NOAA FISHERIES

Application of WHAM to Black Sea Bass

Black sea bass Research Track

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Outline

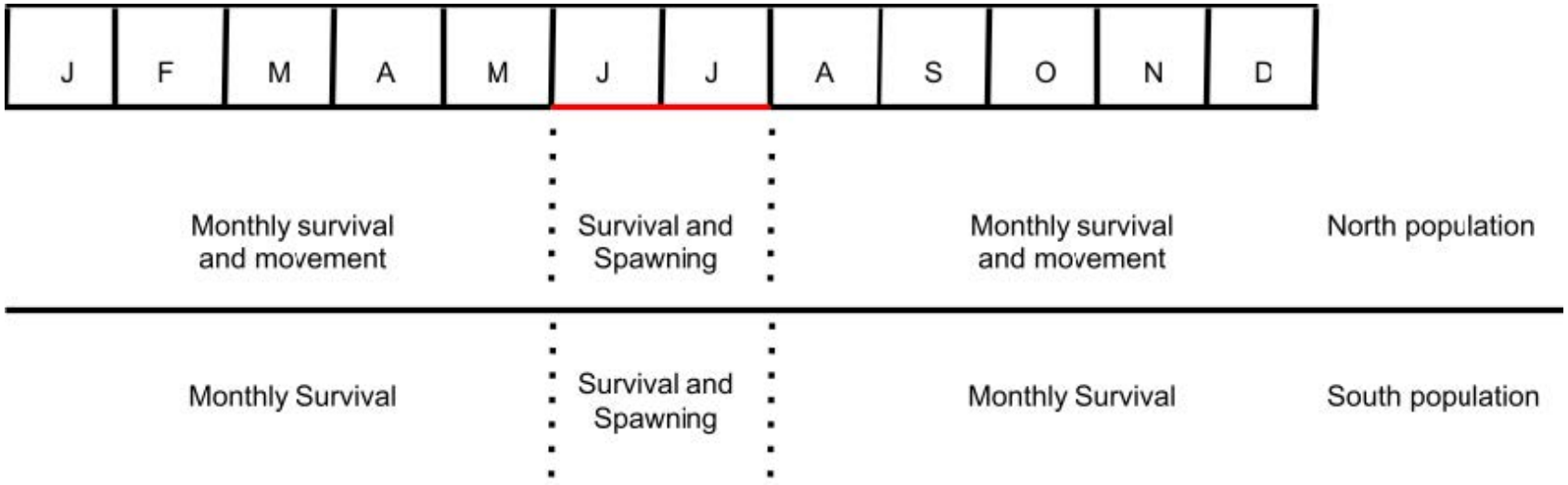
- Description of proposed base model
- Diagnostics
- Results
- Path to the base model
  - Initial bridge building
  - Progression of model development

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,
  - calculated 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.

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

  - Observations of the latent covariate:

$$x_y \sim N\left(X_y, \sigma_x^2\right)$$

- Fit models with and without effects on northern and southern recruitment

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

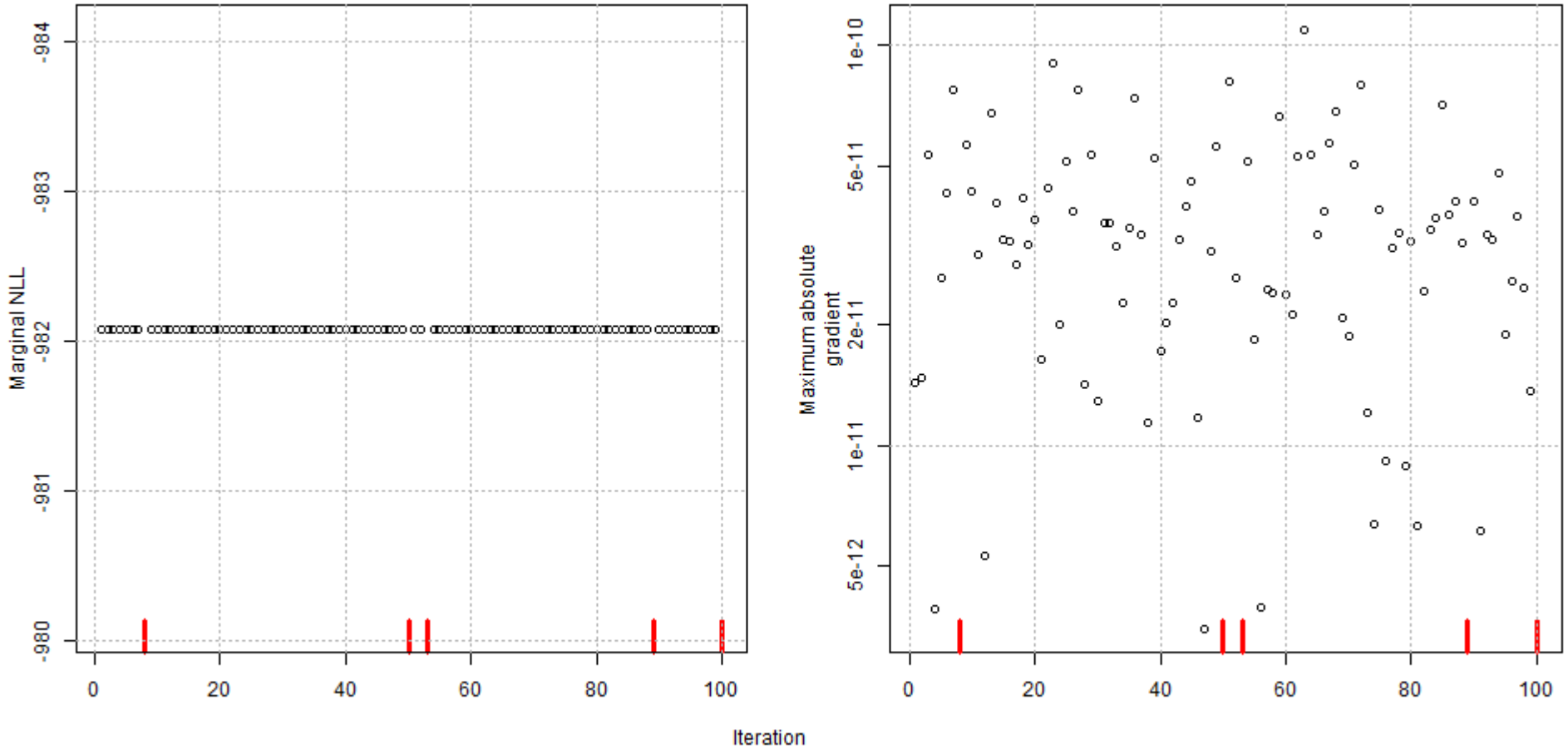
  - Examined AIC for full model and all retrospective peels.
- Might be worth exploring an alternative effect on M for age 1.
  - Would also affect reference points and projections differently.

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 optimzed model.
- All of the re-fits of the mdoel resulted in the same marginal negative log-likelihood.
- The gradients at these optimized values were all satisfactory with maximum absolute values less the 10^{-9}.

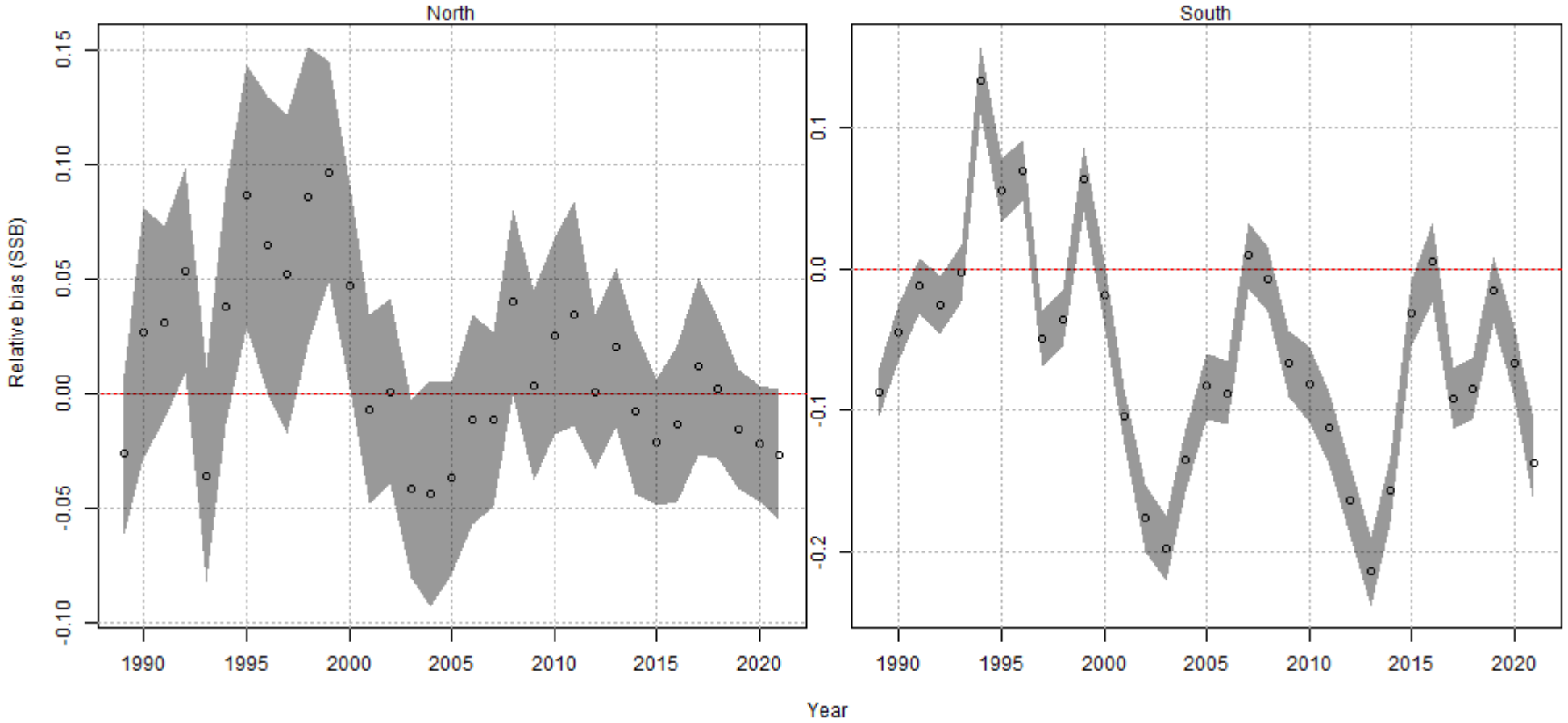
Jitter analysis



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.

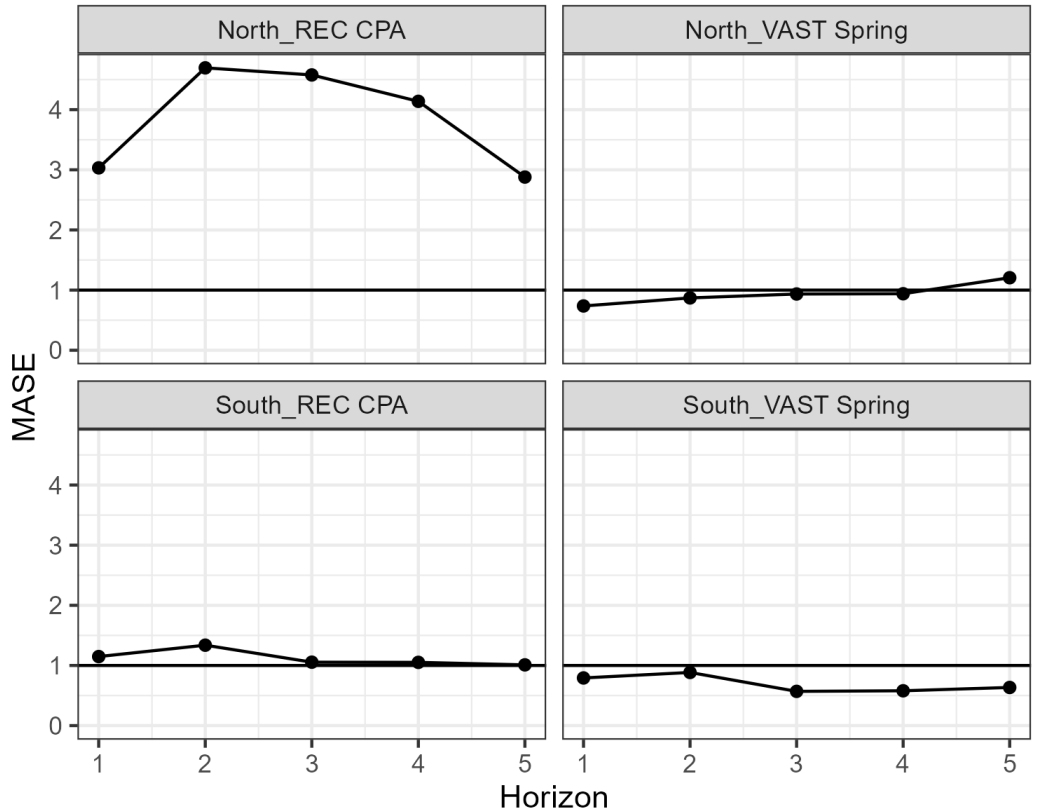
Self-test


North
South
Relative bias (SSB)
Year
0.15
0.10
0.05
0.00
-0.05
-0.10
0.1
0.0
-0.1
-0.2
1990
1995
2000
2005
2010
2015
2020

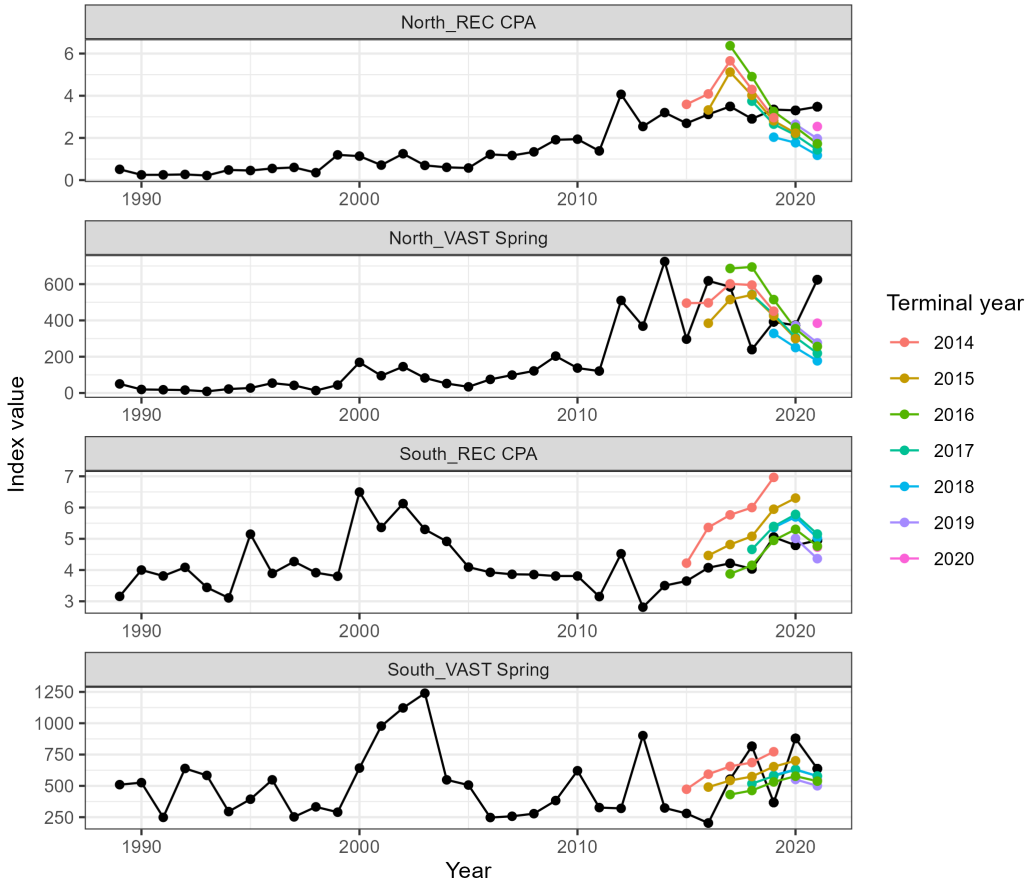
MASE

- 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


North_REC CPA
North_VAST Spring
South_REC CPA
South_VAST Spring
MASE
Horizon
0
1
2
3
4
5

MASE

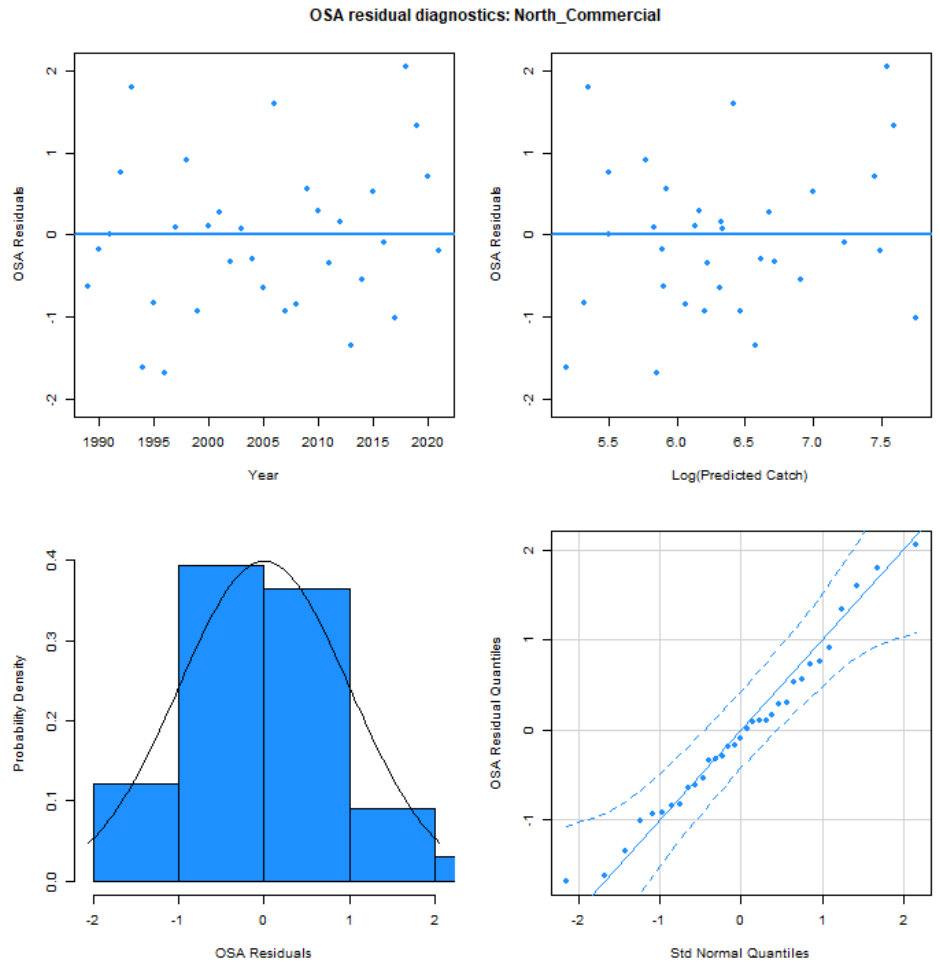

North_REC CPA
North_VAST Spring
South_REC CPA
South_VAST Spring
Index value
Year
1990
2000
2010
2020
Terminal year
2014
2015
2016
2017
2018
2019
2020

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.

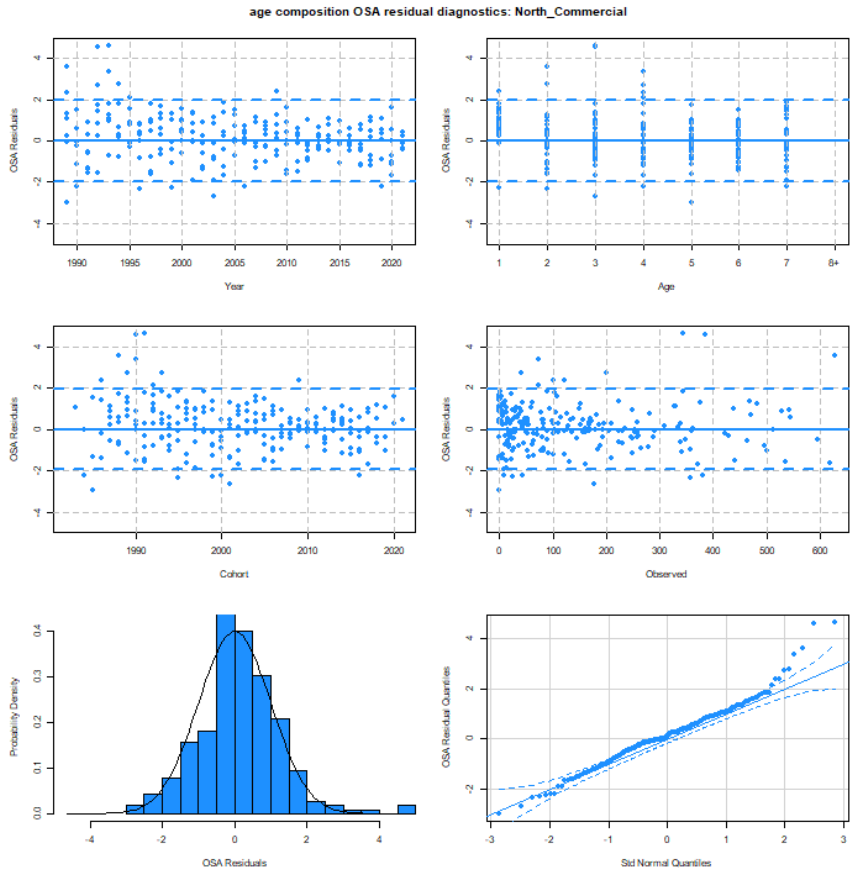
OSA: North commercial fleet

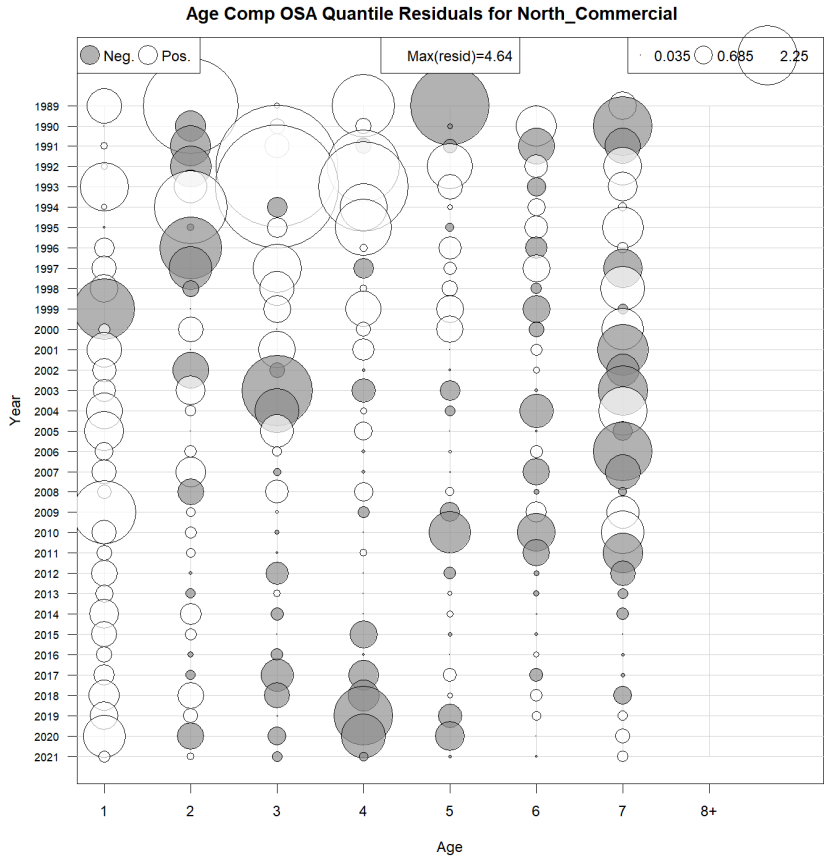
- no evidence of mis-specification aggregate catch.



