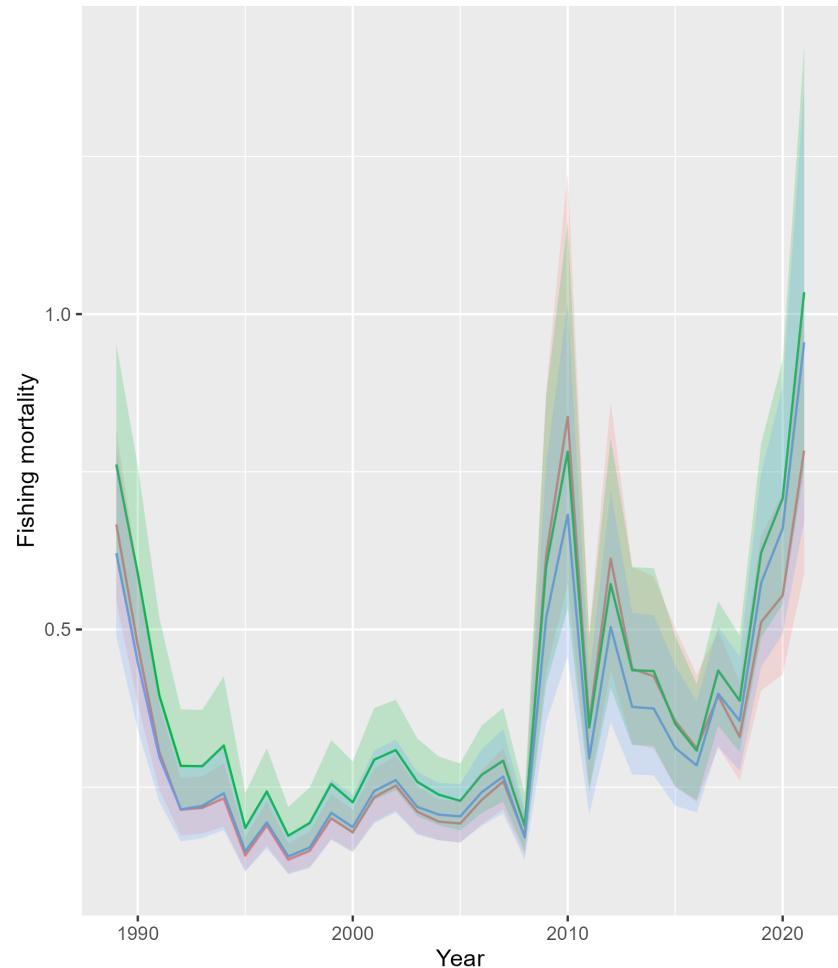
South

# Bridge runs

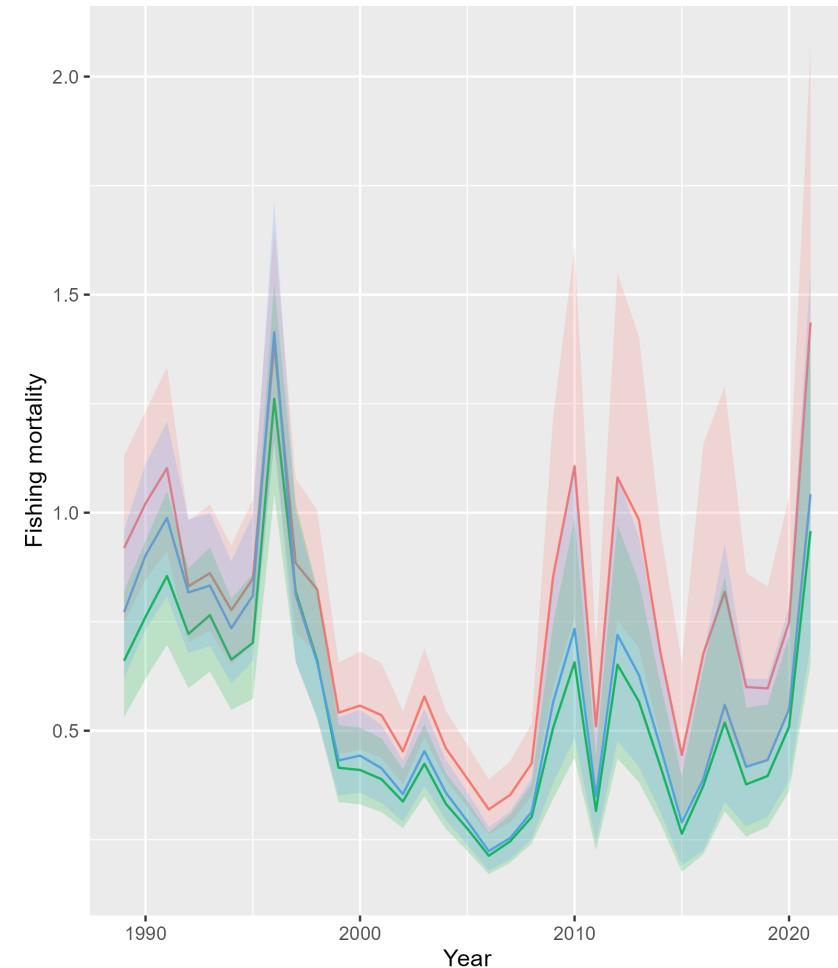
Separate fits for north and south regions