OSA: North commercial fleet

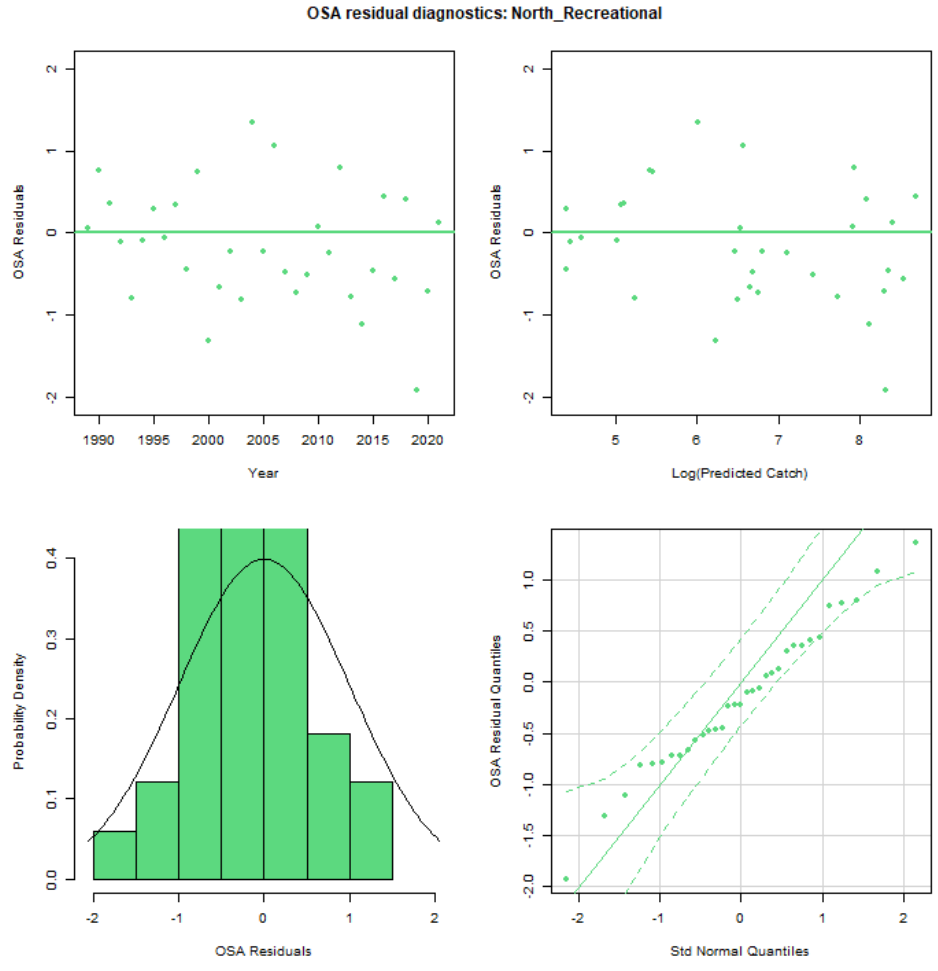
- some indication of trends in residuals of some of the age composition observations early in the time series and for the the first age class.





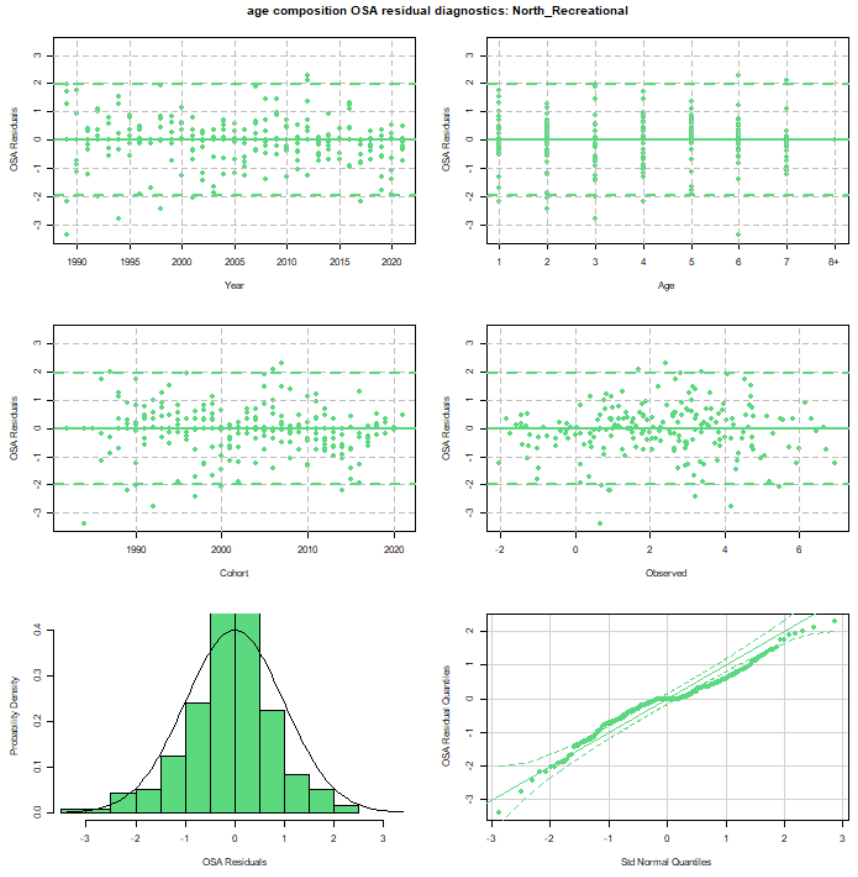
OSA: North recreational fleet

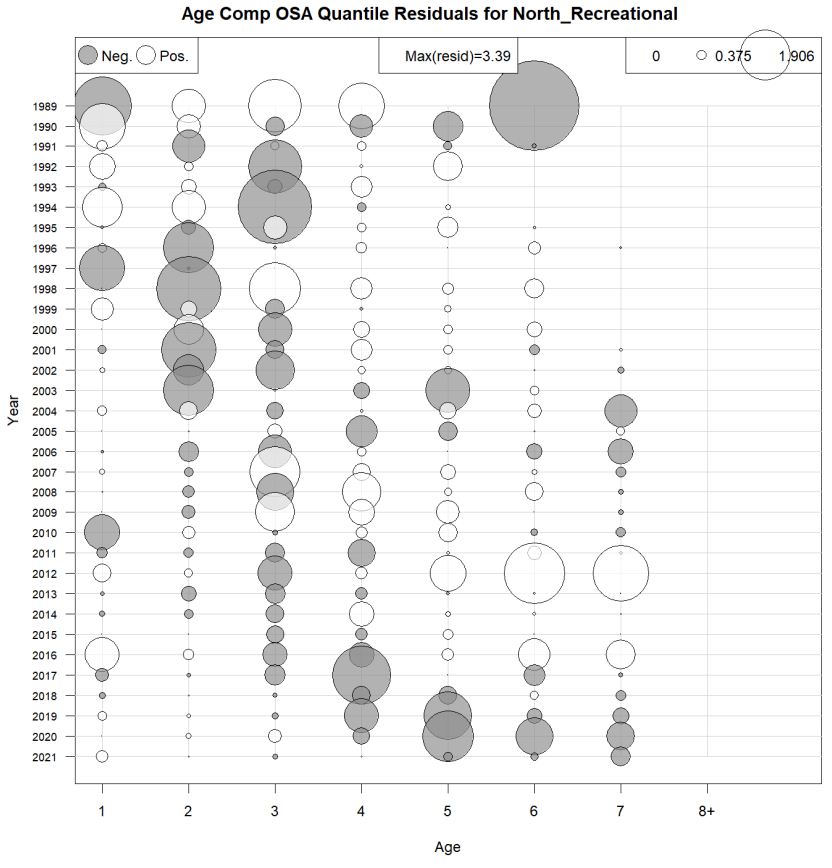
- residuals appeared satisfactory.



OSA: North recreational fleet

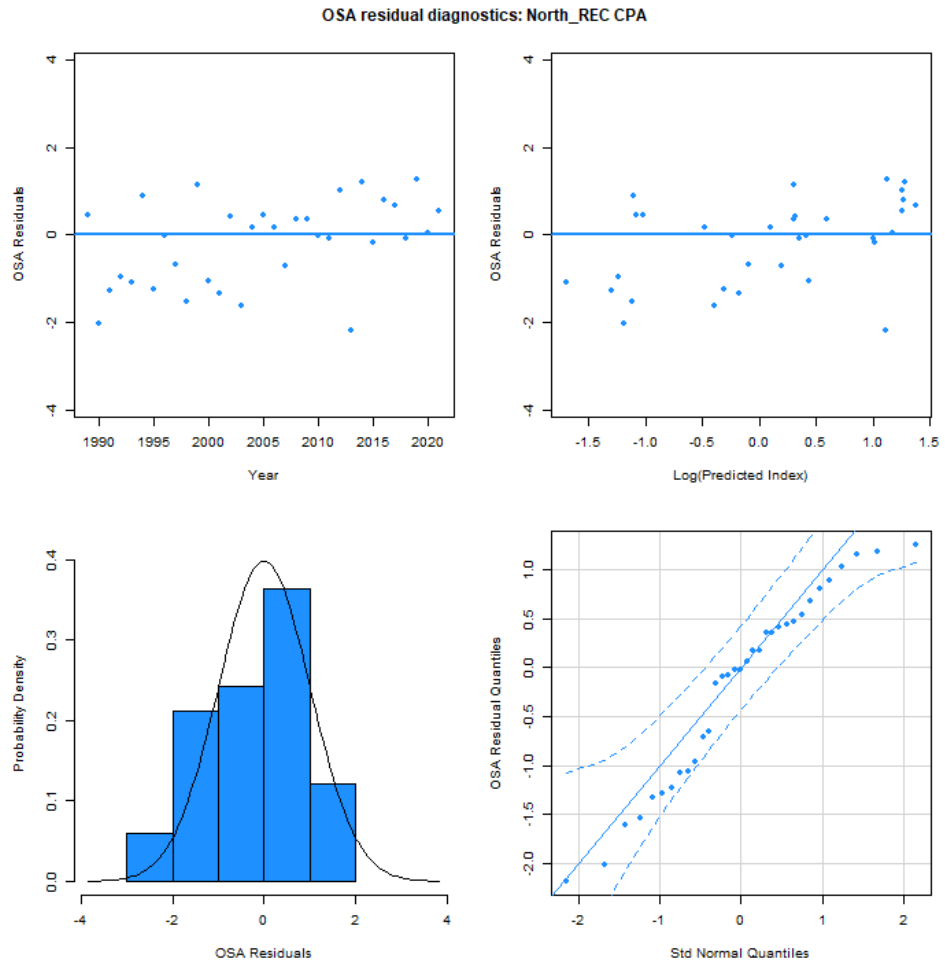
- residuals showed some tendency of underdispersion





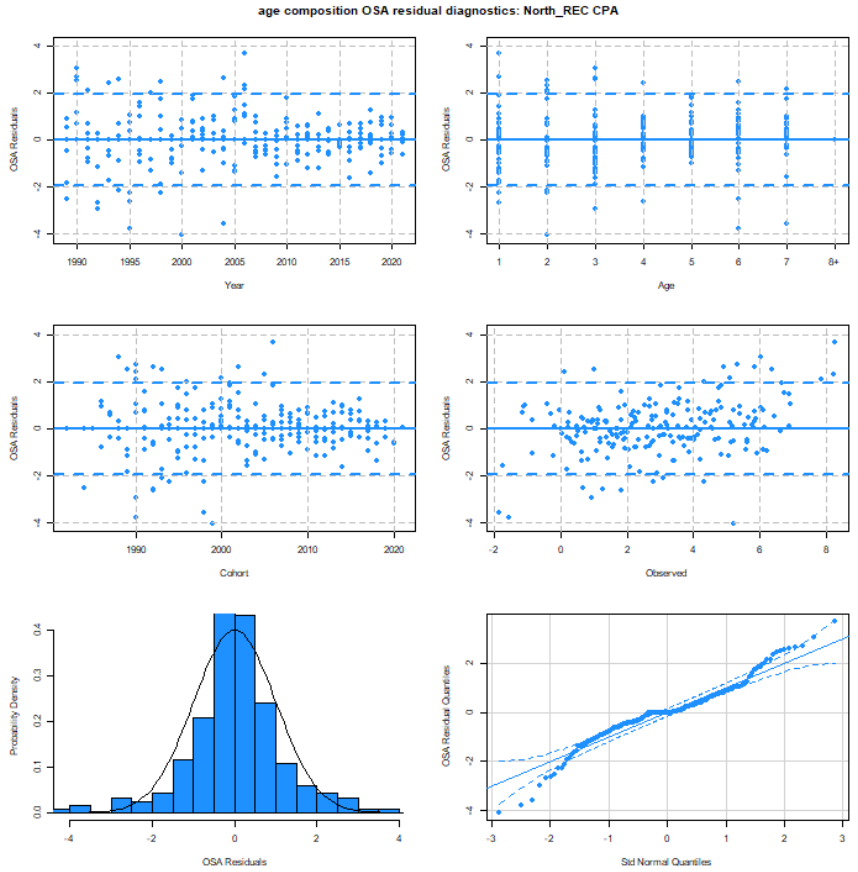
OSA: North Rec CPA index

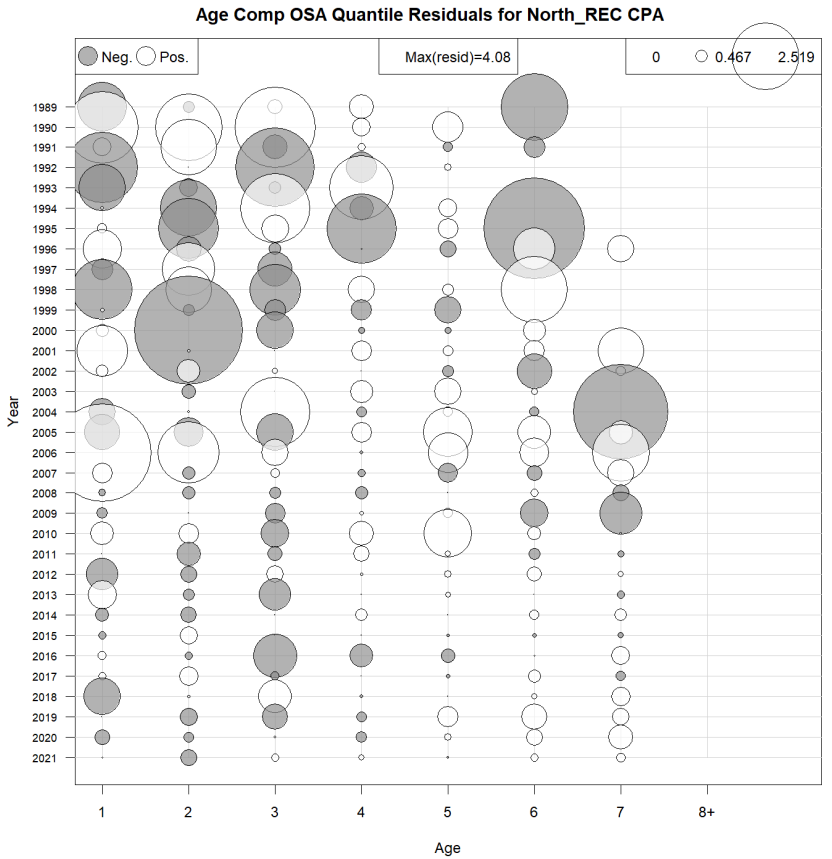
- no signs of mis-specification



OSA: North Rec CPA index

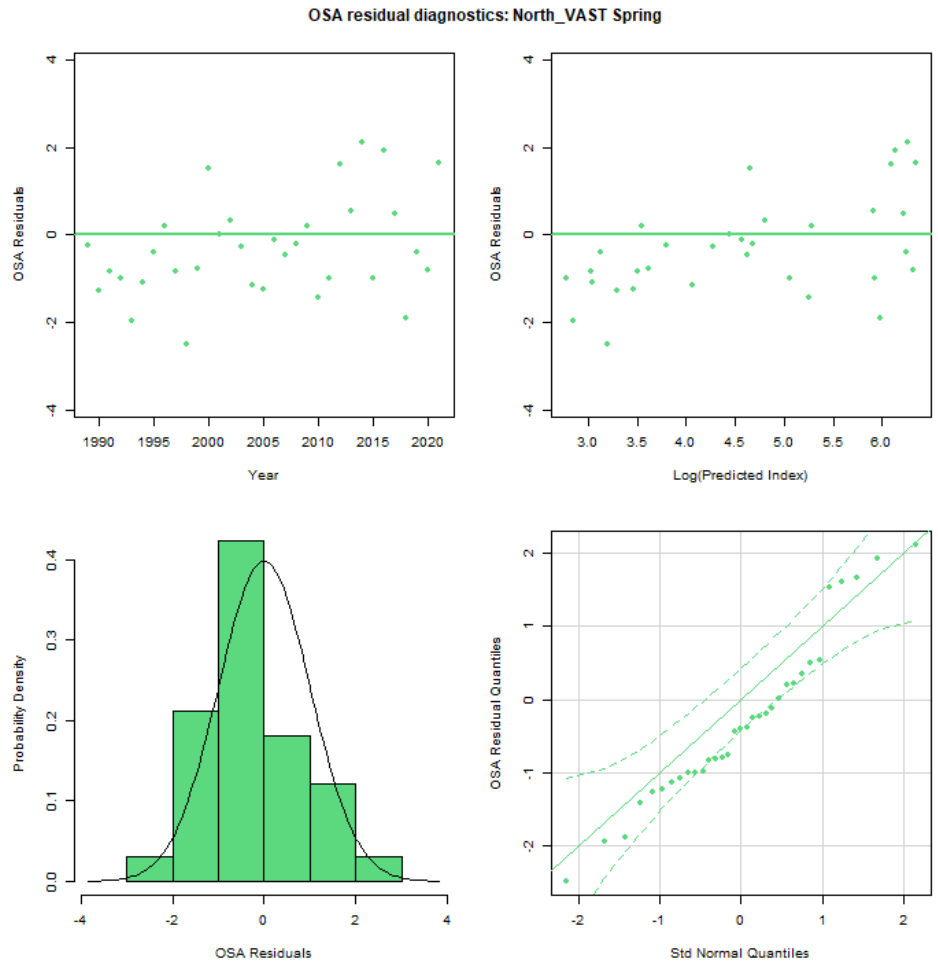
- no signs of mis-specification





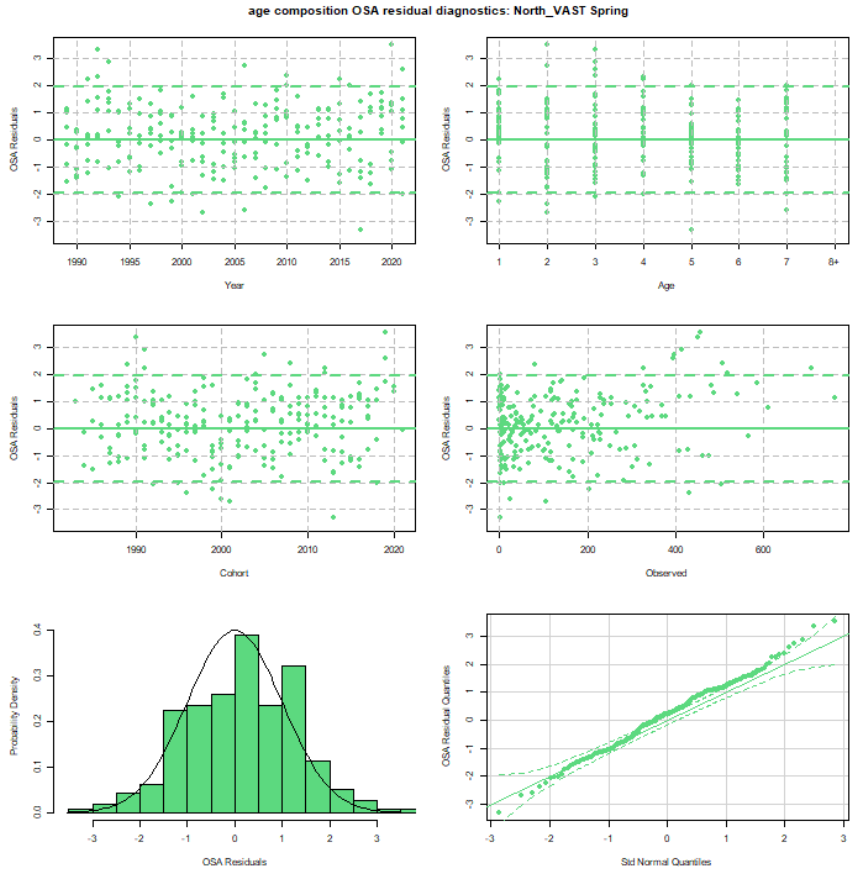
OSA: North VAST index

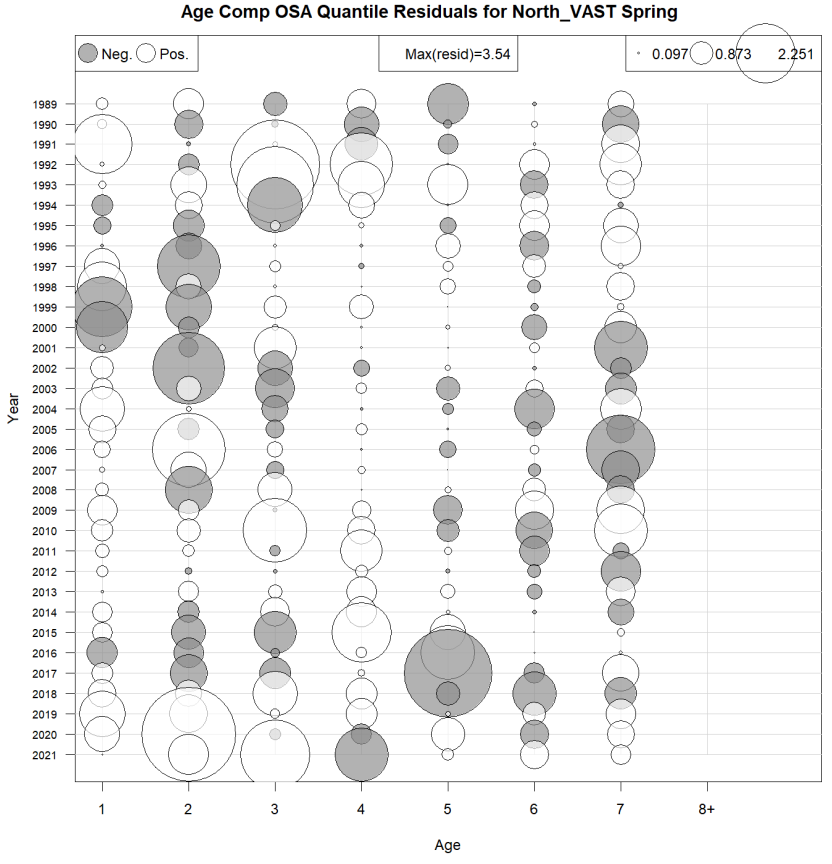
- some evidence of tendency toward negative residuals