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- 3: Update Spring BTS and Rec CPA
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# Bridge runs 7, 8, and 9

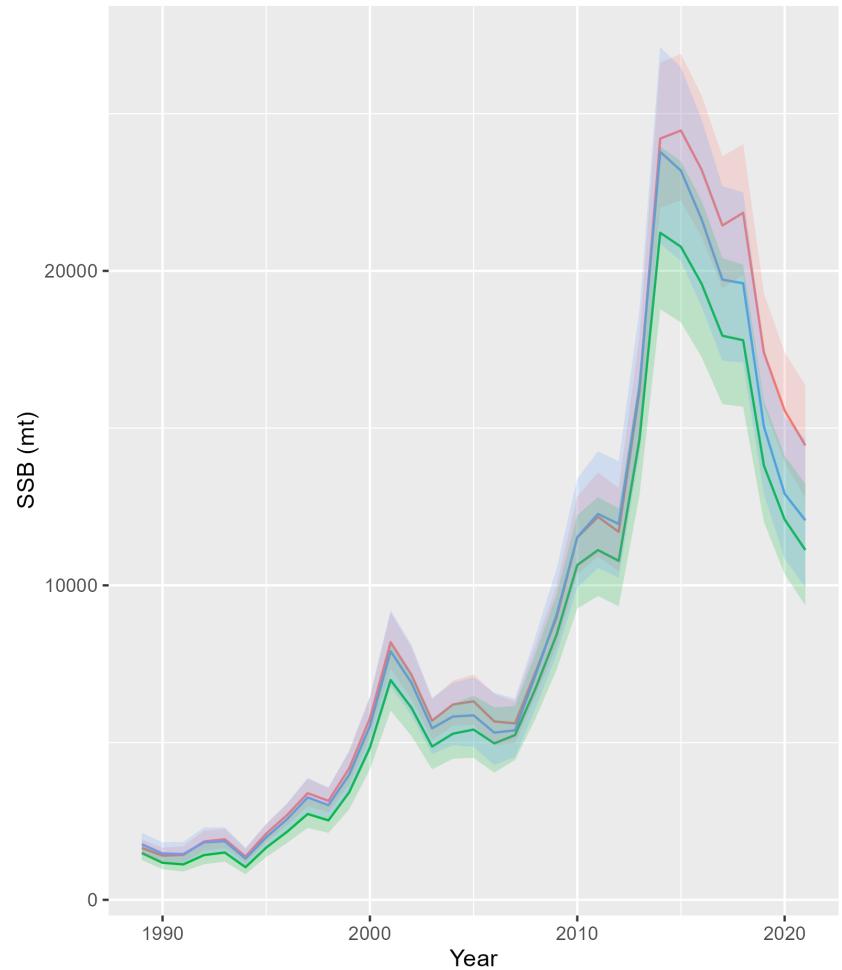


North

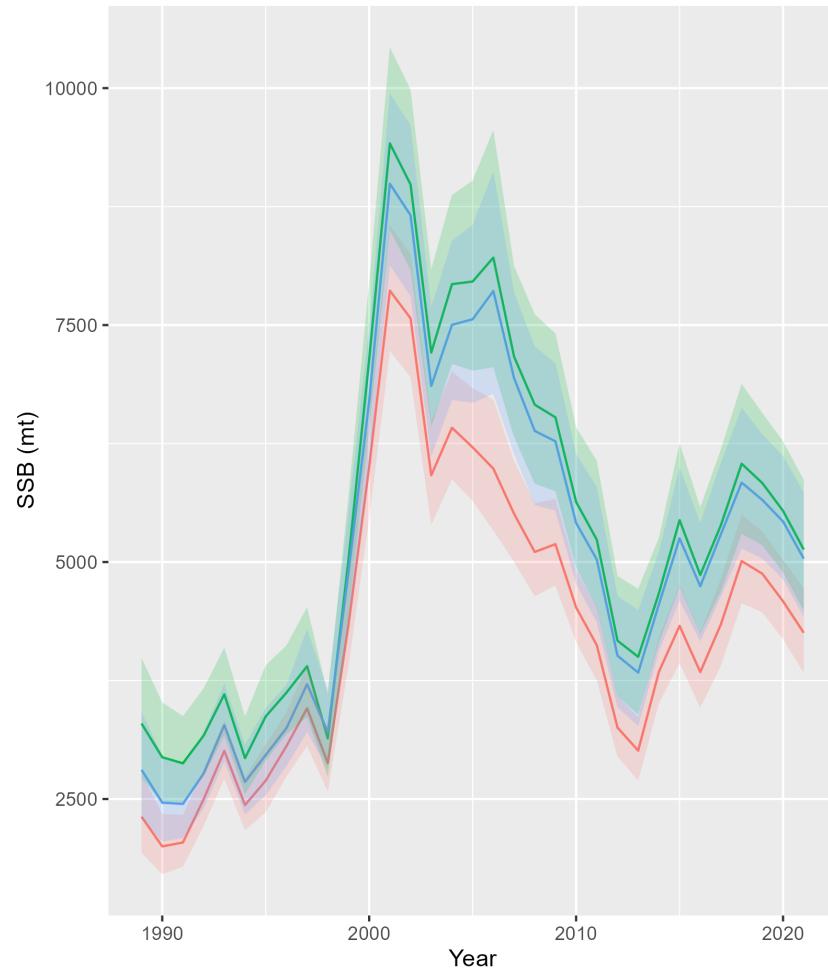


South

# Bridge runs 7, 8, and 9

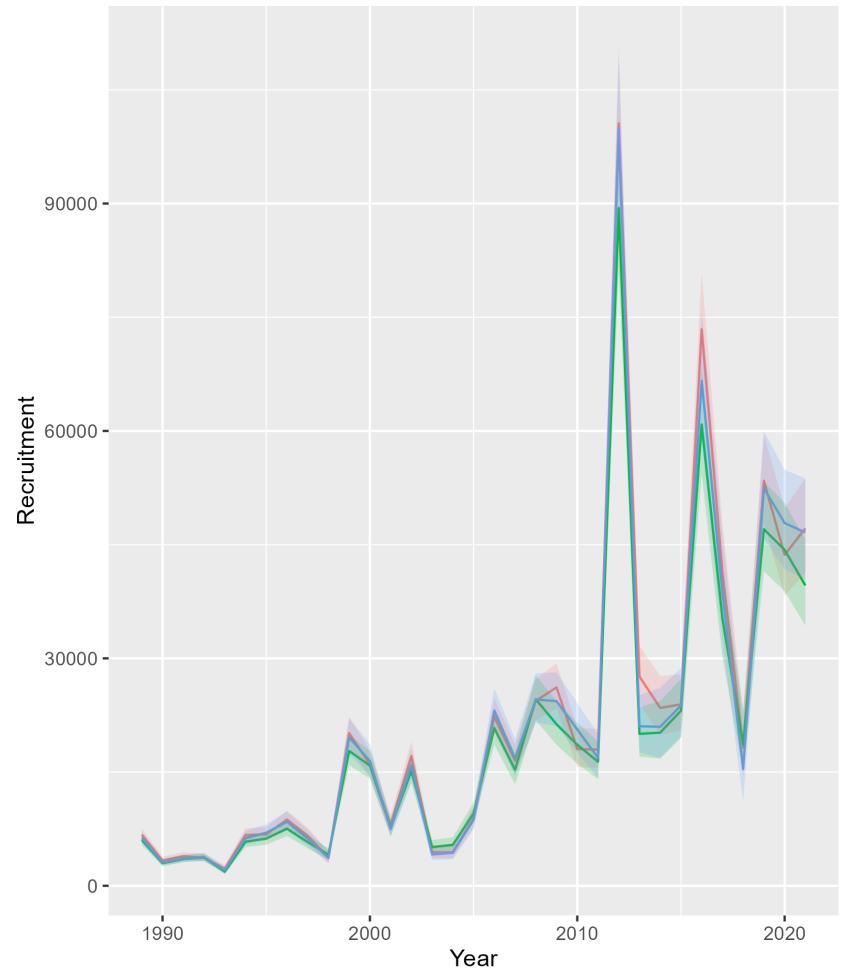


North

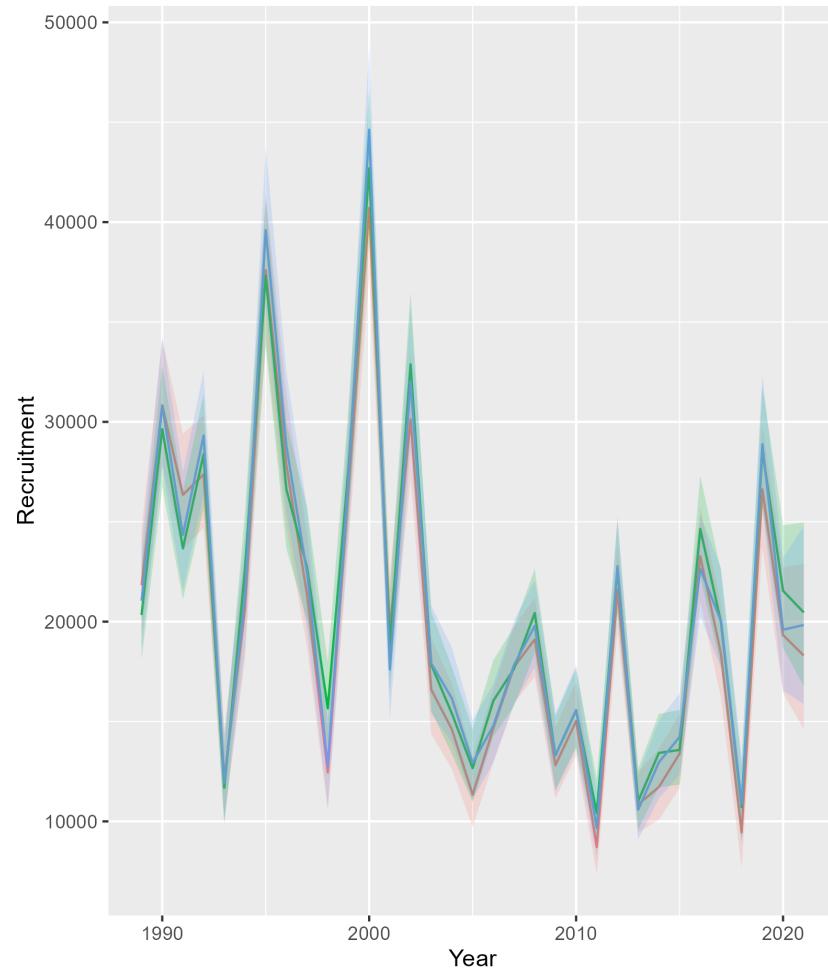


South

# Bridge runs 7, 8, and 9



North



South

# Early research track runs (1-18)

- See table in the working paper
- Used updated and new observations
- Included surveys as either separate indices or combined in fall and spring VAST indices (other than the recreational CPA)
- Explored alternative selectivity and age comp likelihood assumptions: reduce patterns in age comp OSA residuals.
- WG determined to use aggregate VAST indices that account for changes in catchability.
- However, age comp for fall VAST and NEAMAP were incorrectly calculated
- Runs 19+ only used the spring VAST and Rec CPA indices.

# Middle runs (19-27)

- Issues with patterns in OSA residuals remained
- Sometimes large retrospective patterns for the northern component.
- After Run 27, we used separate models for north and south to more efficiently explore alternative assumptions about selectivity and age composition likelihoods
- These analyses resulted in assumptions that remained the same across all later runs
  - Different age composition model assumptions for some of the fleets and indices.
  - Use of selectivity random effects for the northern fleets and indices.