OSA: North VAST index

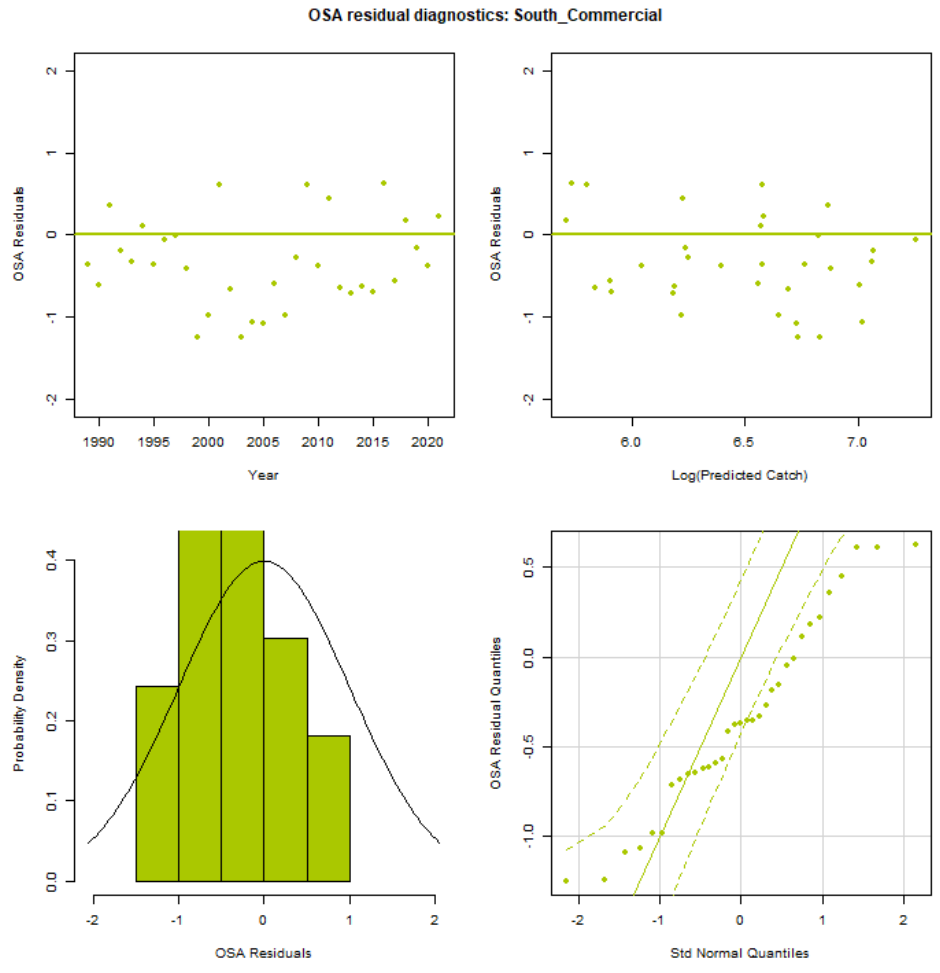
- some indication of positive residuals, particularly at age 1





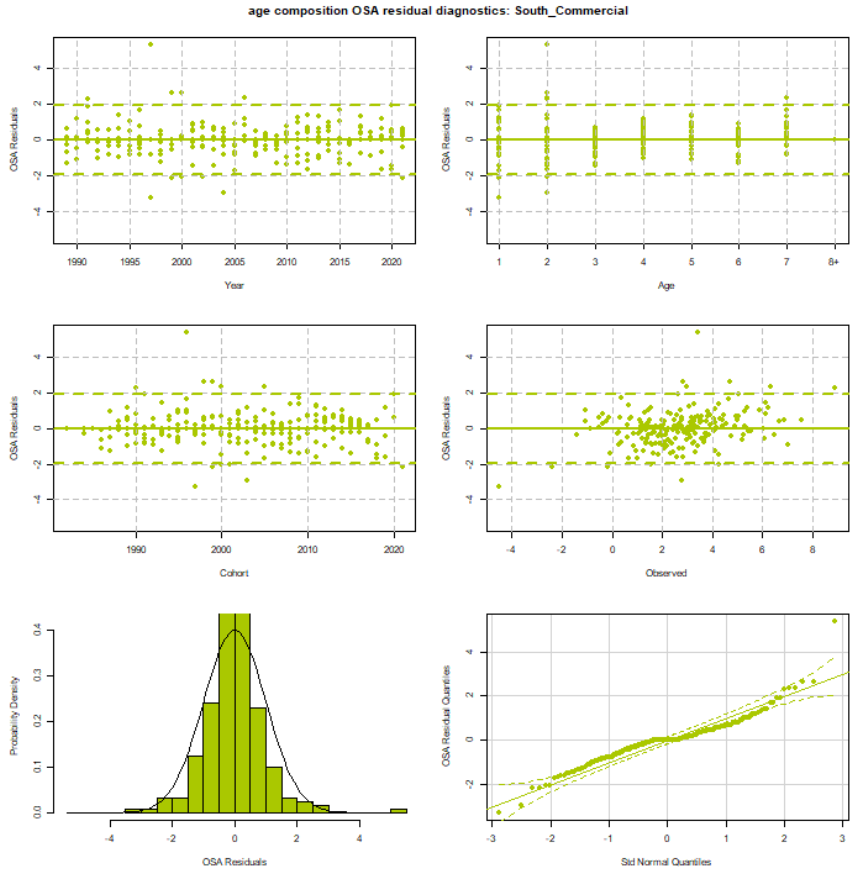
OSA: South commercial fleet

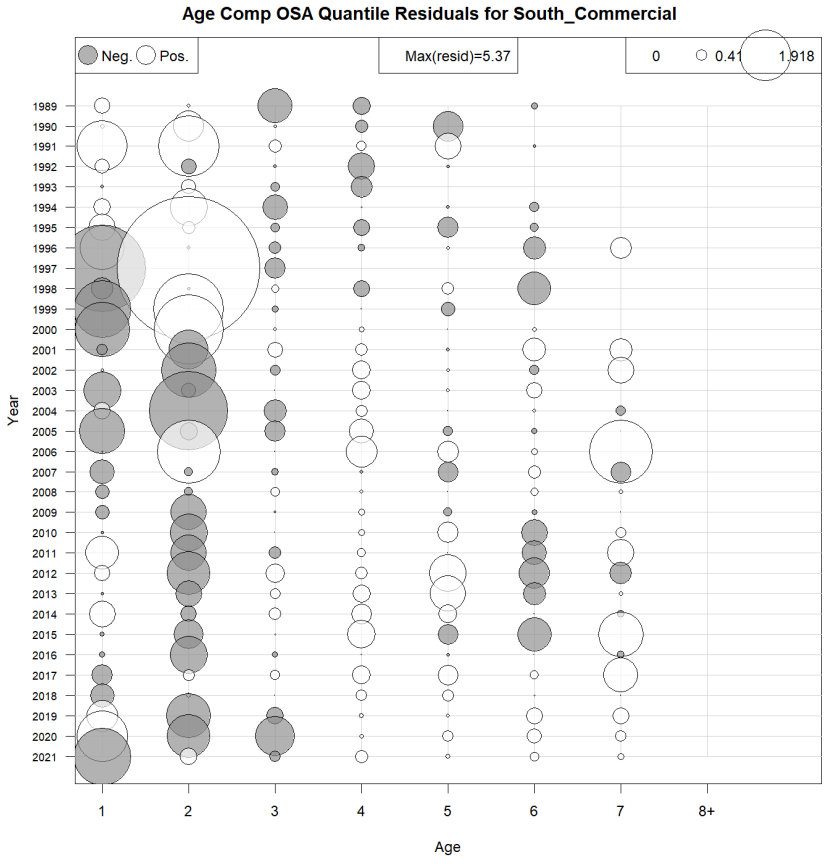
- residuals tended to be negative



OSA: South commercial fleet

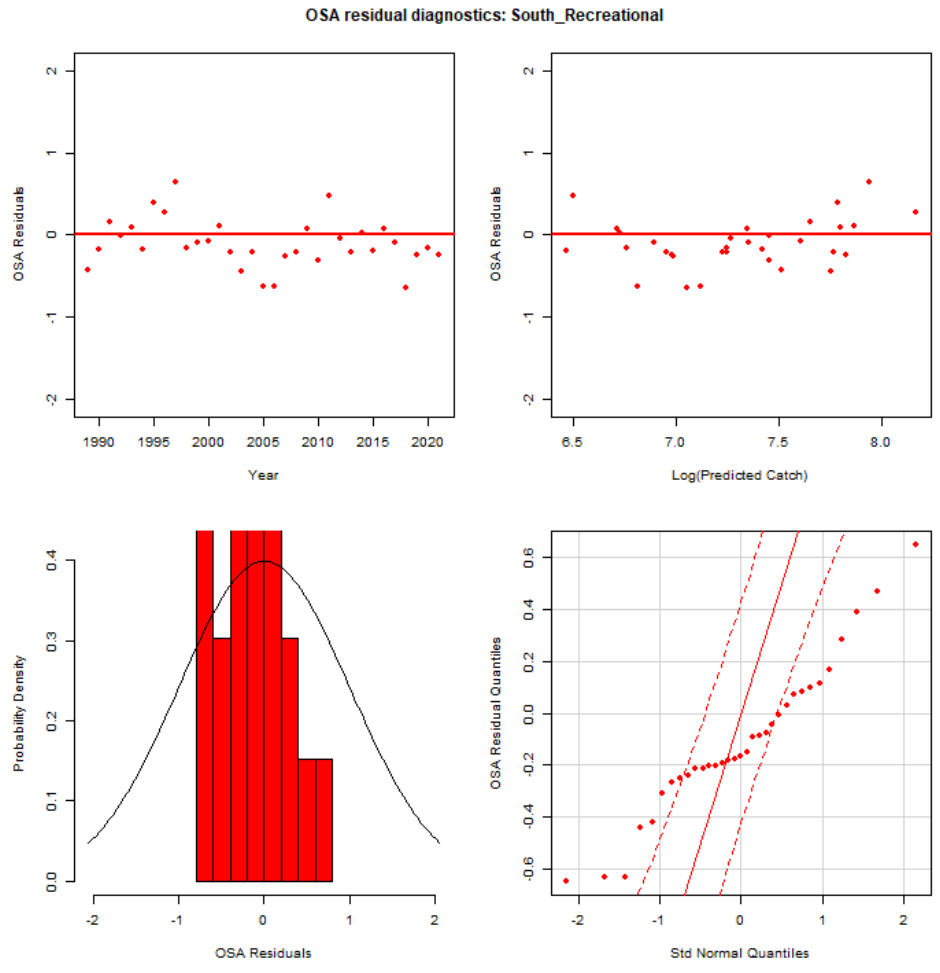
- no evidence of mis-specification





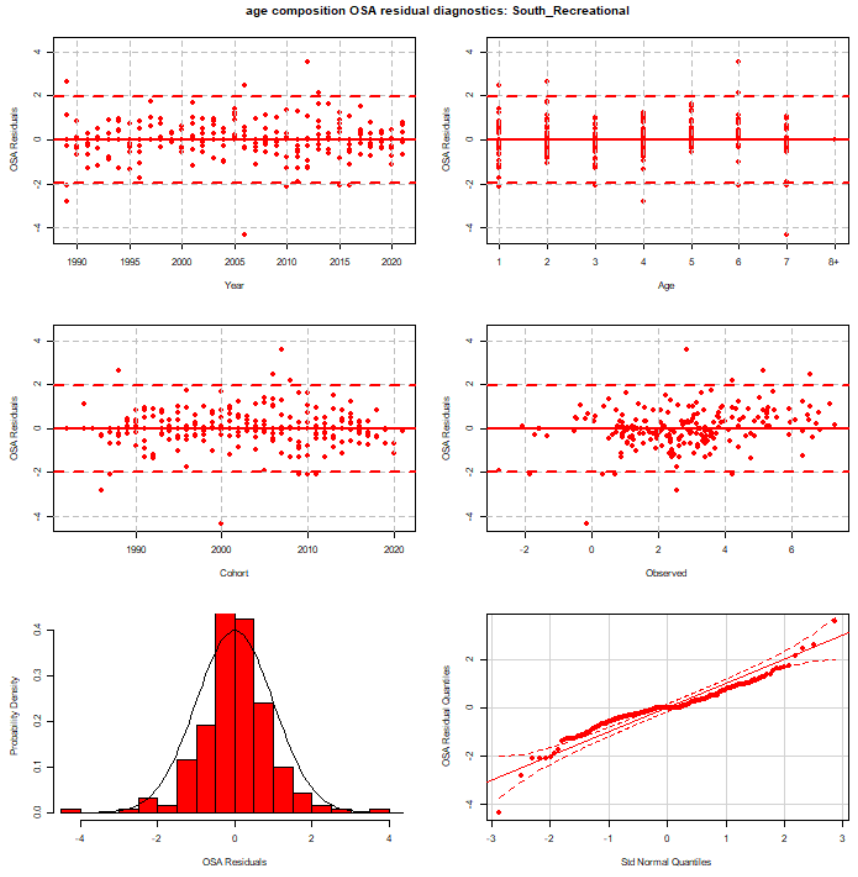
OSA: South recreational fleet

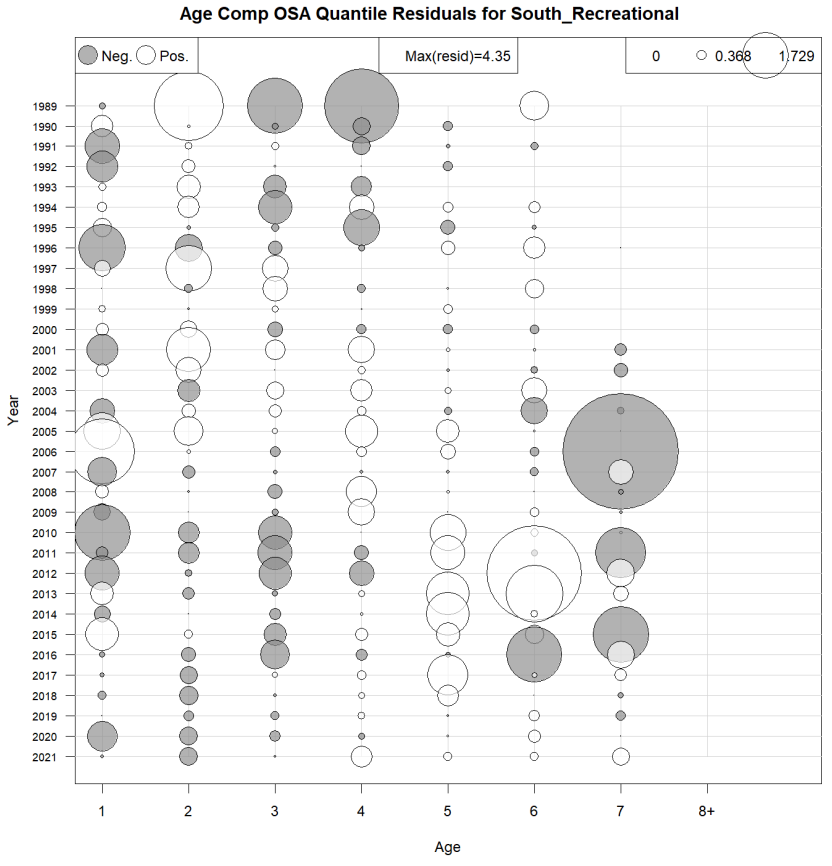
- residuals were under-dispersed but no trends.



OSA: South recreational fleet

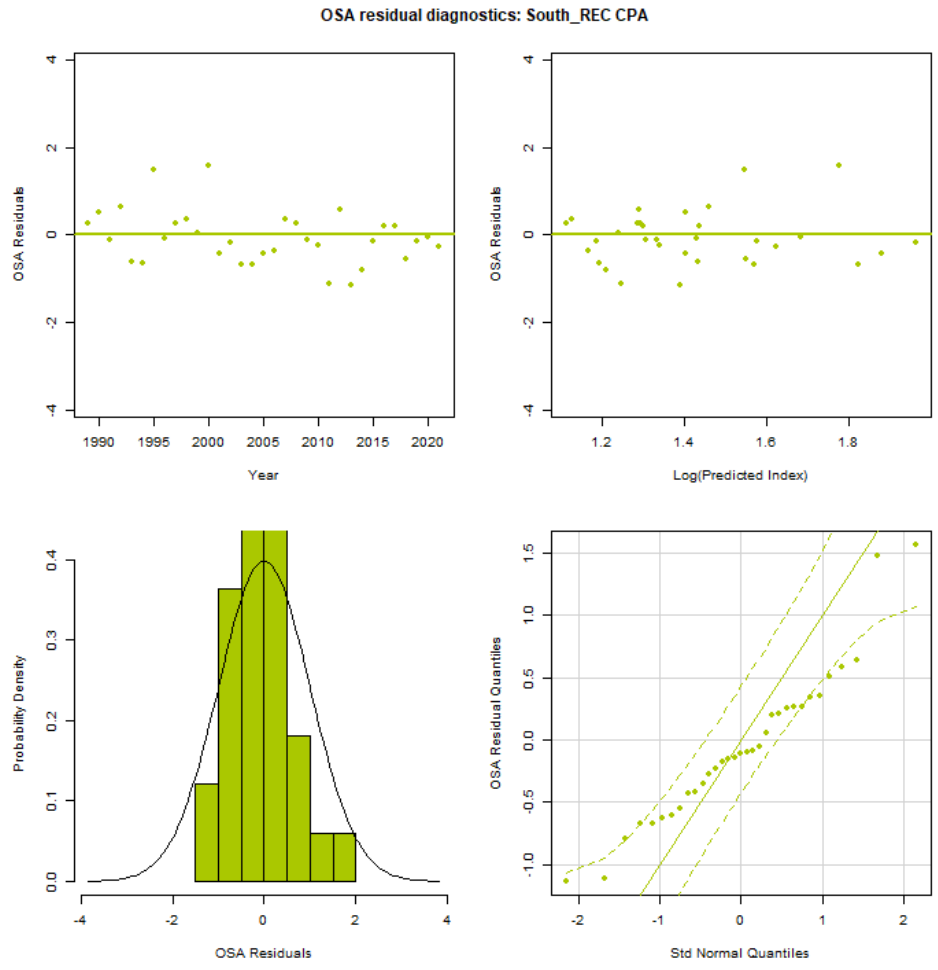
- somewhat underdispersed, but no trends





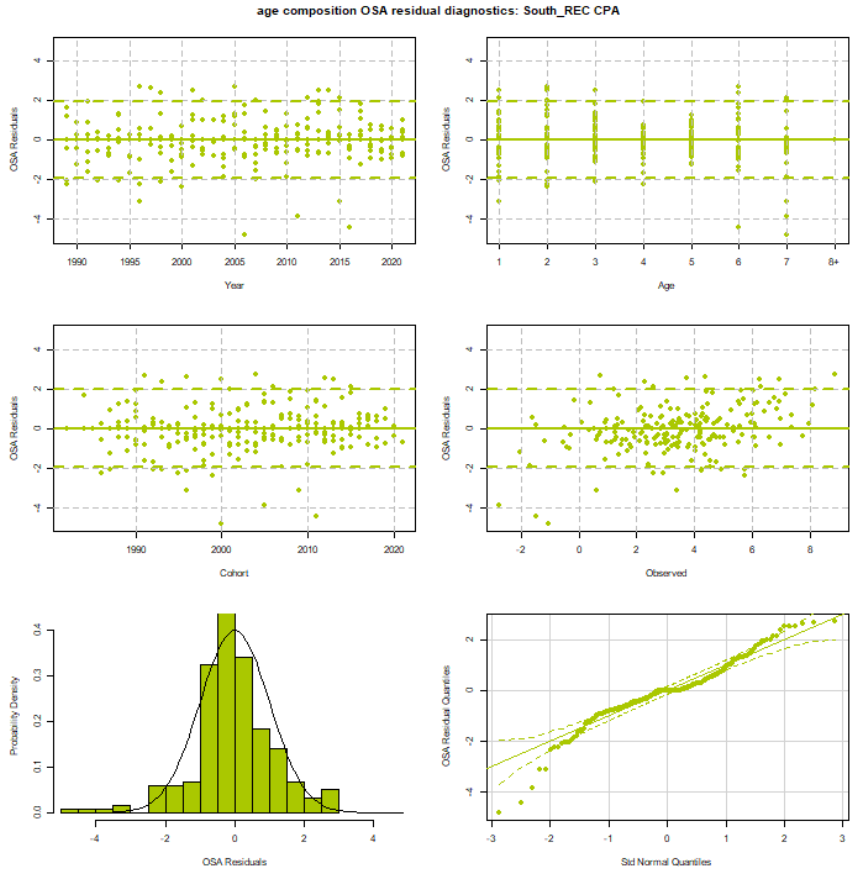
OSA: South Rec CPA index

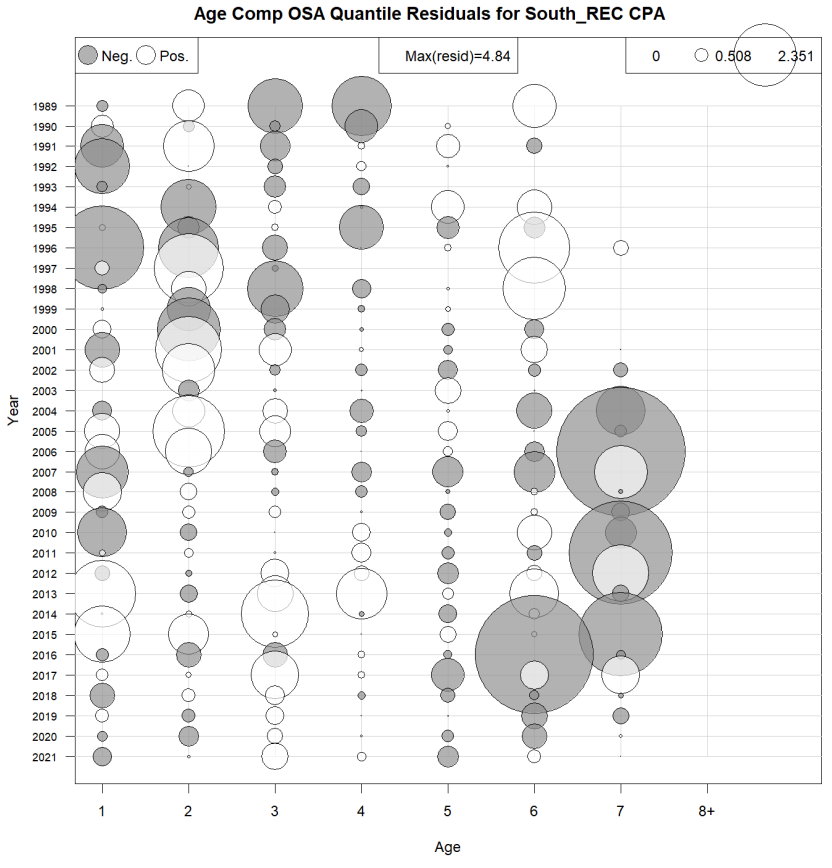
- somewhat under-dispersed



OSA: South Rec CPA index

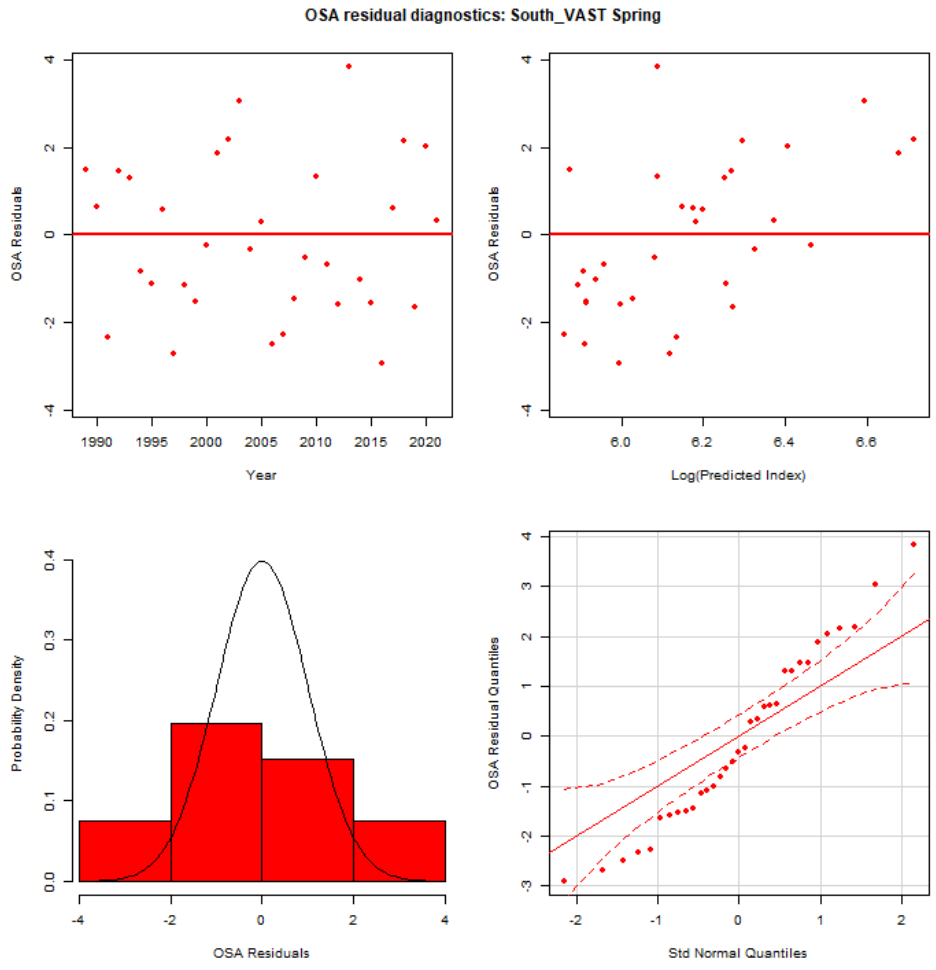
- a few large negative residuals at older ages, but otherwise no apparent trends