# Late runs (28-34)

- Corrected some previous assumptions about movement.
  - Rates from SS were not corrected for differences in seasonal time steps
  - Rates of movement for northern component to and from north were both occurring over all seasonal intervals outside of spawning
  - Incorrect movement rate from south to north.
- Runs 30+ assume negligible variance of survival random effects for northern origin fish occurring in the south on Jan 1.
  - Allows yearly AR1 correlation to be estimated.
- Runs that did not converge well:
  - Run 31 assumed temporal random effects on the movement rate from the north to the south
  - Run 32 assumed a Beverton-Holt stock recruit relationships for both the north and south components
- Run 33 investigated bottom temperature effects on recruitment and we found evidence of an effect on northern recruitment.
- Run 34 relaxed estimated scalar for uncertainty in the Recreational CPA indices
- \*\*After these runs we discovered a coding error in constructing initial numbers at age under an equilibrium assumption.
  - Small changes in results Run 34: absolute differences in annual SSB estimates were less than 7%.
  - **Refit Runs 30, 33, and 34 with the corrected model**
  - None of the choices among these models would have changed.

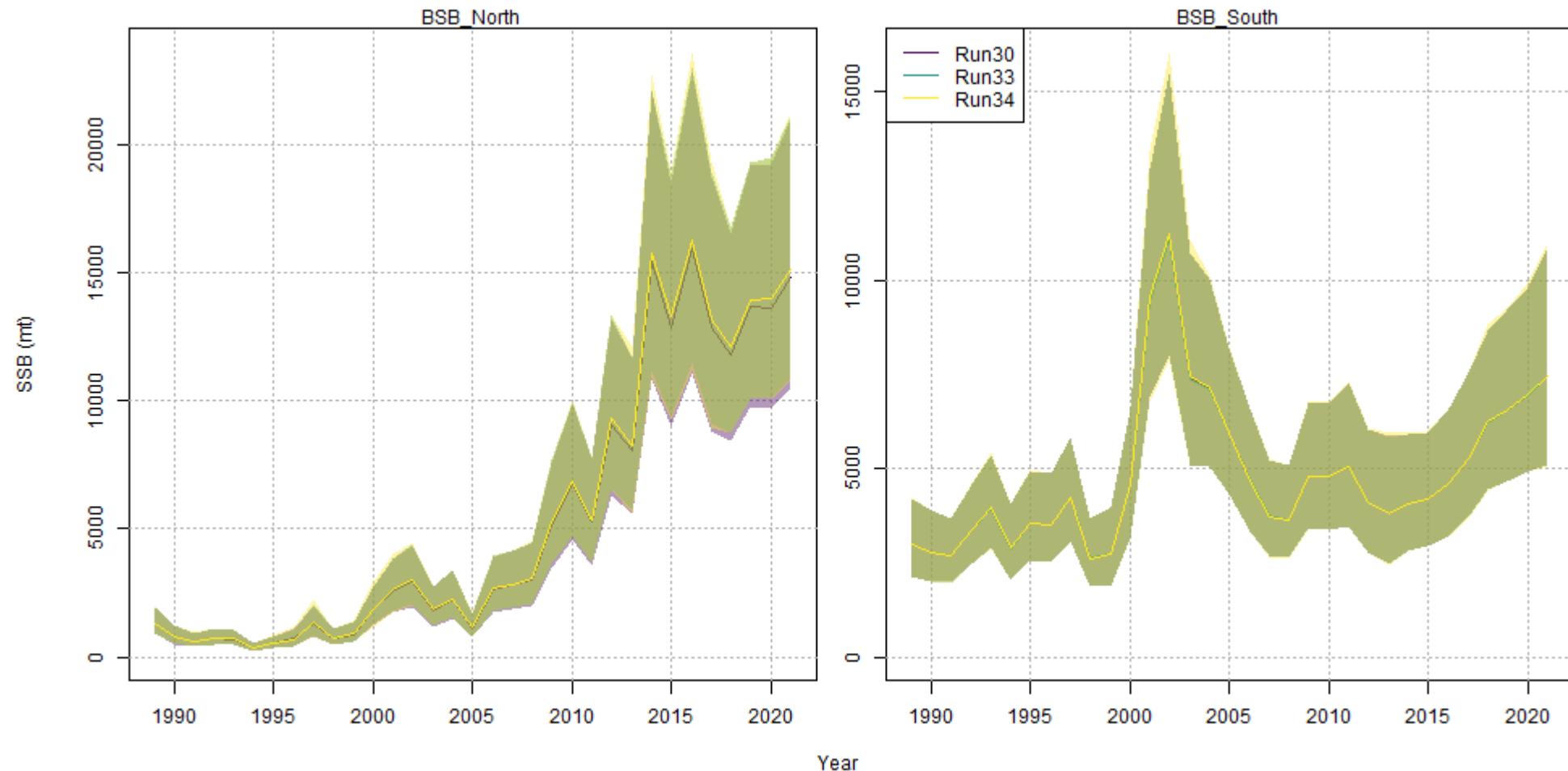
# Evidence for bottom temperature effects on recruitment

	AIC	North $\hat{\sigma}_R$	Peel	No effect	North only	North and South
No effect	-1551.79	0.92	0	10.35	0.00	0.53
North temperature effect only	-1562.14	0.74	1	10.17	0.00	0.38
Both temperature effects	-1561.61	0.74	2	9.22	0.00	0.65
			3	9.29	0.00	0.56
			4	9.07	0.00	0.70
			5	8.53	0.00	0.31
			6	8.20	0.36	0.00
			7	7.78	0.11	0.00

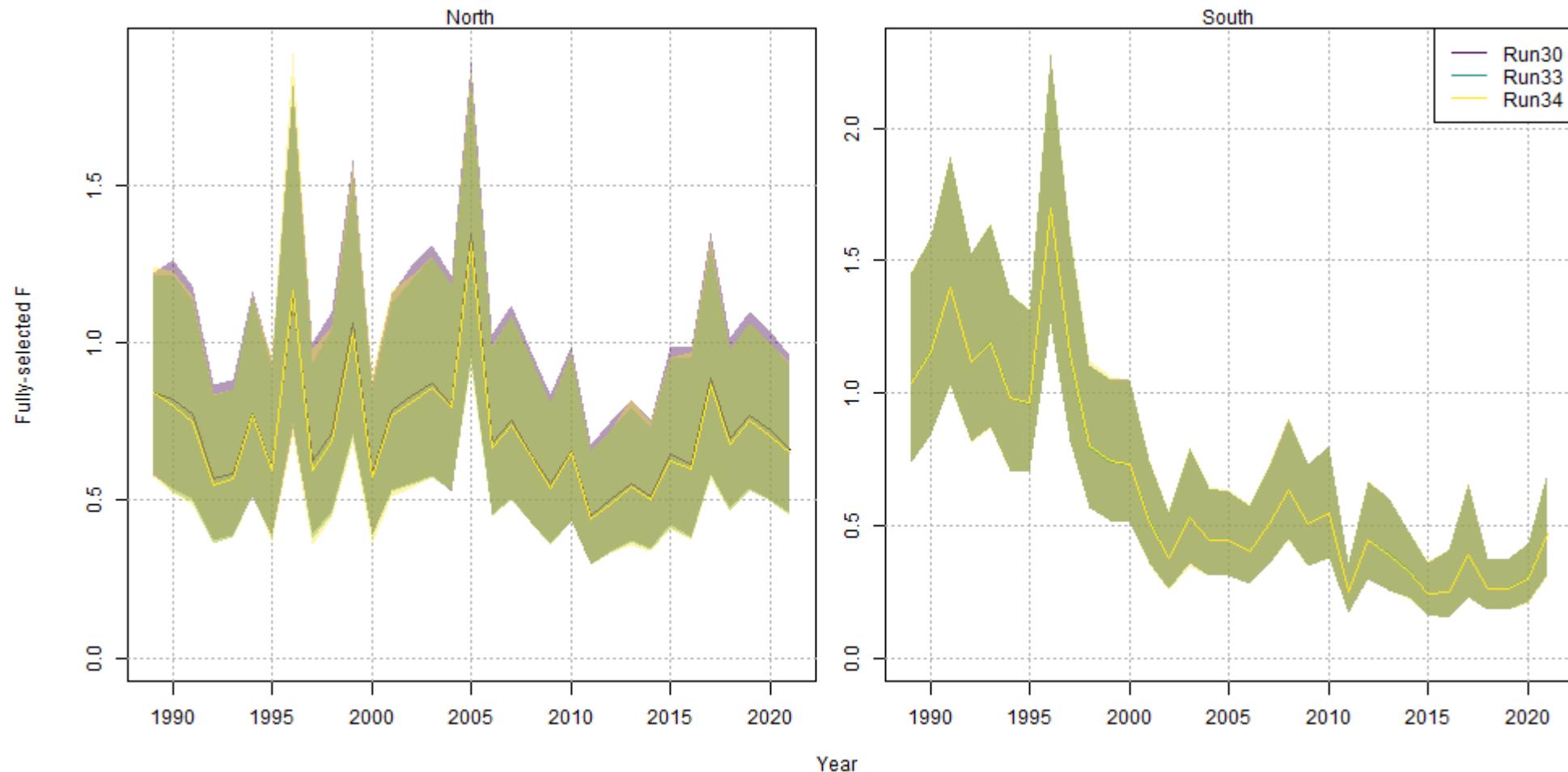
# Comparison of Runs 30, 33 and 34

- Run 30: like run 34, but fixed Rec CPA CVs, no temperature effects on northern recruitment.
- Run 33: like Run 34, but fixed Rec CPA CVs
- The estimates of SSB, fully-selected fishing mortality, and recruitment were very similar for Runs 30, 33, and 34