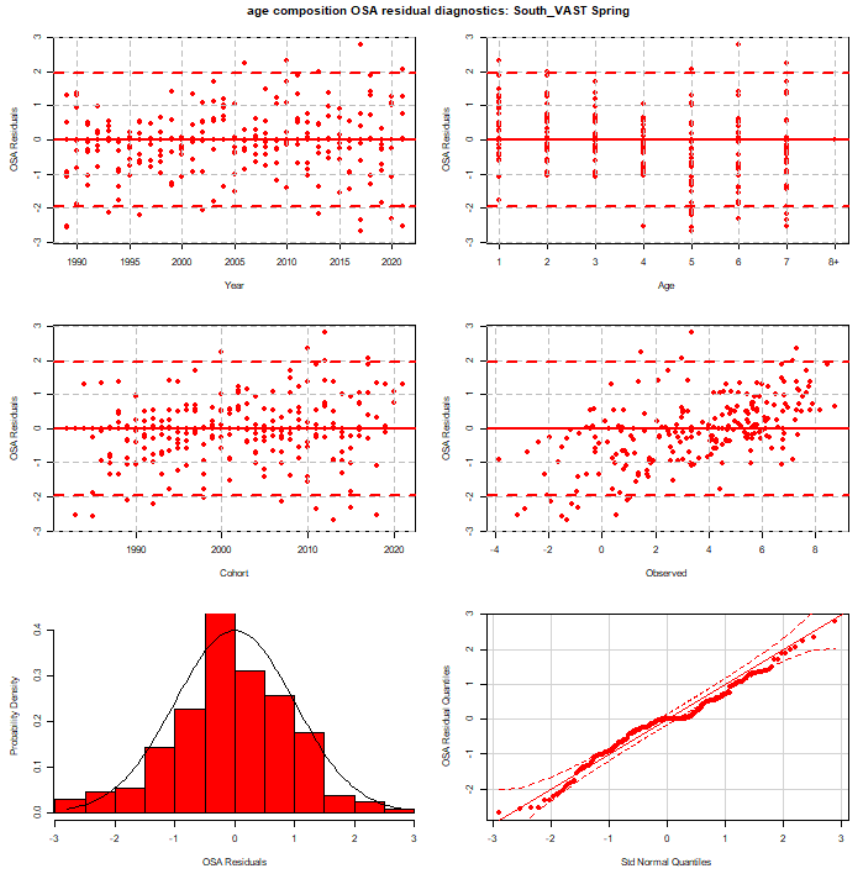
OSA: South VAST index

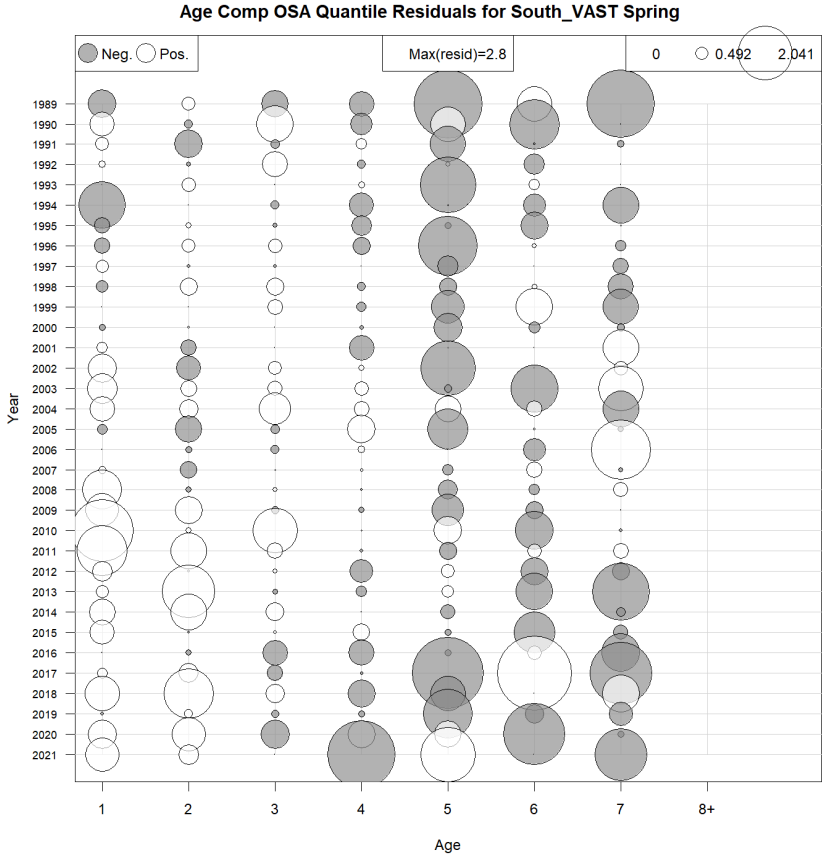
- somewhat over-dispersed



OSA: South VAST index

- some trend with observed proportion and age

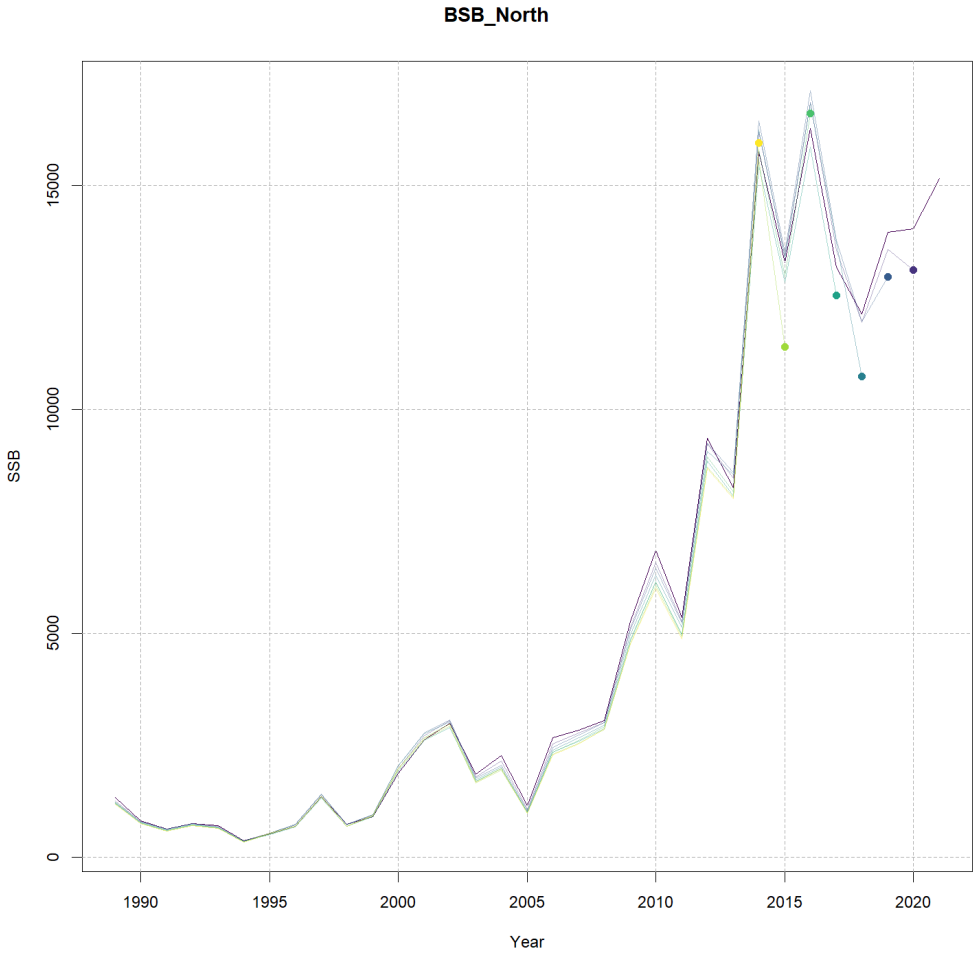


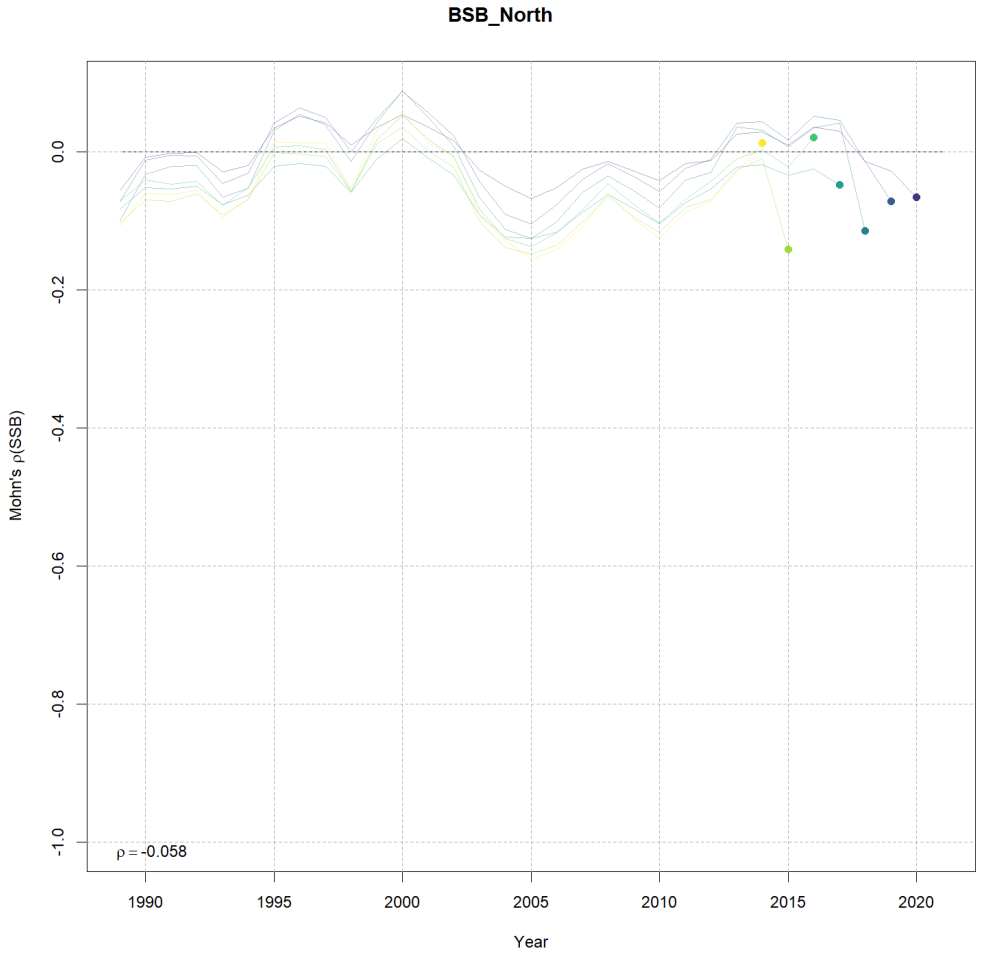


Retrospective patterns

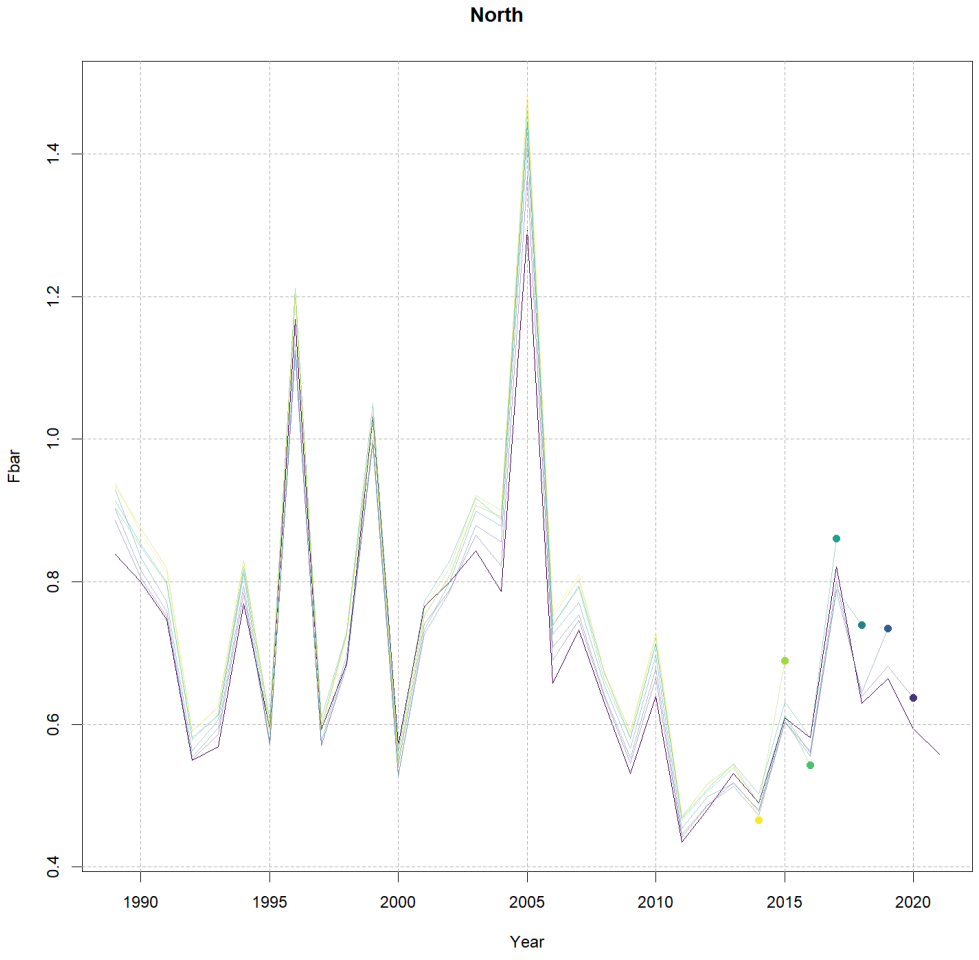
- Seven peels of the base model.
- Strong retrospective patterns in the most recent management track assessment for the northern component of the stock, do not occur in base model.

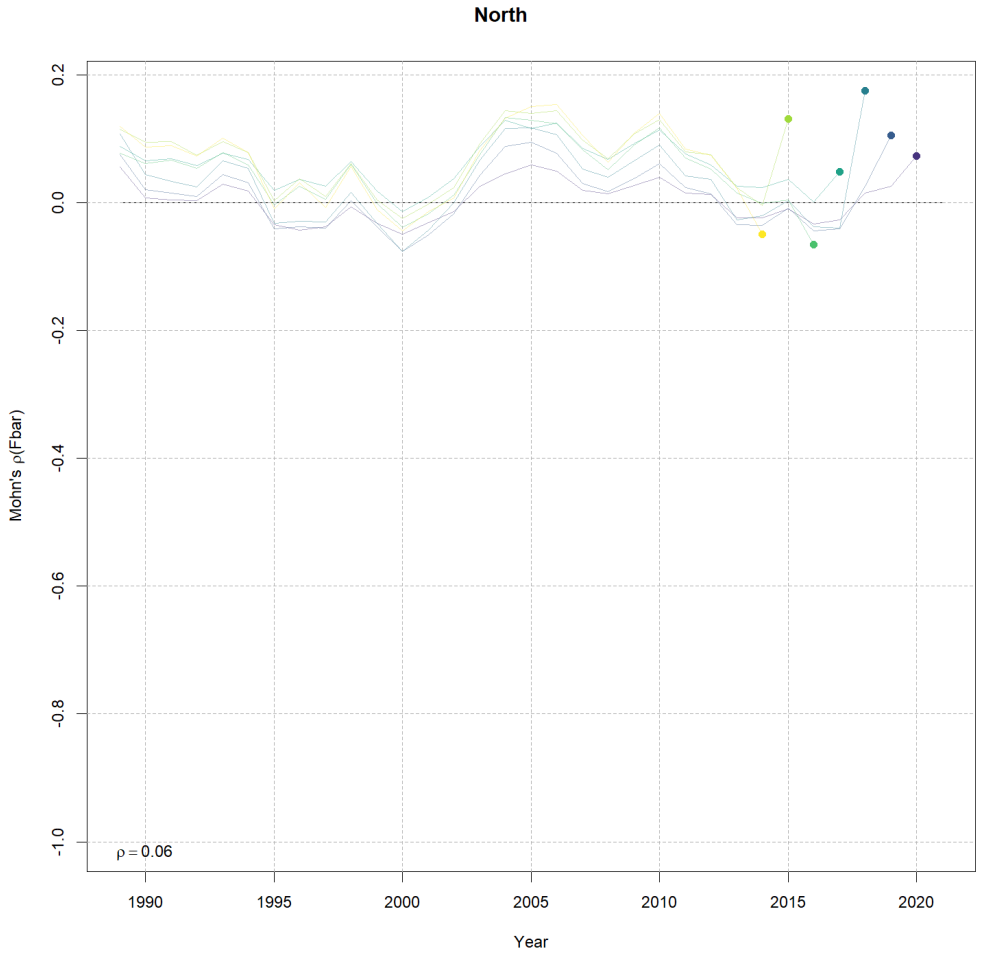
Retrospective patterns: North SSB



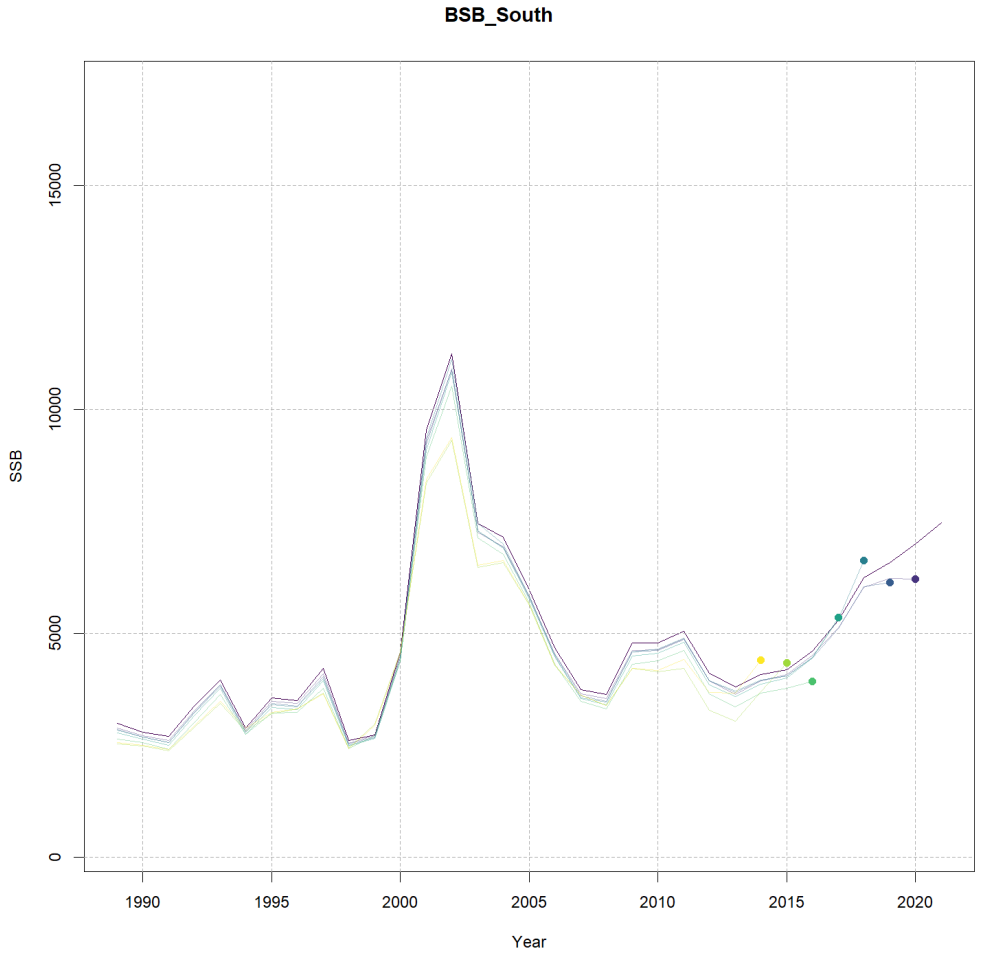


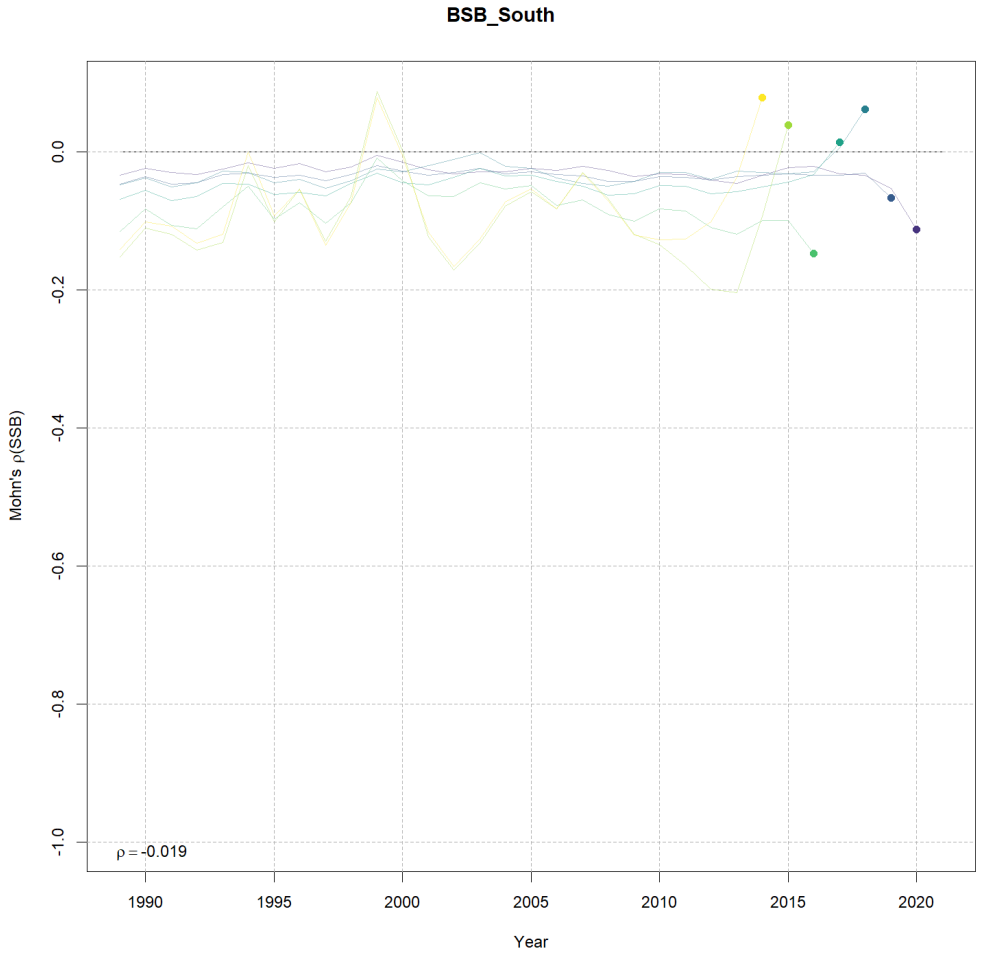
Retrospective patterns: North F (average of ages 6-7)