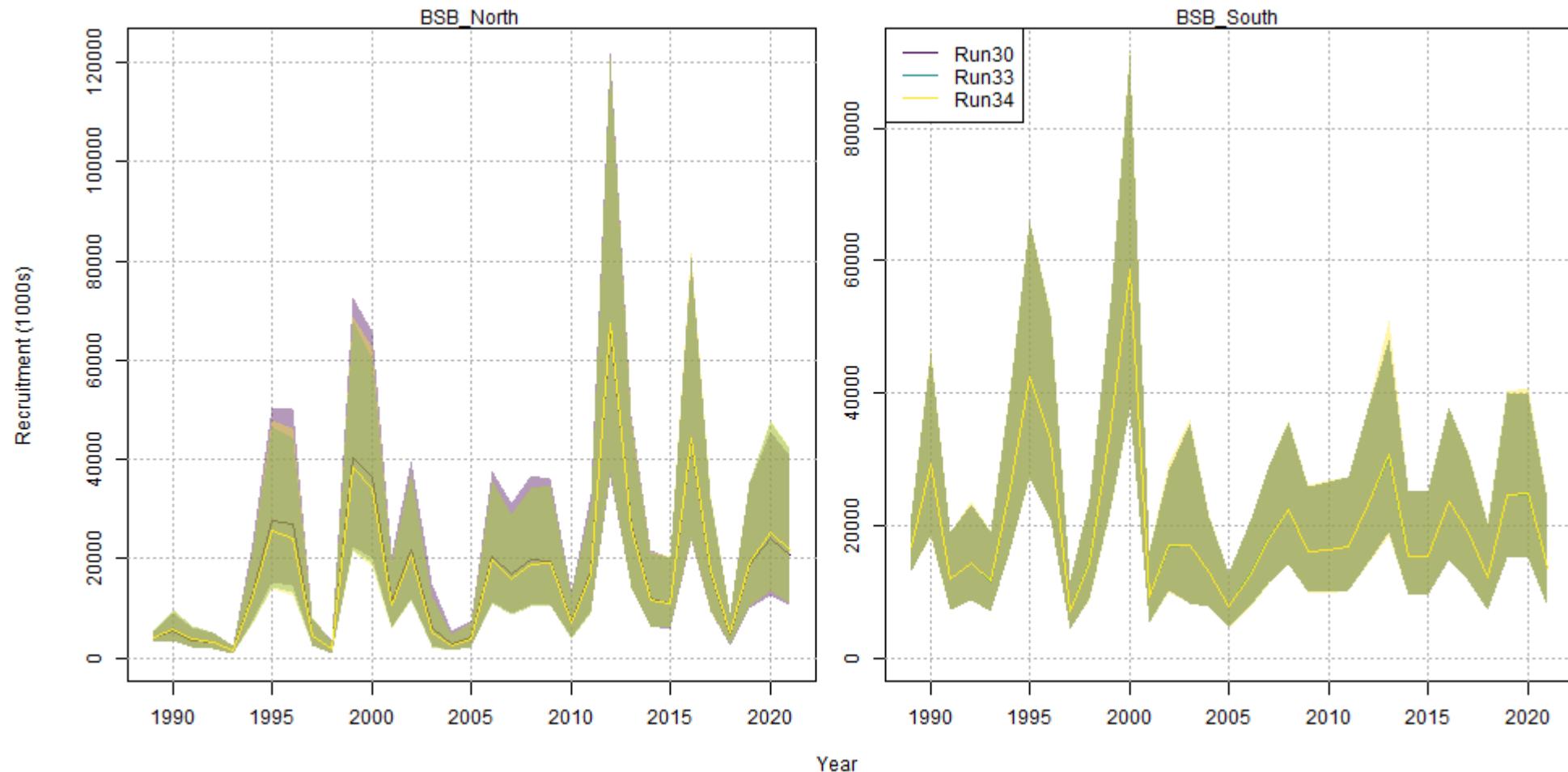
# Comparison of Runs 30, 33 and 34: SSB



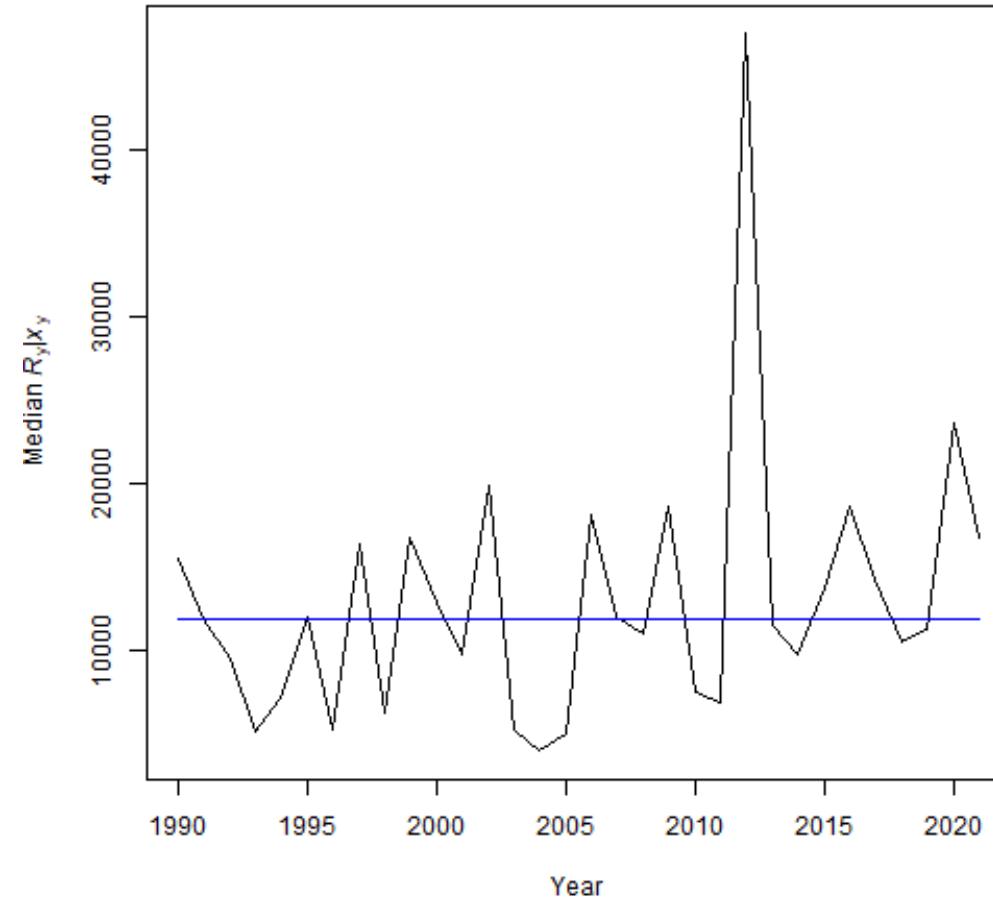
# Comparison of Runs 30, 33 and 34: Fishing mortality



# Comparison of Runs 30, 33 and 34: Recruitment



# Expected recruitment with and without temperature effects



# Comparison of Runs 33 and 34

- Allowing the scalar for the standard error of the log-transformed Rec CPA indices to be estimated in the proposed base model results in a slight increase in uncertainty of spawning stock biomass and recruitment estimates.
- fitted models with ( $\hat{SE}_1$ ) and without ( $\hat{SE}_2$ ) the scalar of the Recreational CPA index standard errors estimated.