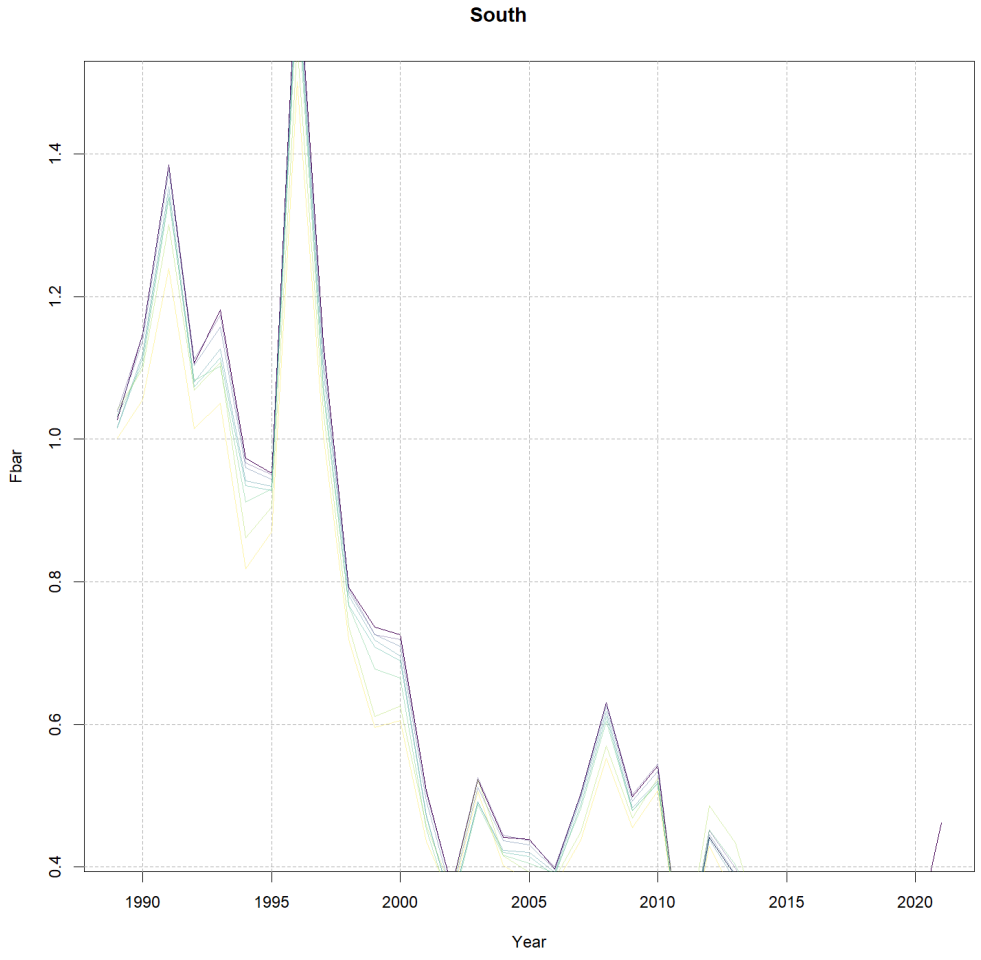


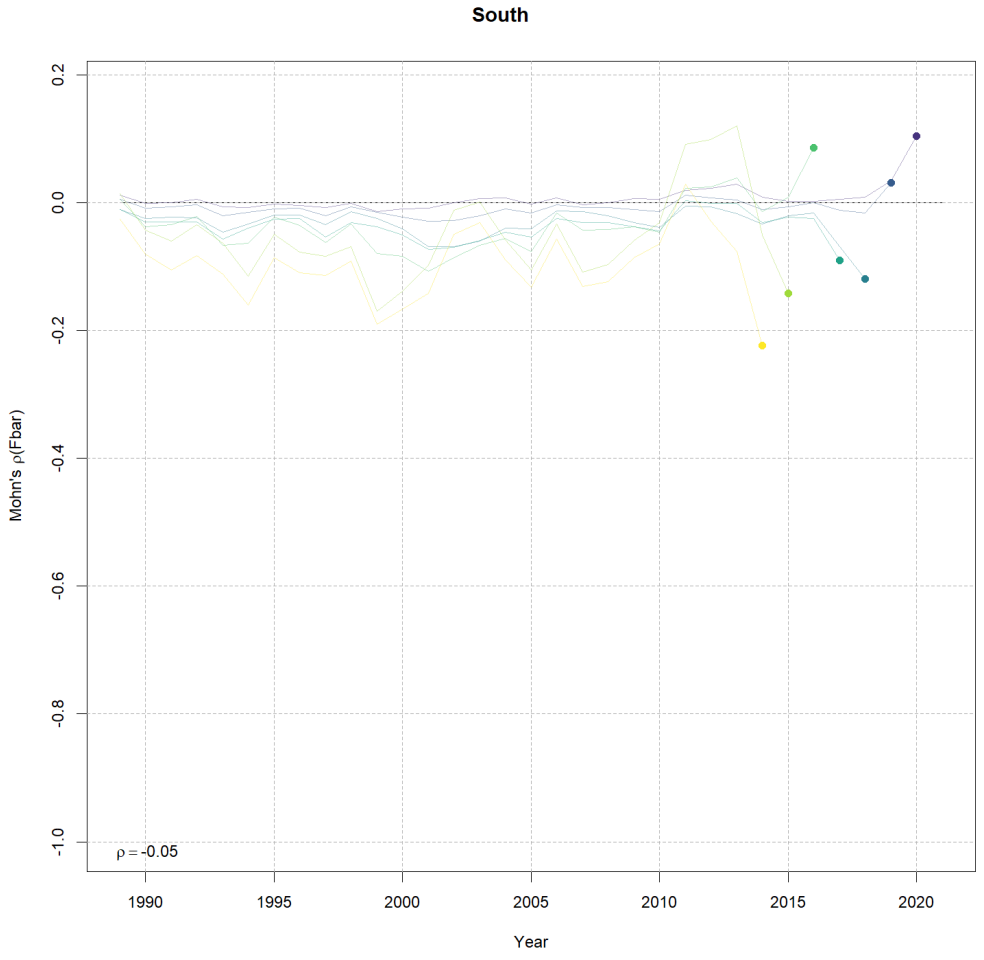
Retrospective patterns: South SSB





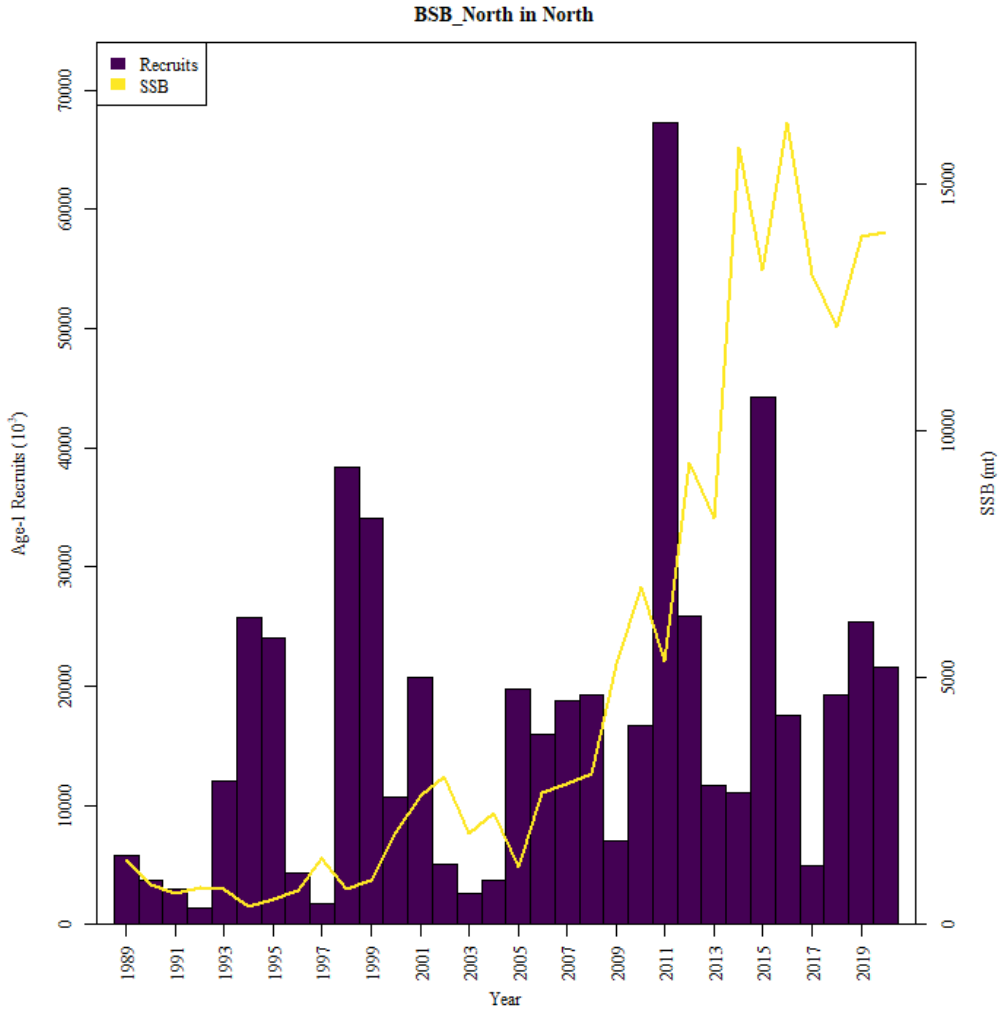
Retrospective patterns: South F (average of ages 6-7)



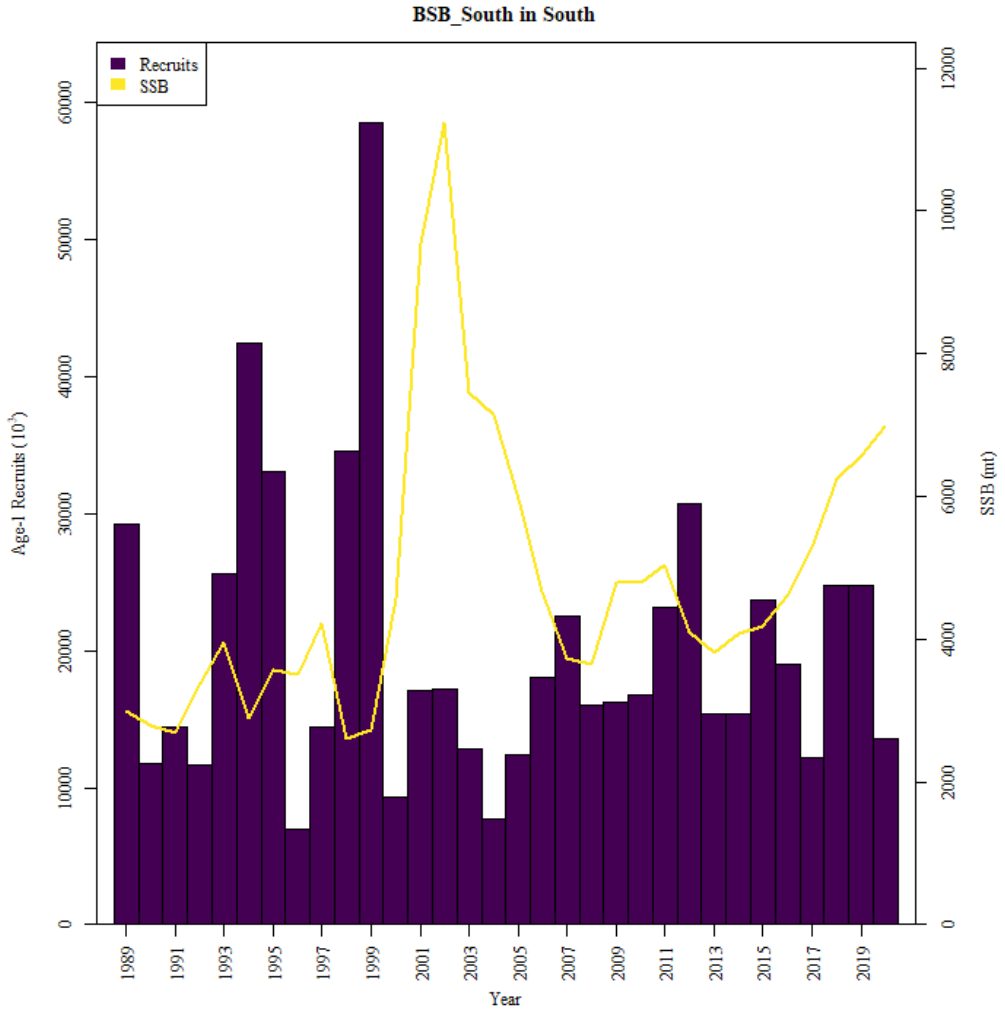


Results

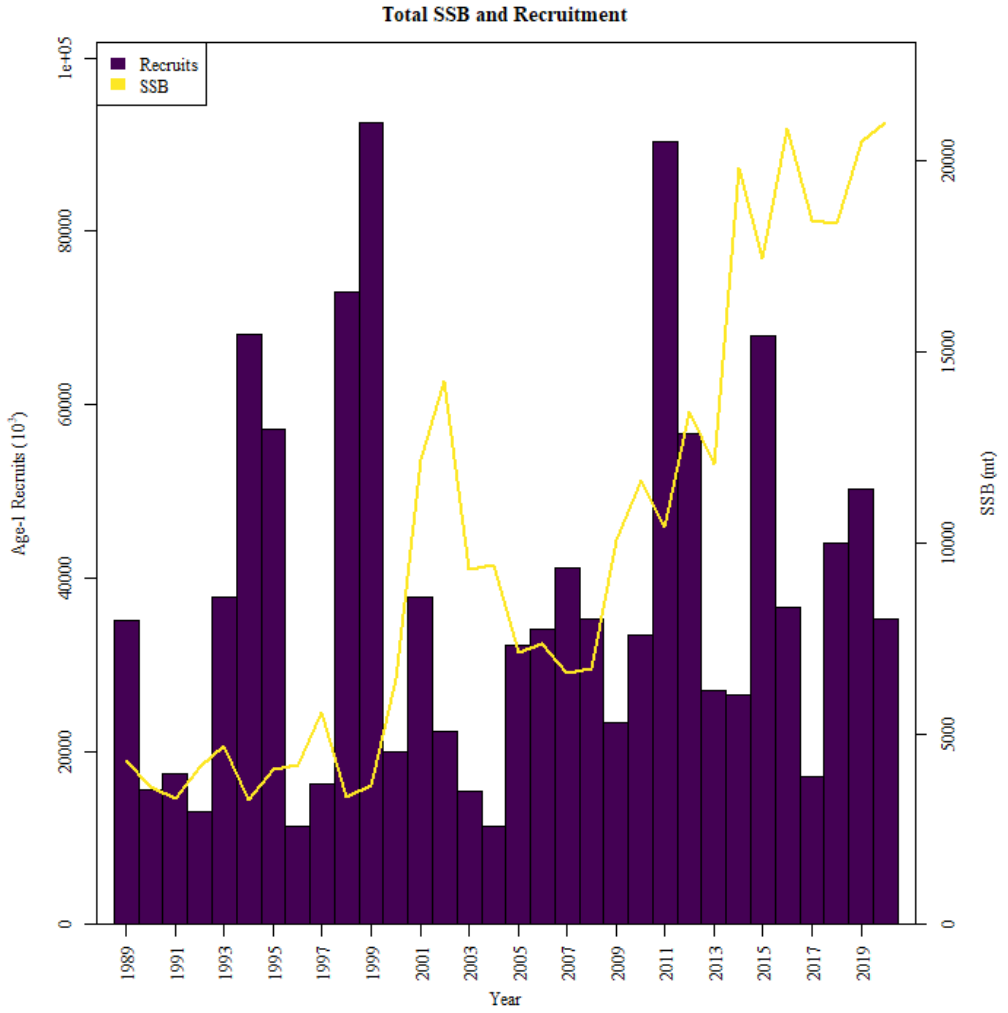
SSB, R: North


BSB_North in North
Recruits
SSB
Age-1 Recruits (10^3)
SSB (mt)
Year
0
10000
20000
30000
40000
50000
60000
70000
0
5000
10000
15000
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

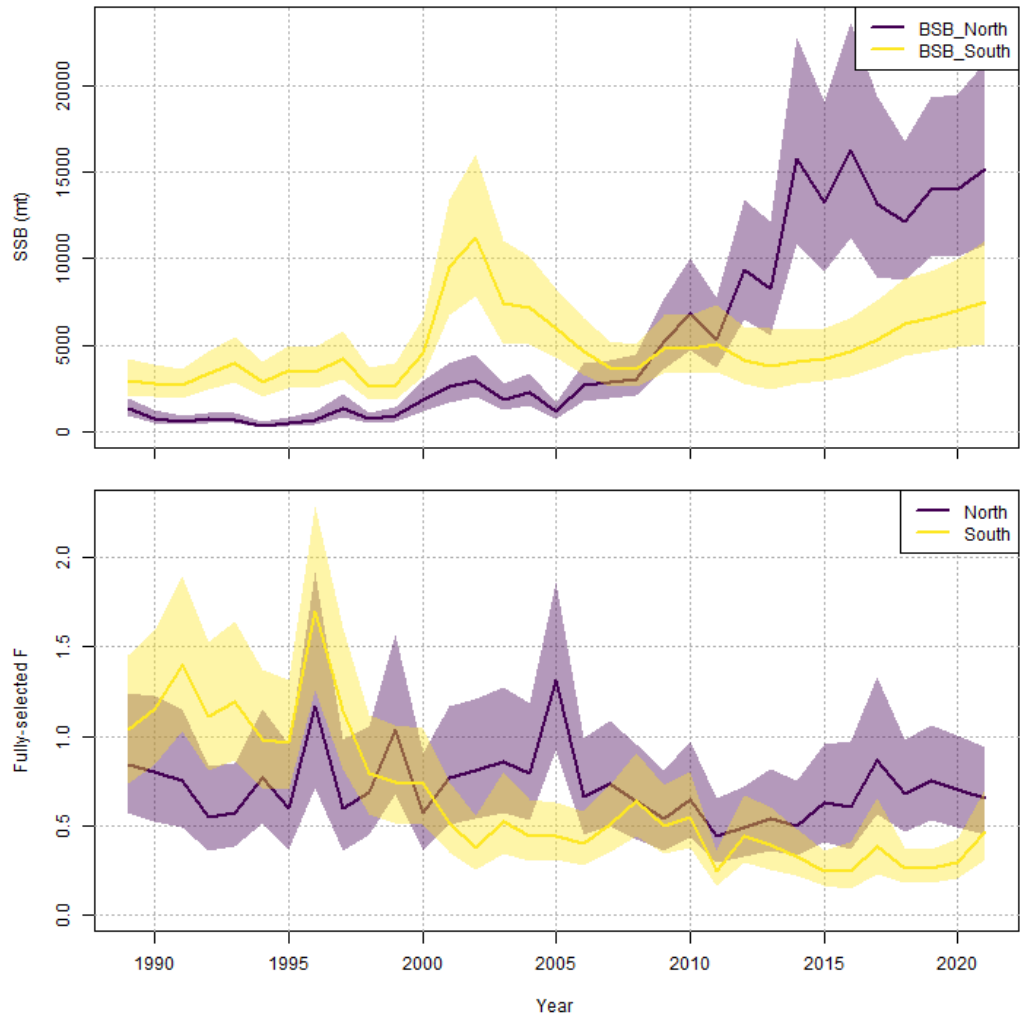
SSB, R: South


BSB_South in South
Recruits
SSB
Age-1 Recruits (10^3)
SSB (mt)
Year
0
10000
20000
30000
40000
50000
60000
2000
4000
6000
8000
10000
12000
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

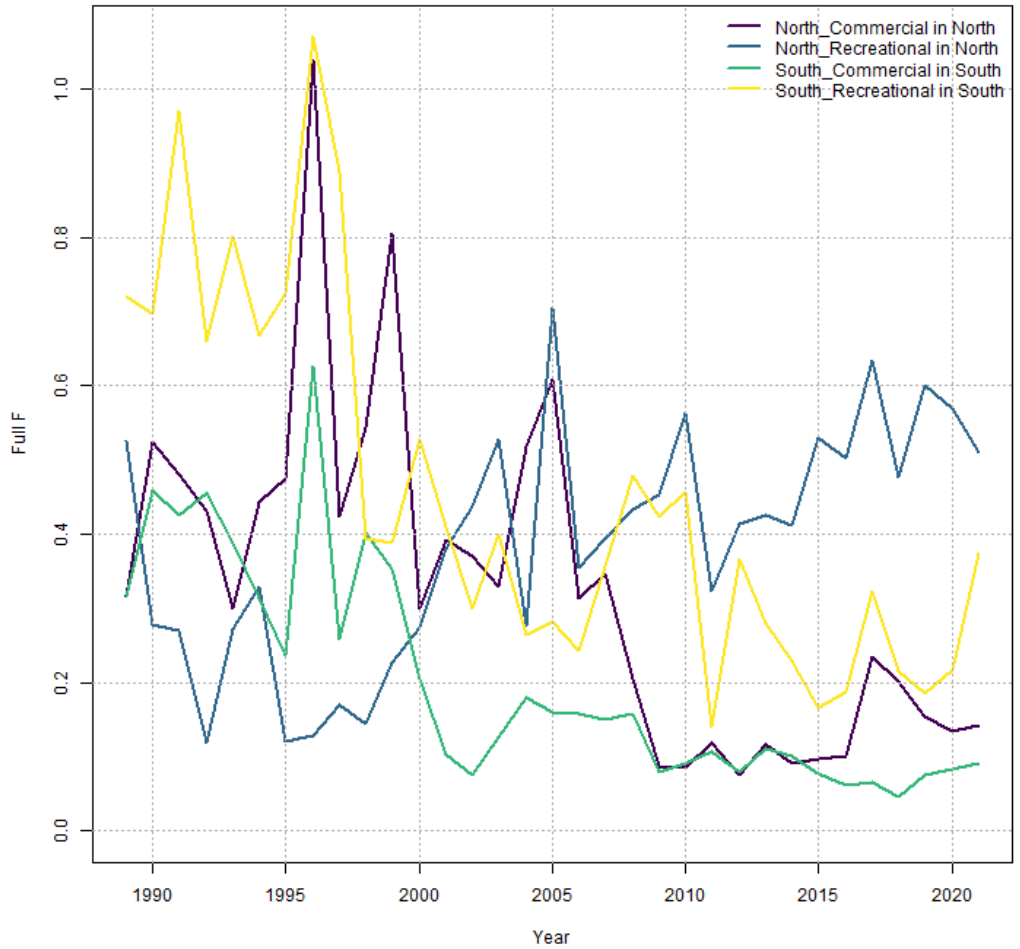
SSB, R: Total


Total SSB and Recruitment
Recruits
SSB
Age-1 Recruits (10^3)
SSB (mt)
Year
0
20000
40000
60000
80000
1e+05
0
5000
10000
15000
20000
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

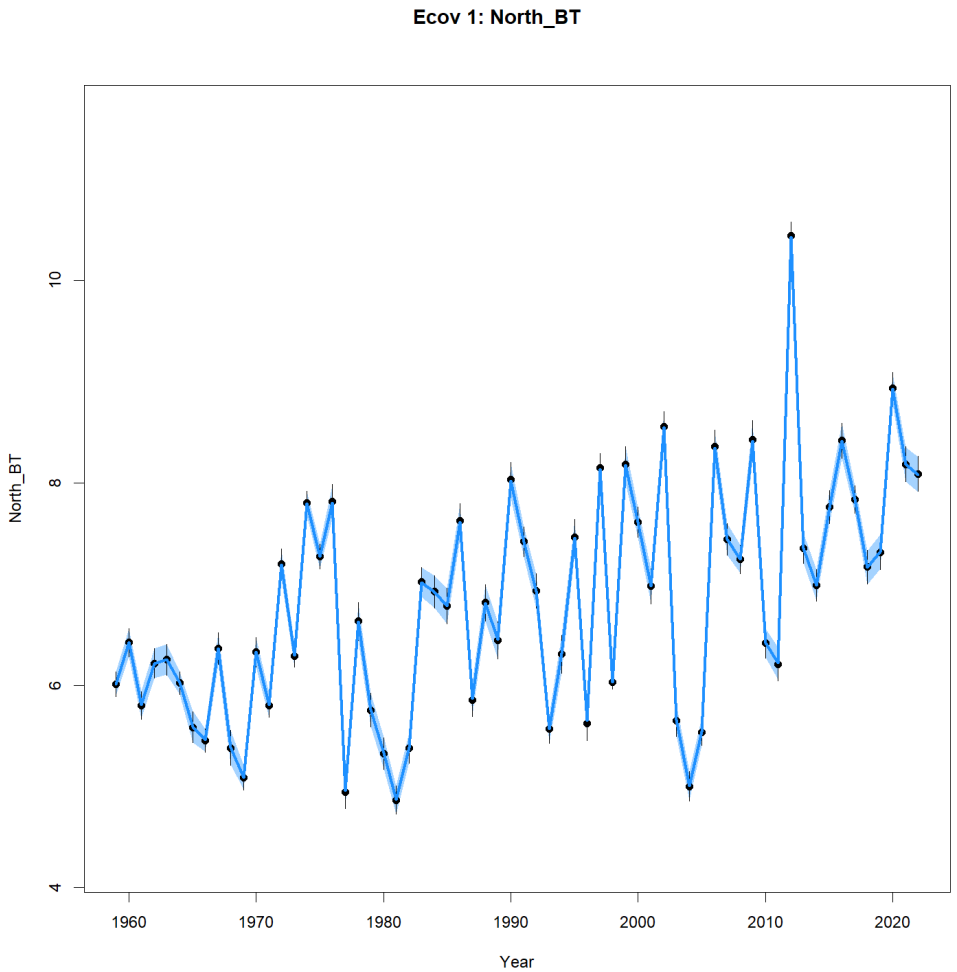
SSB, F

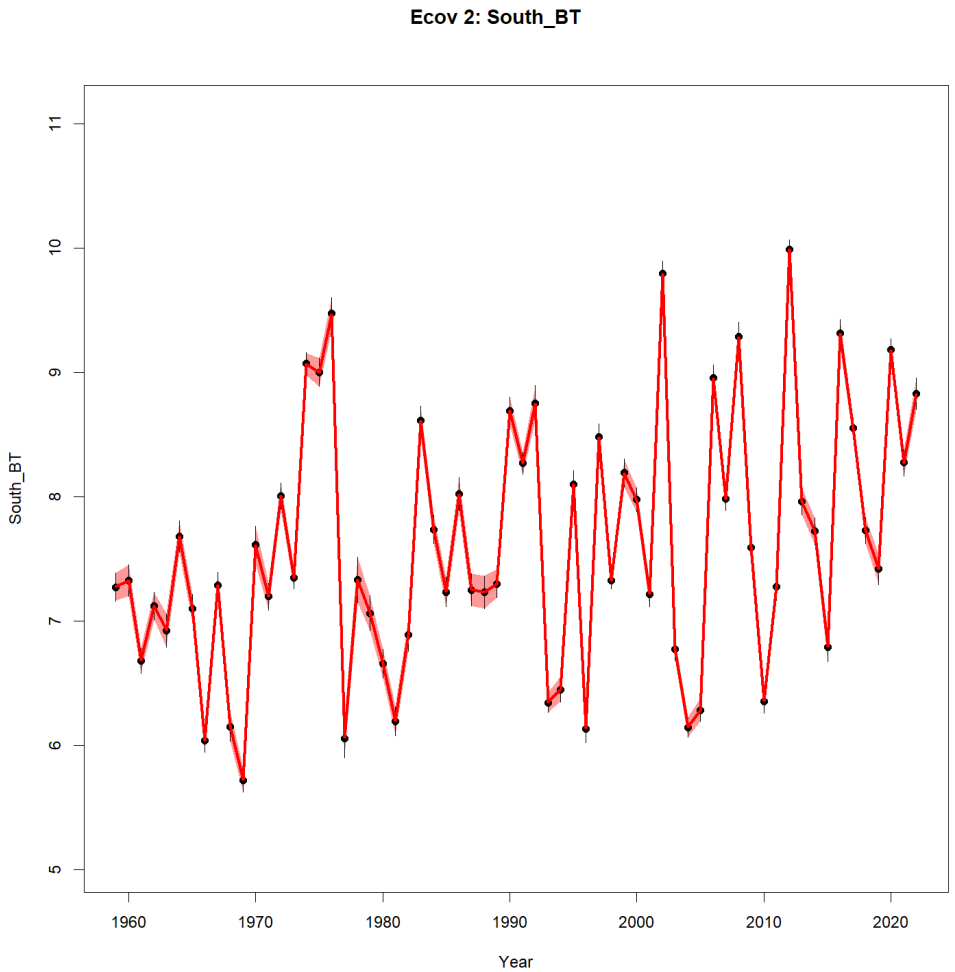

BSB_North
BSB_South
SSB (mt)
0
5000
10000
15000
20000
North
South
Fully-selected F
0.0
0.5
1.0
1.5
2.0
1990
1995
2000
2005
2010
2015
2020
Year

F by fleet

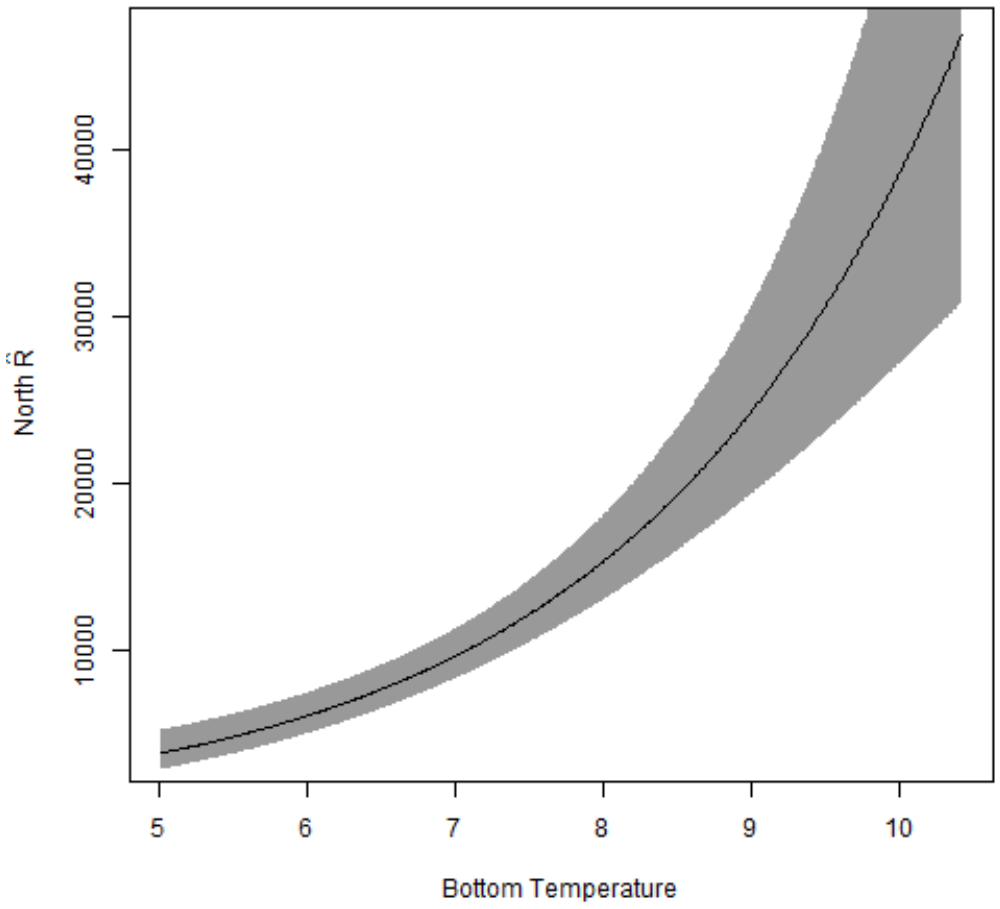

North_Commercial in North
North_Recreational in North
South_Commercial in South
South_Recreational in South
Full F
0.0
0.2
0.4
0.6
0.8
1.0
1990
1995
2000
2005
2010
2015
2020
Year

Bottom temperature

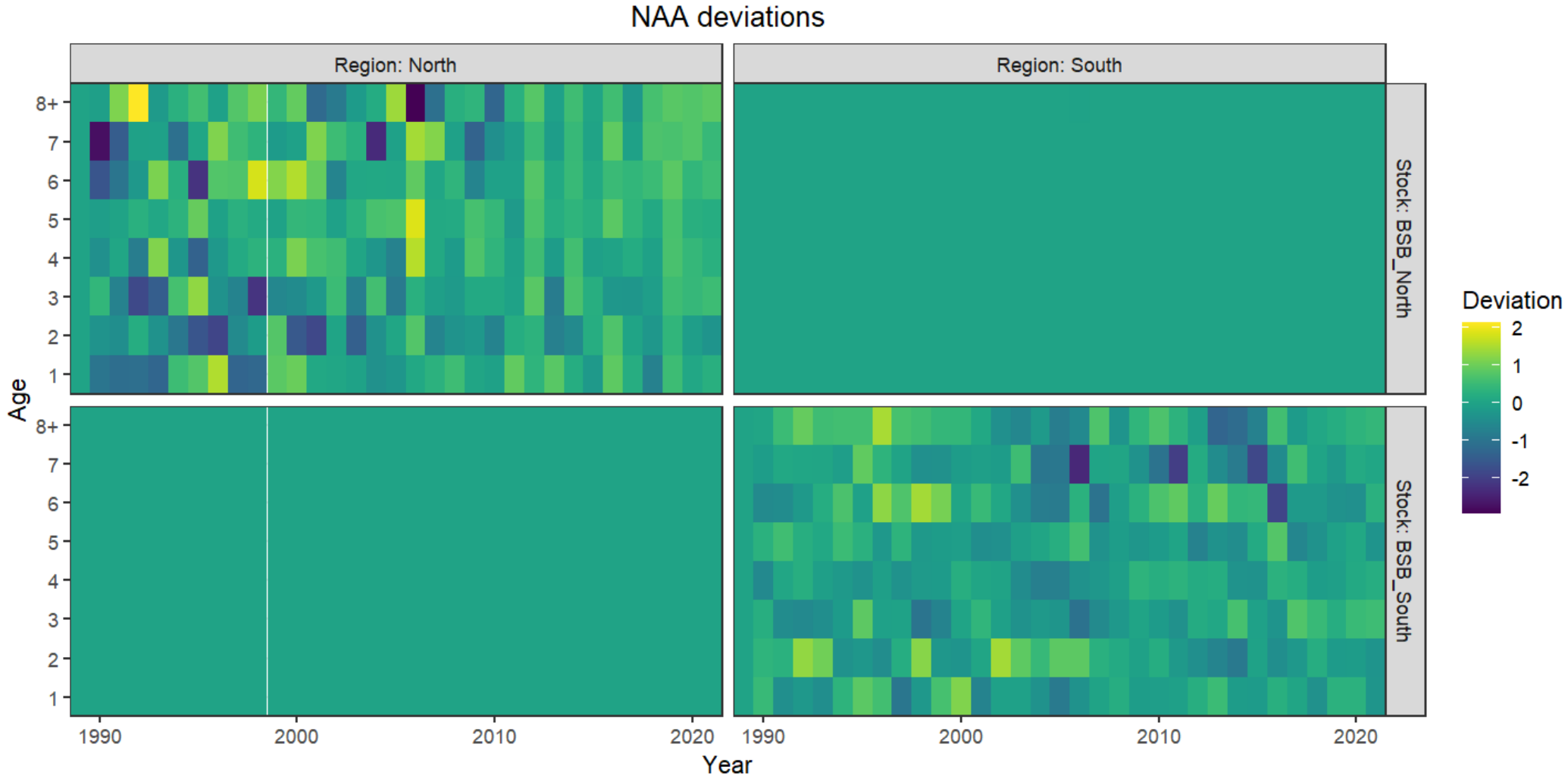




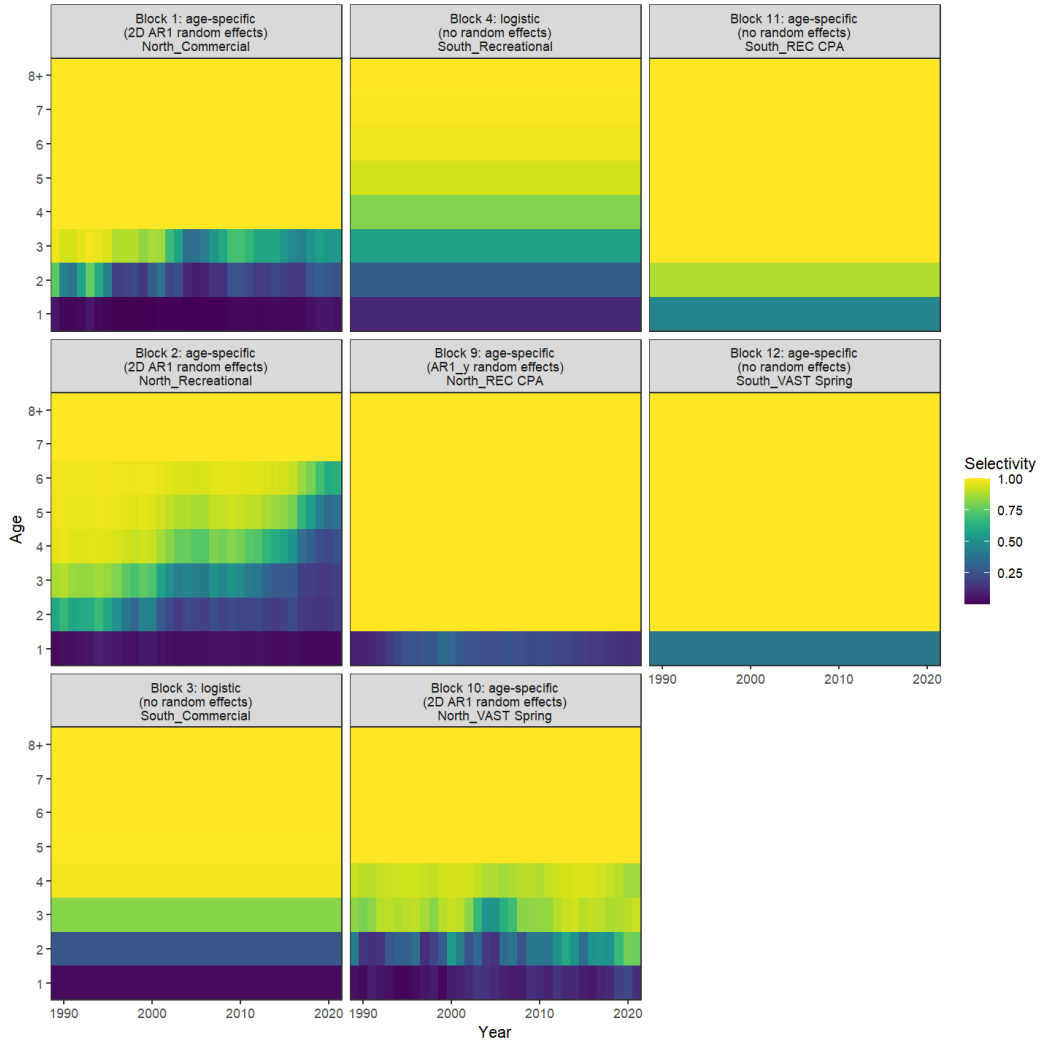
Northern recruitment and bottom temperature



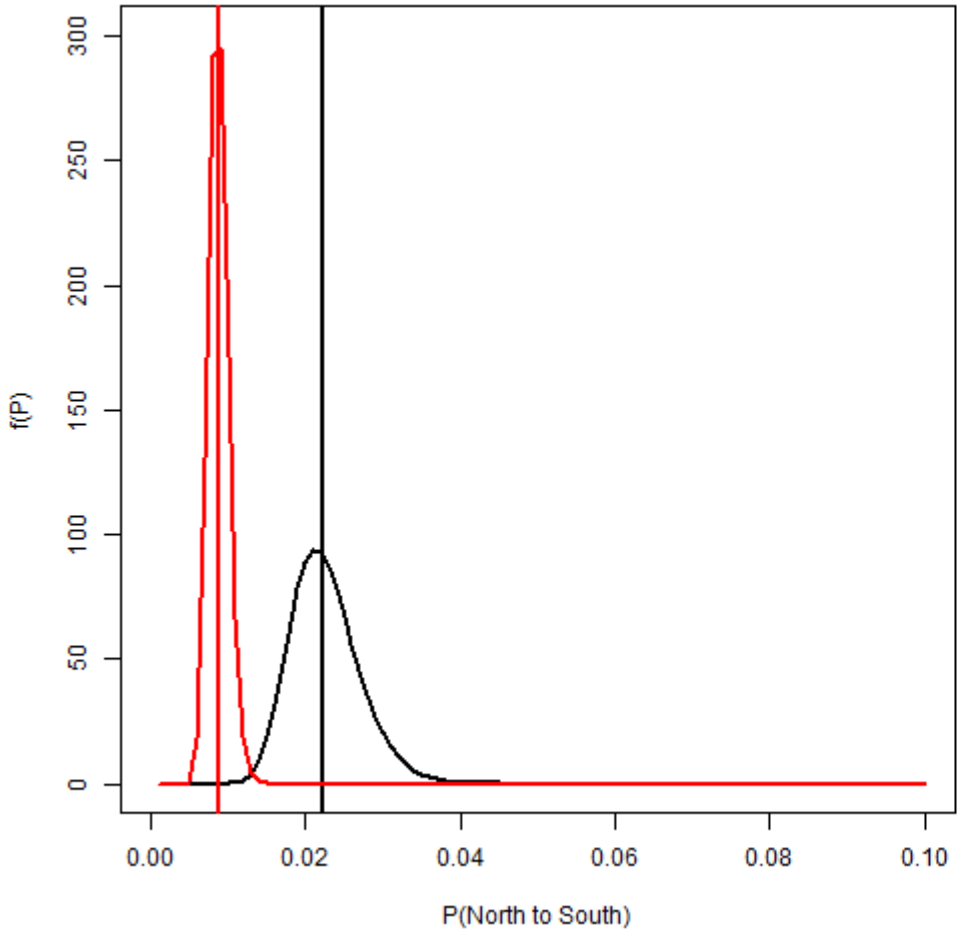
NAA random effects deviations

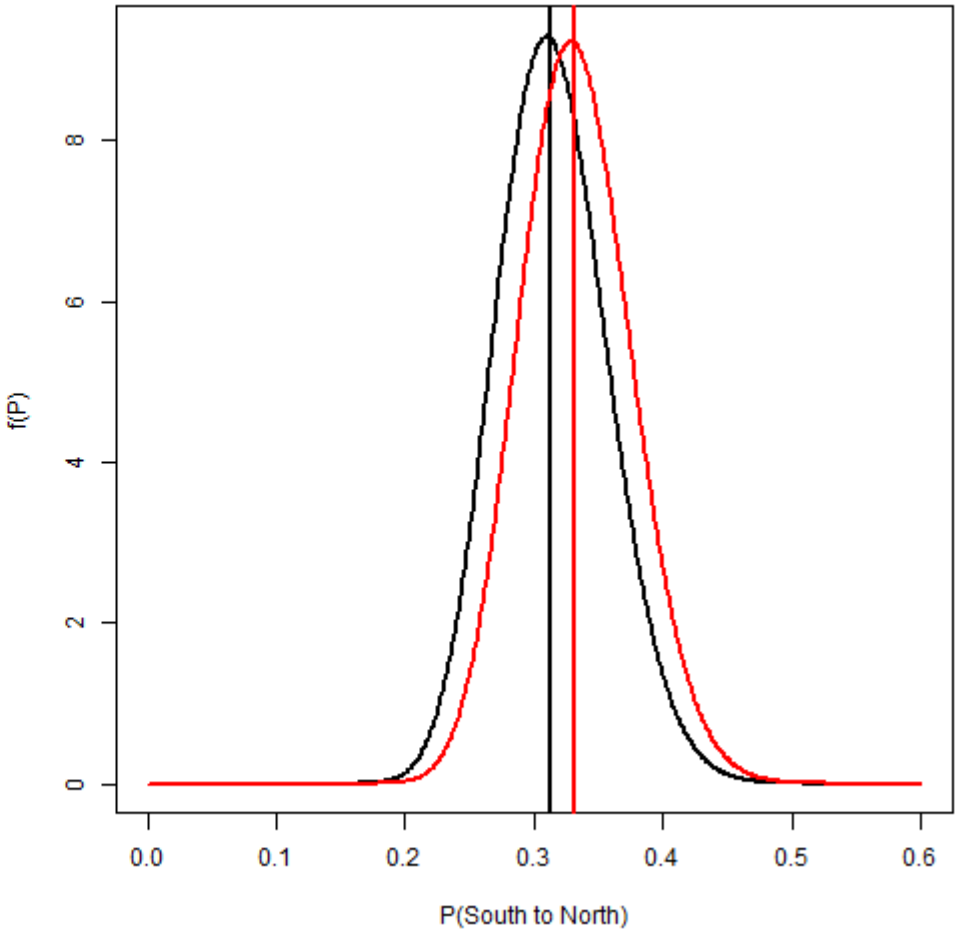


Selectivity



Prior and posterior movement rates

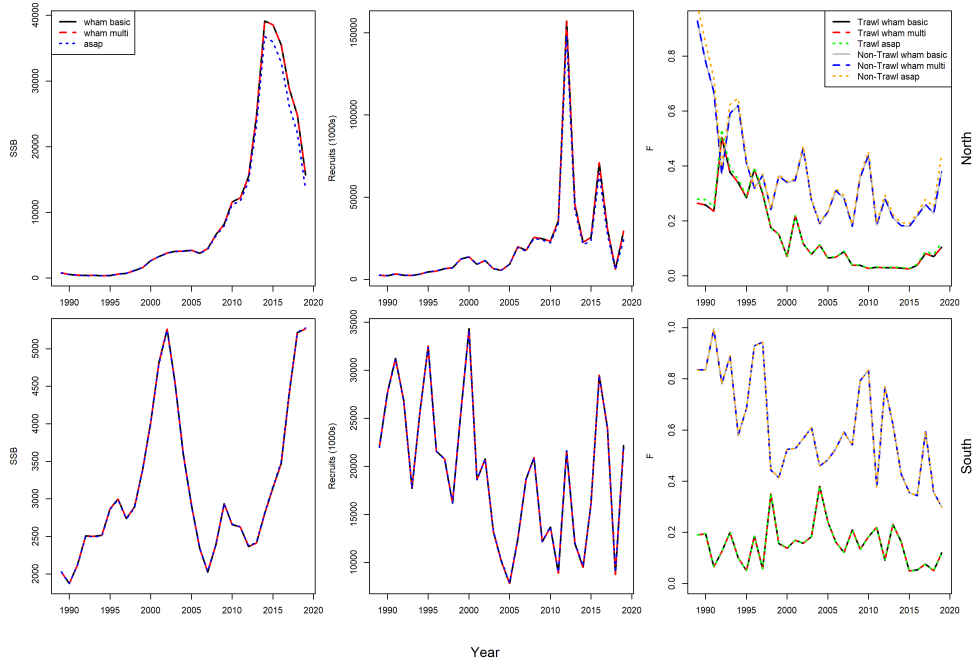




Path to the base model

Comparing ASAP with standard WHAM and Multi-WHAM: Run 0

- Based on data used in 2021 management track
  - Time series of observations not updated
  - Use previous fleet definitions (Trawl and Non-Trawl).
- Compared
  - 2021 Management track ASAP
  - Separate fits in standard WHAM
  - Simultaneous (separate) fits in Multi-WHAM



Bridge runs

Separate fits for north and south regions

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- 4: Add 2020-2021
- 5: Update maturity
- 6: Add NEAMAP
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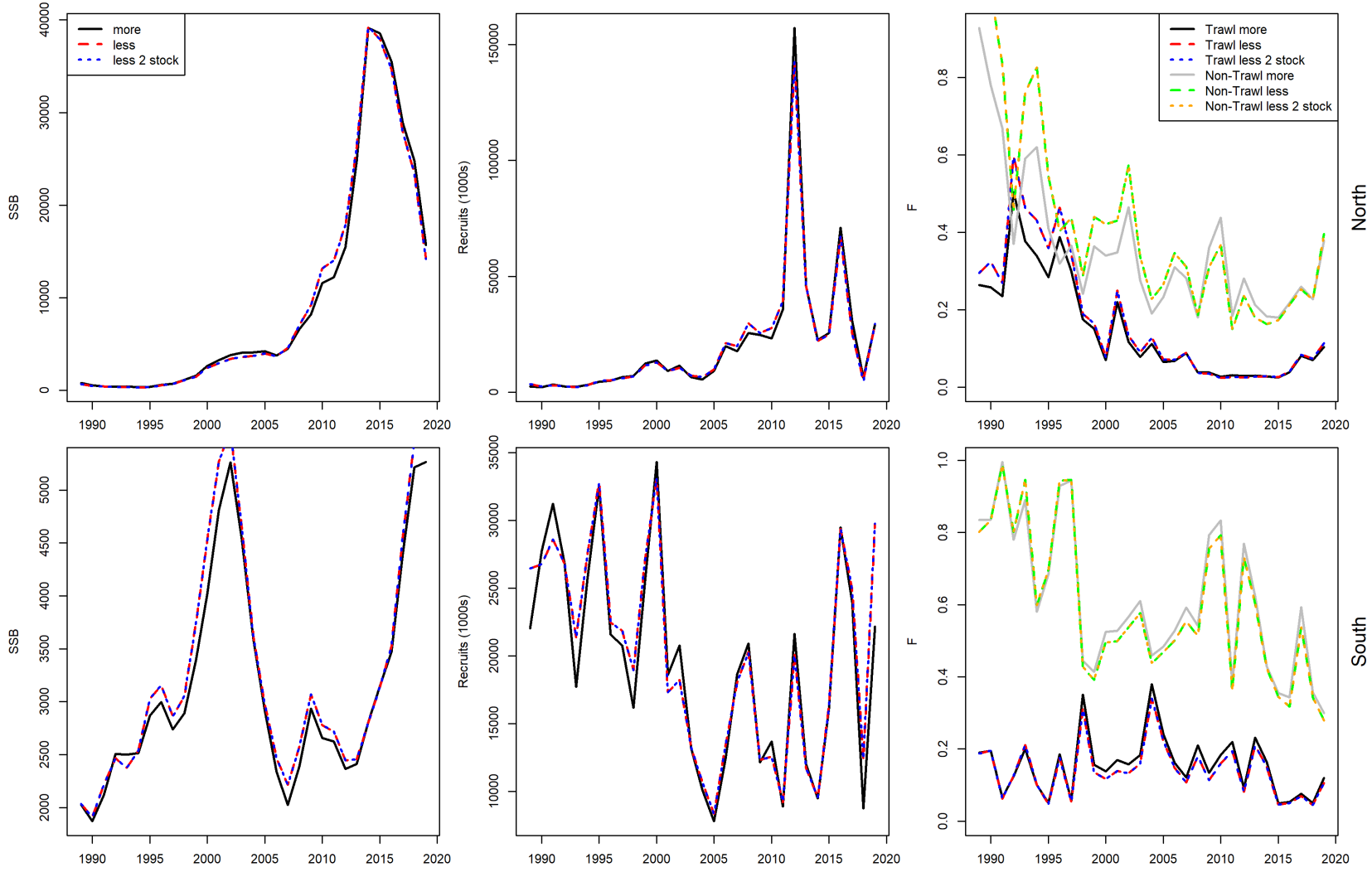
Bridge runs 0 and 1



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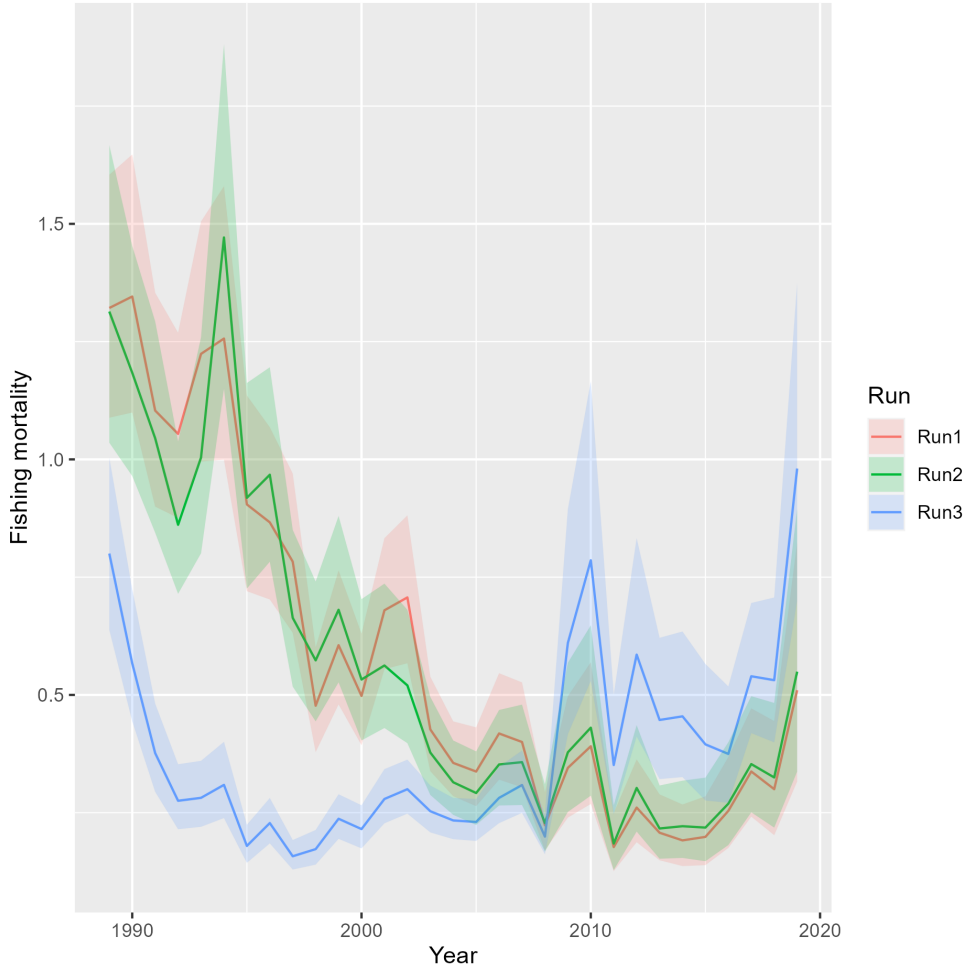
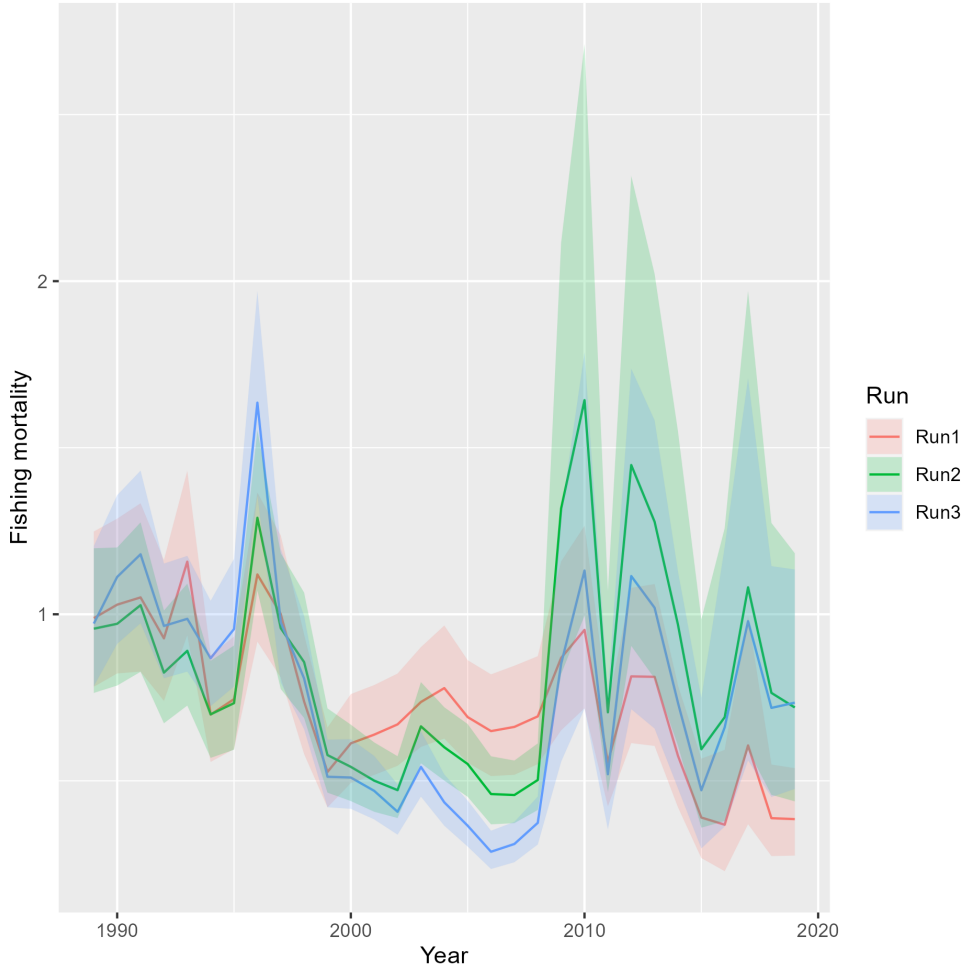
Bridge runs 1, 2, and 3

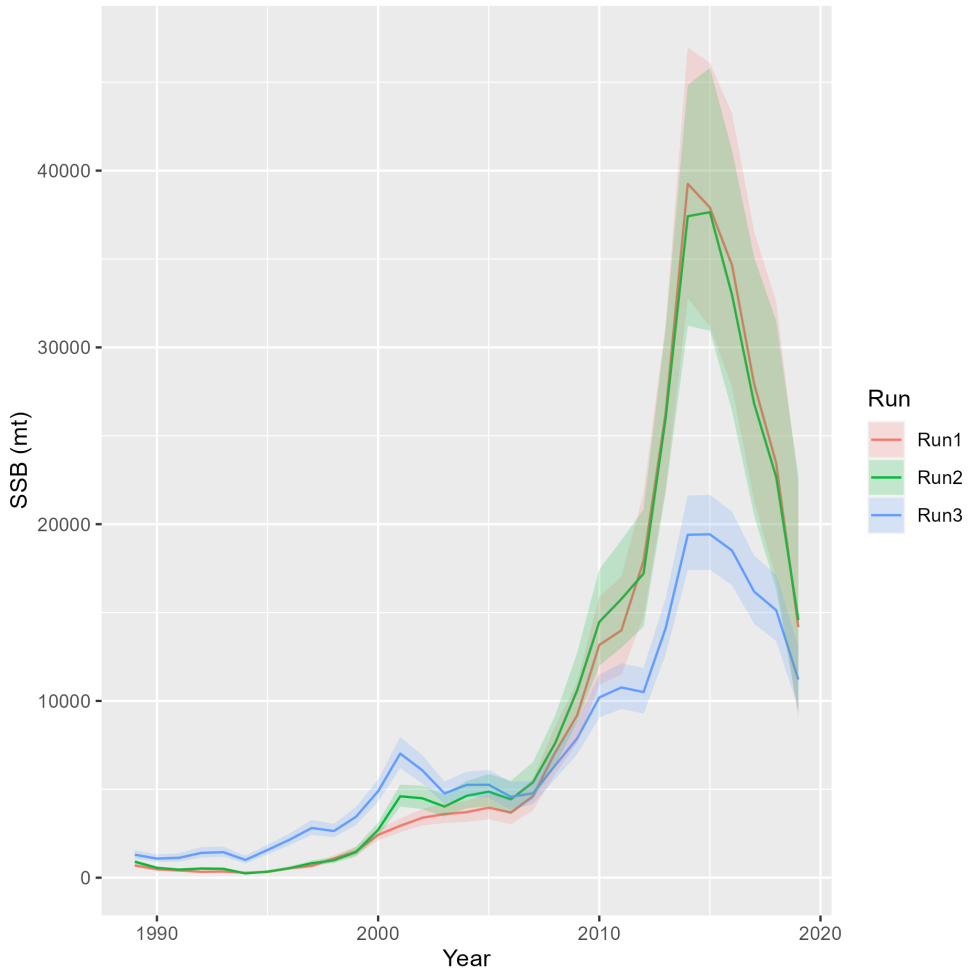


North

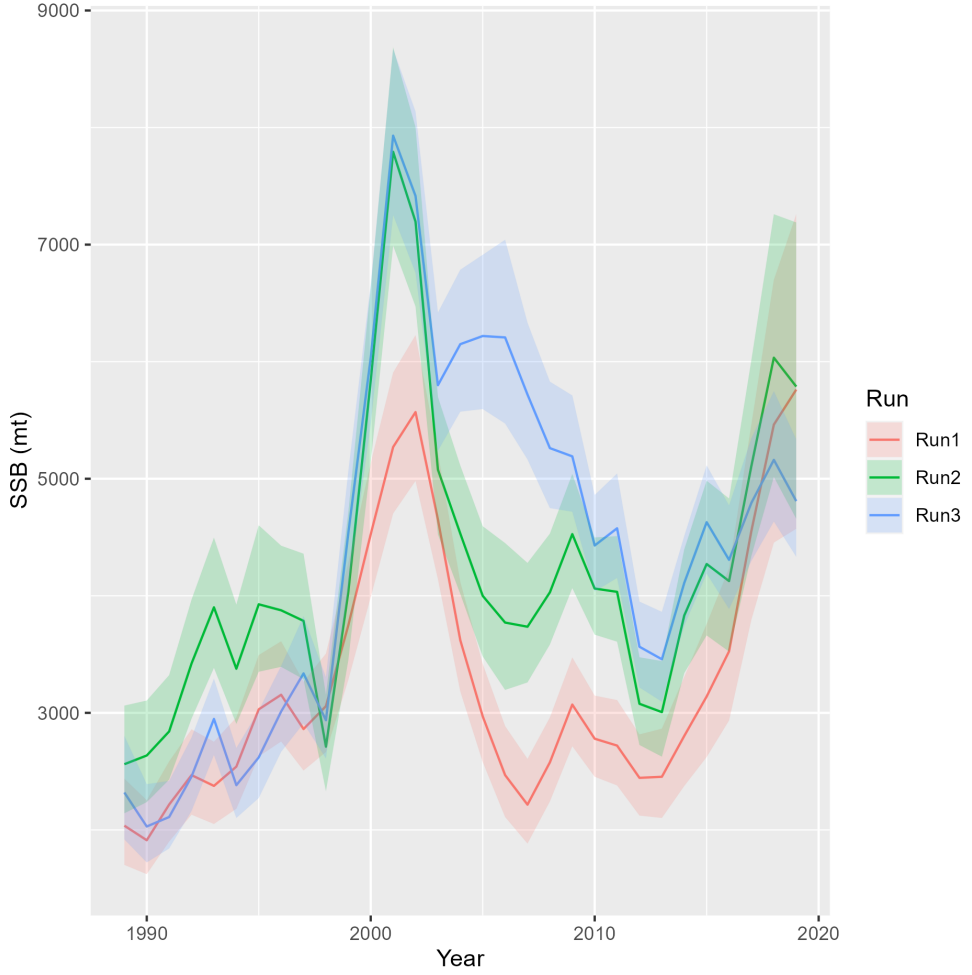


South

Bridge runs 1, 2, and 3

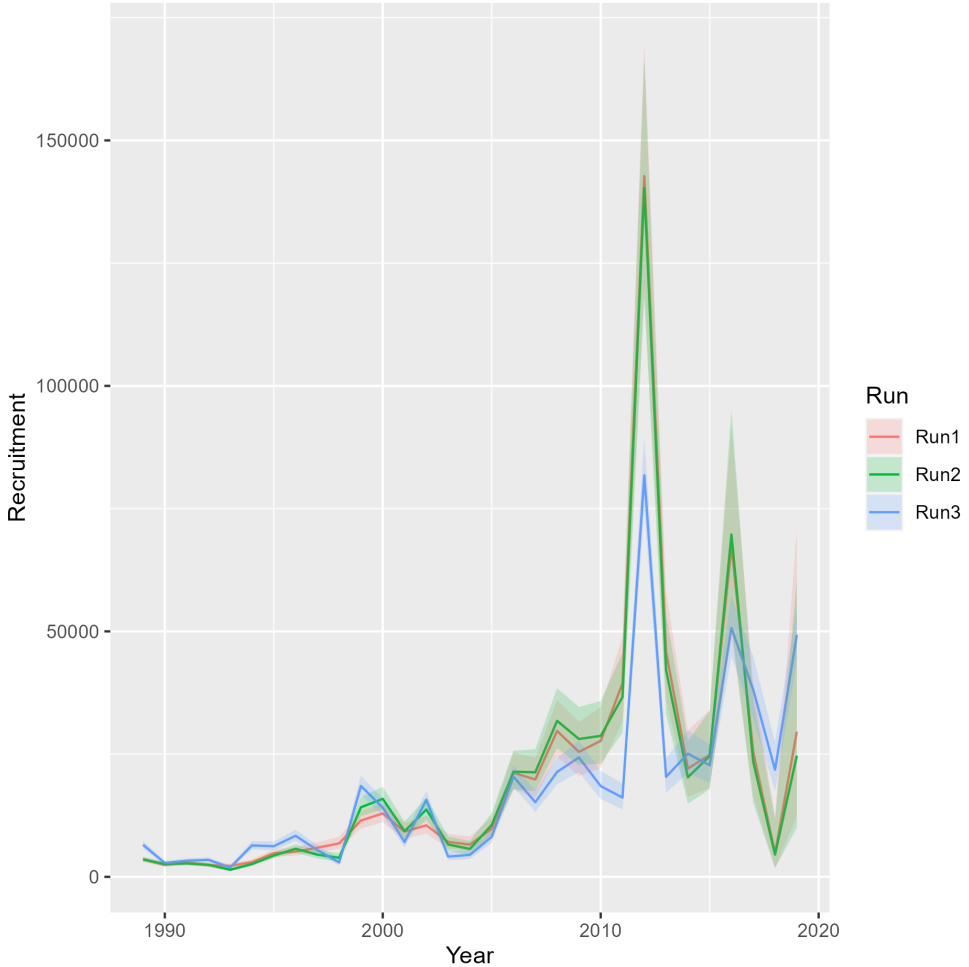


North

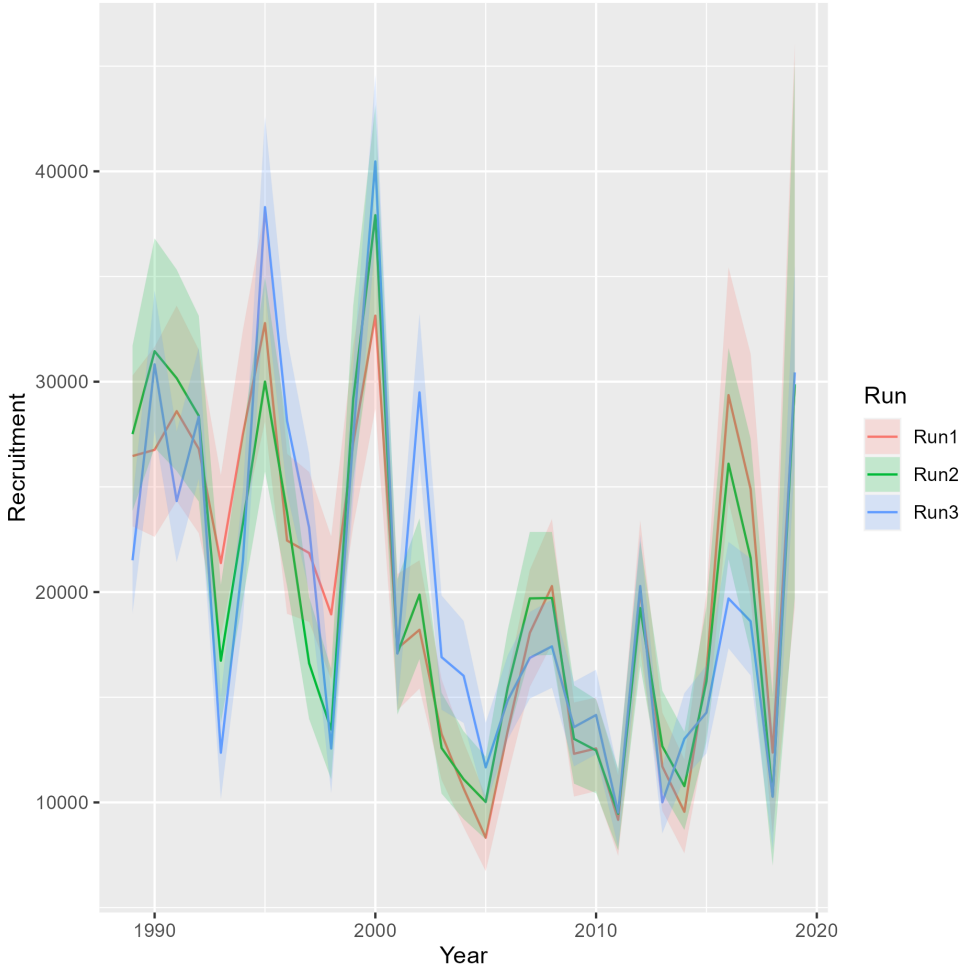


South

Bridge runs 1, 2, and 3



North



South

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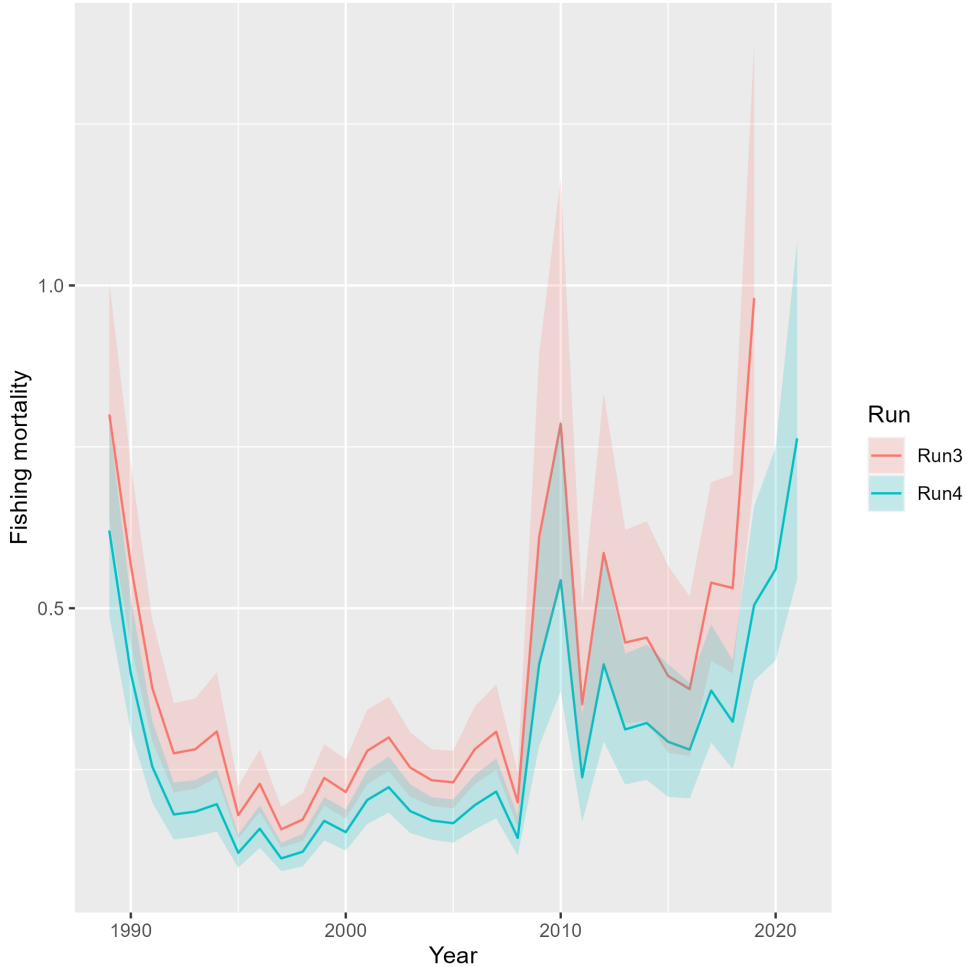
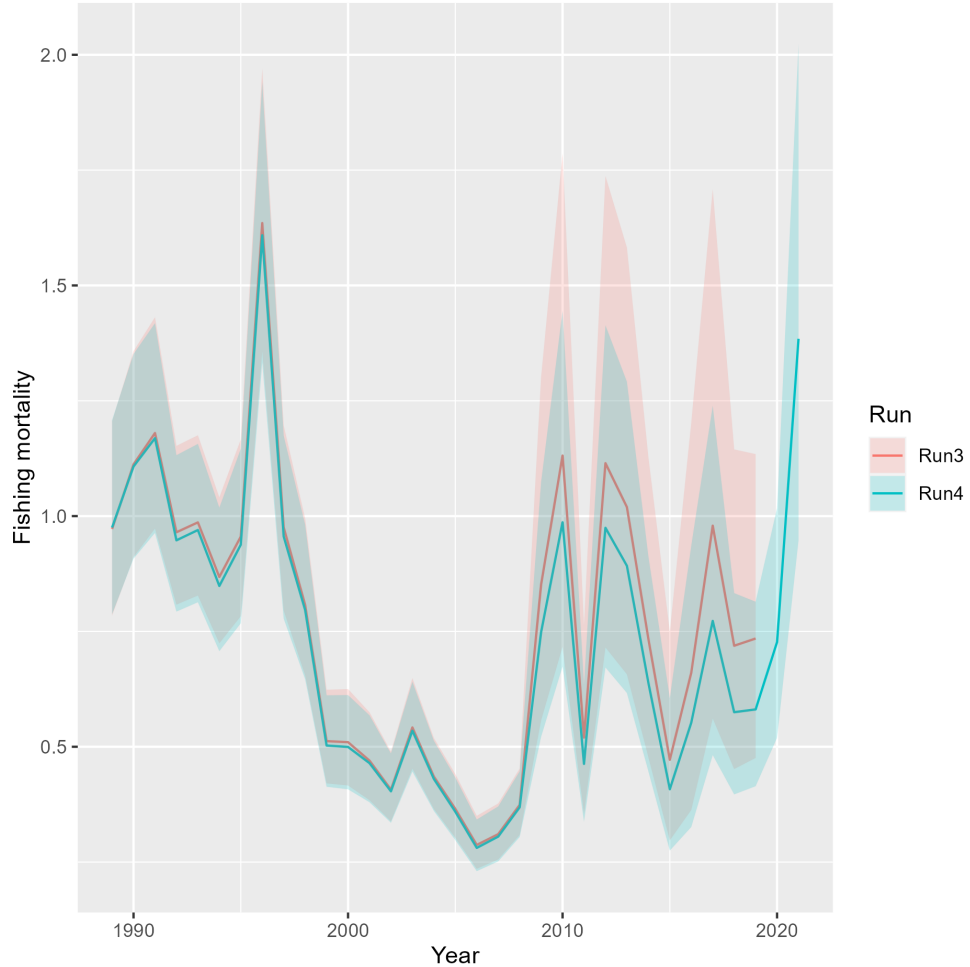
Bridge runs 3 and 4



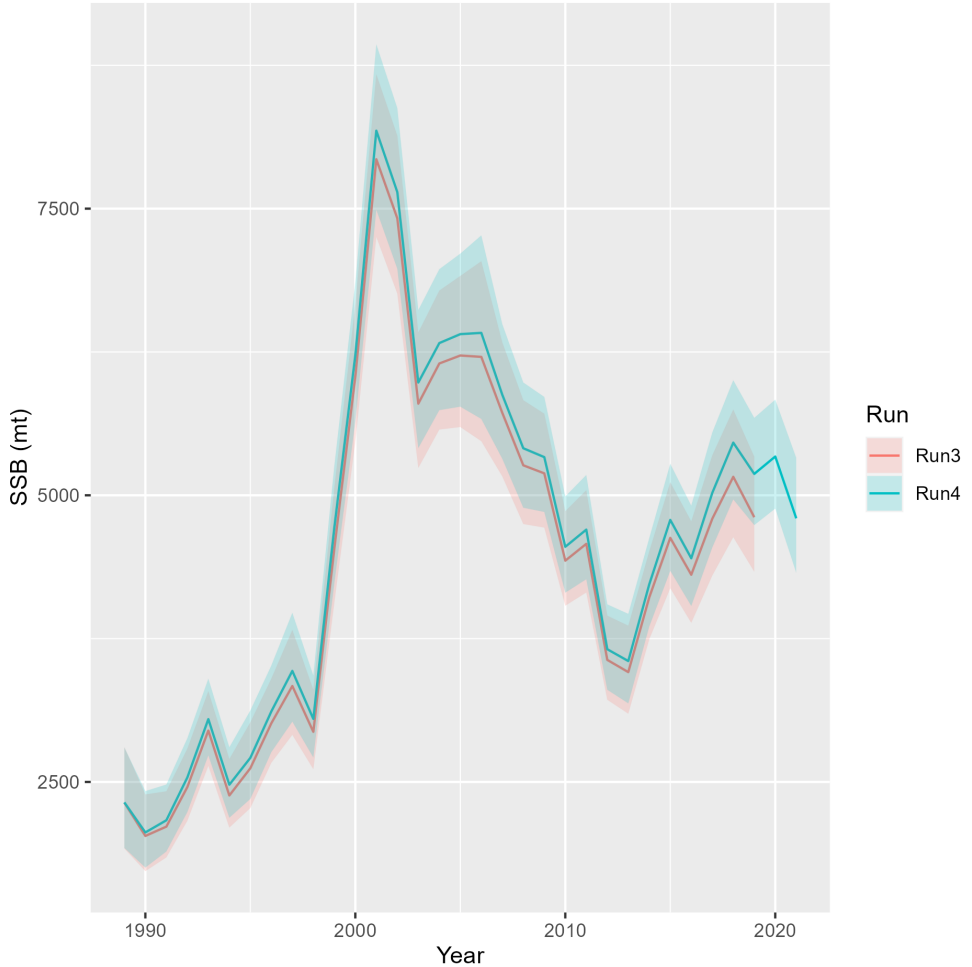
North



South

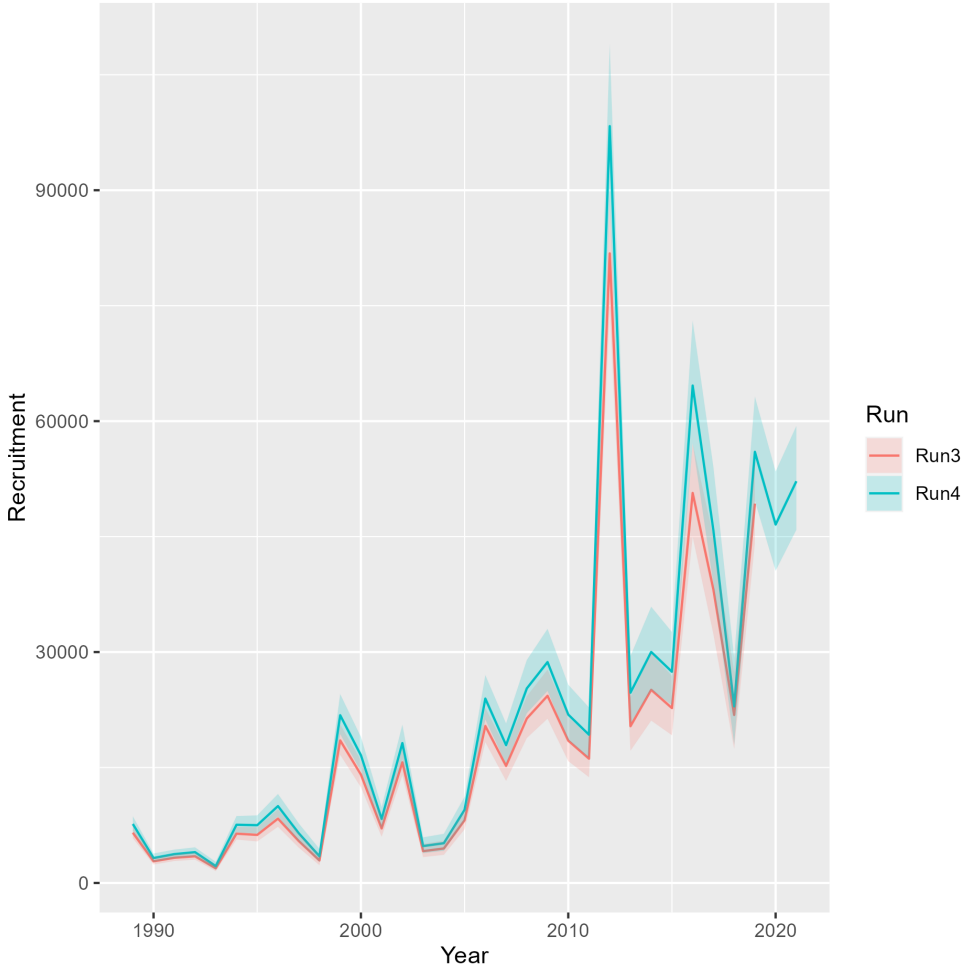
Bridge runs 3 and 4

North

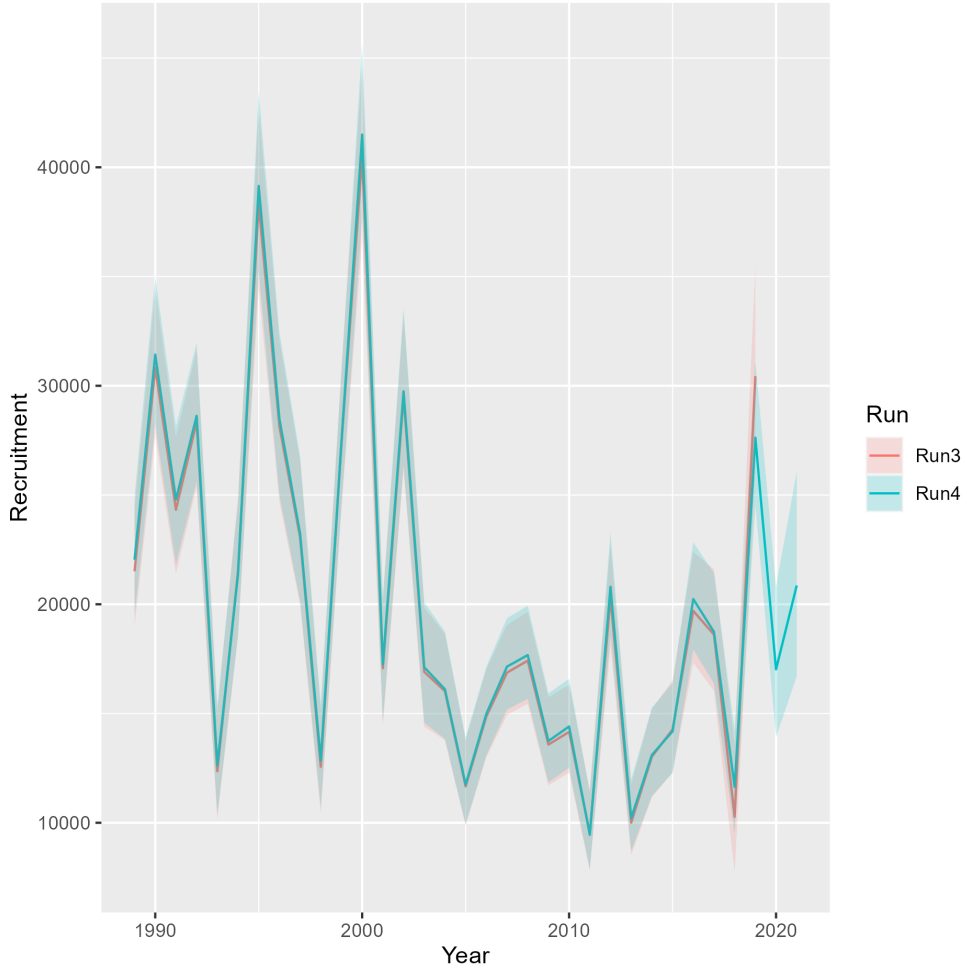


South

Bridge runs 3 and 4



North



South

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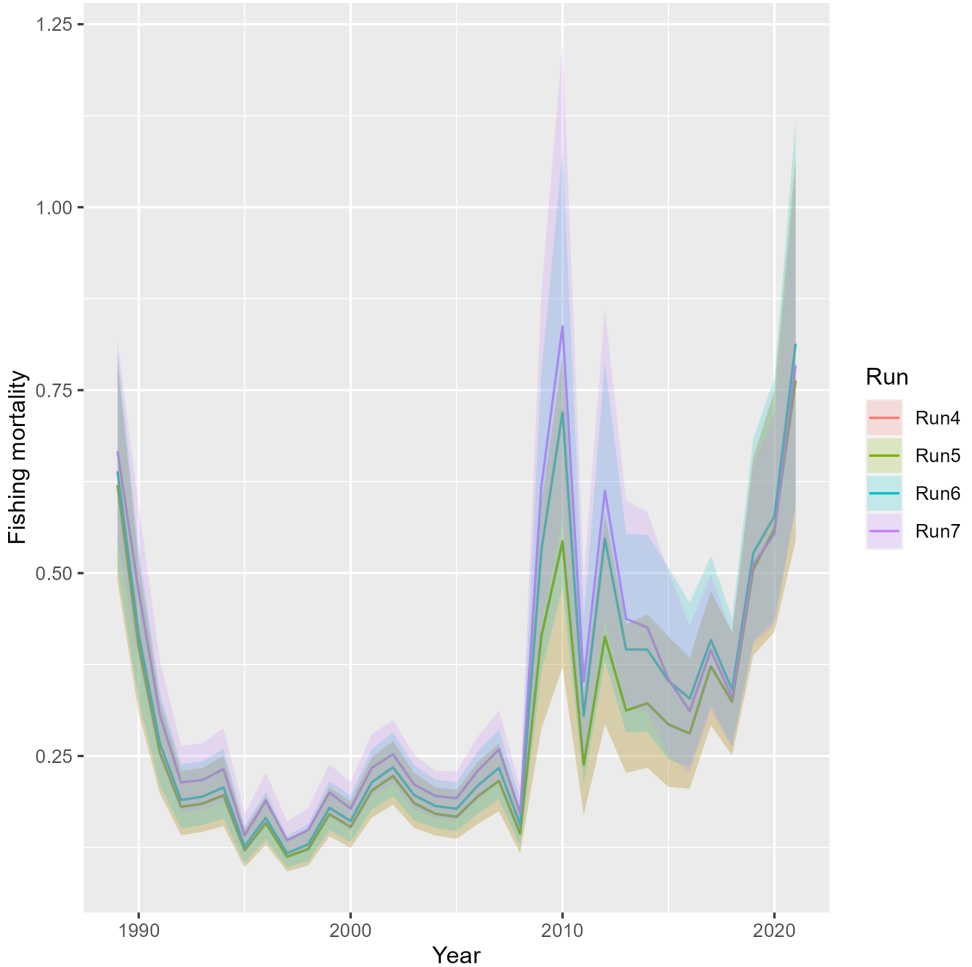
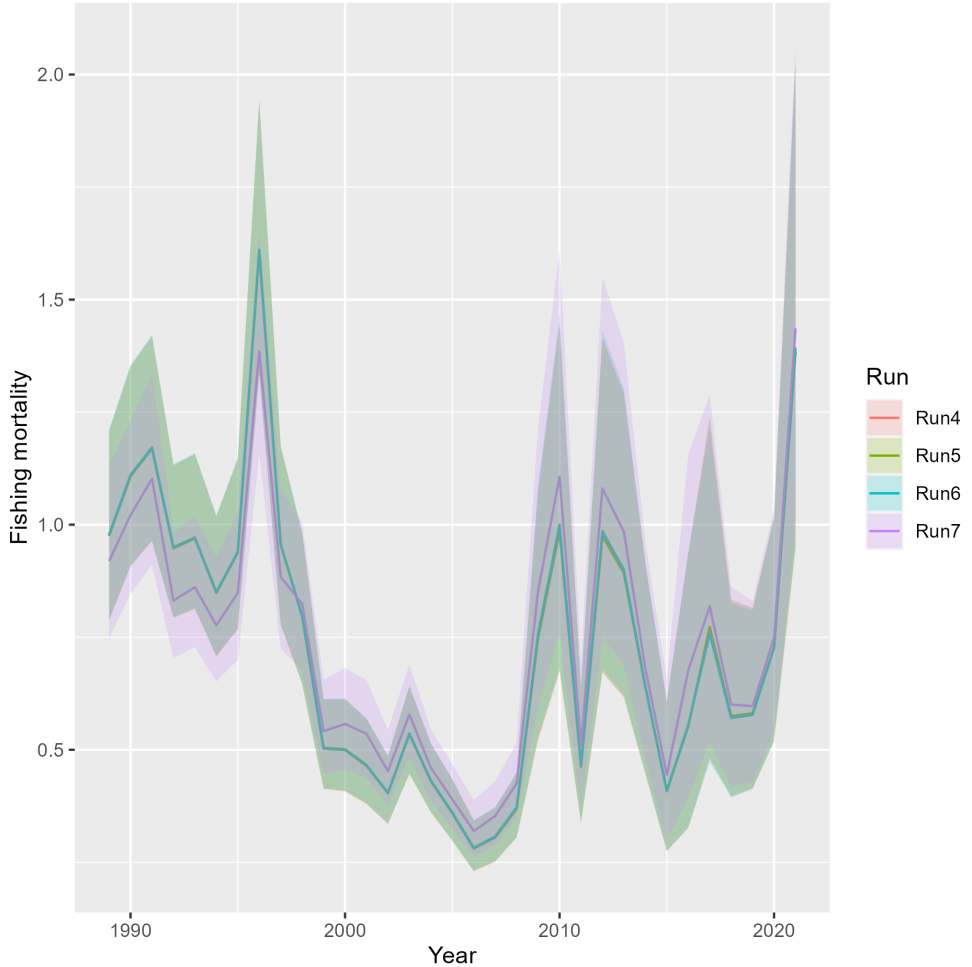
Bridge runs 4, 5, 6, and 7

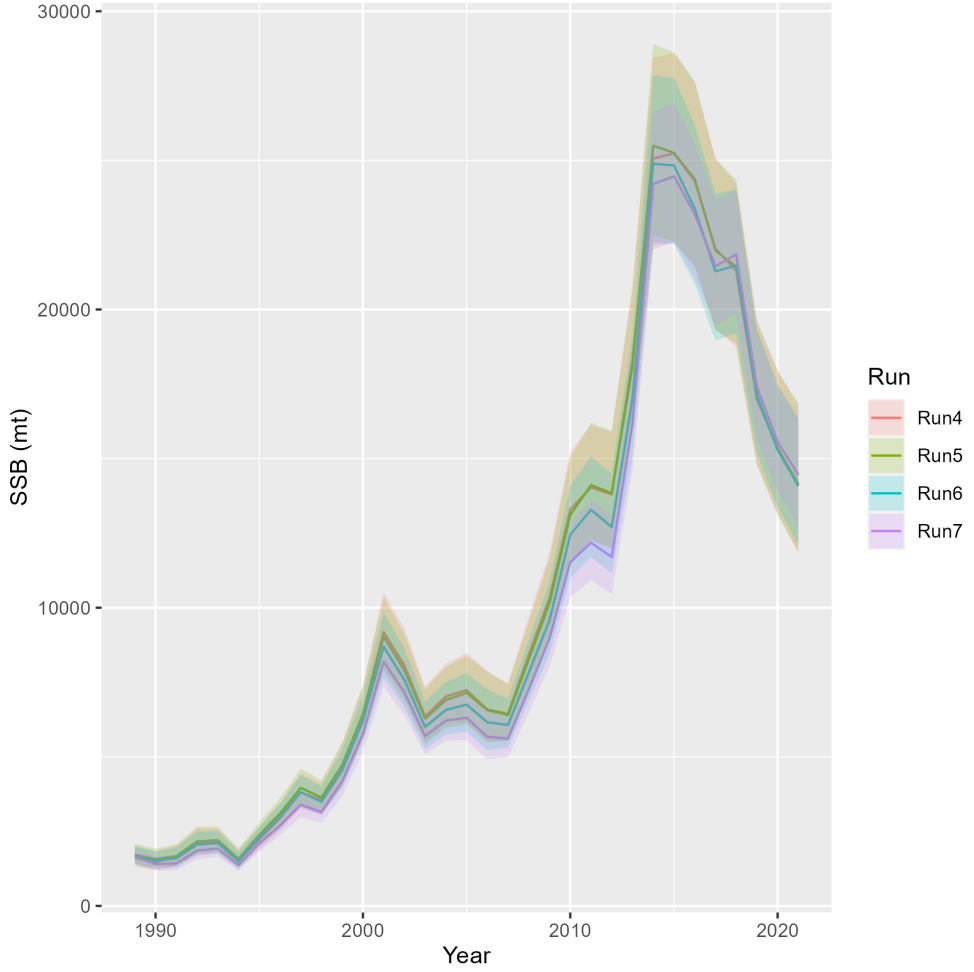


North

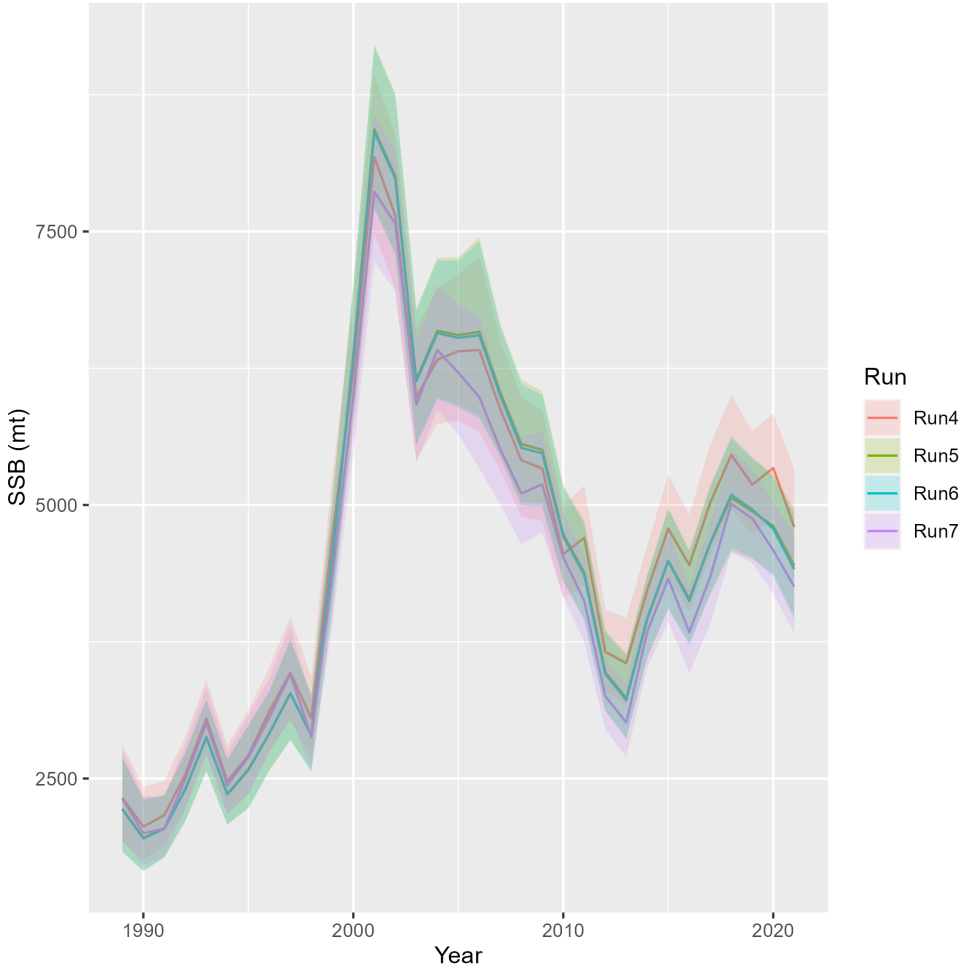


South

Bridge runs 4, 5, 6, and 7

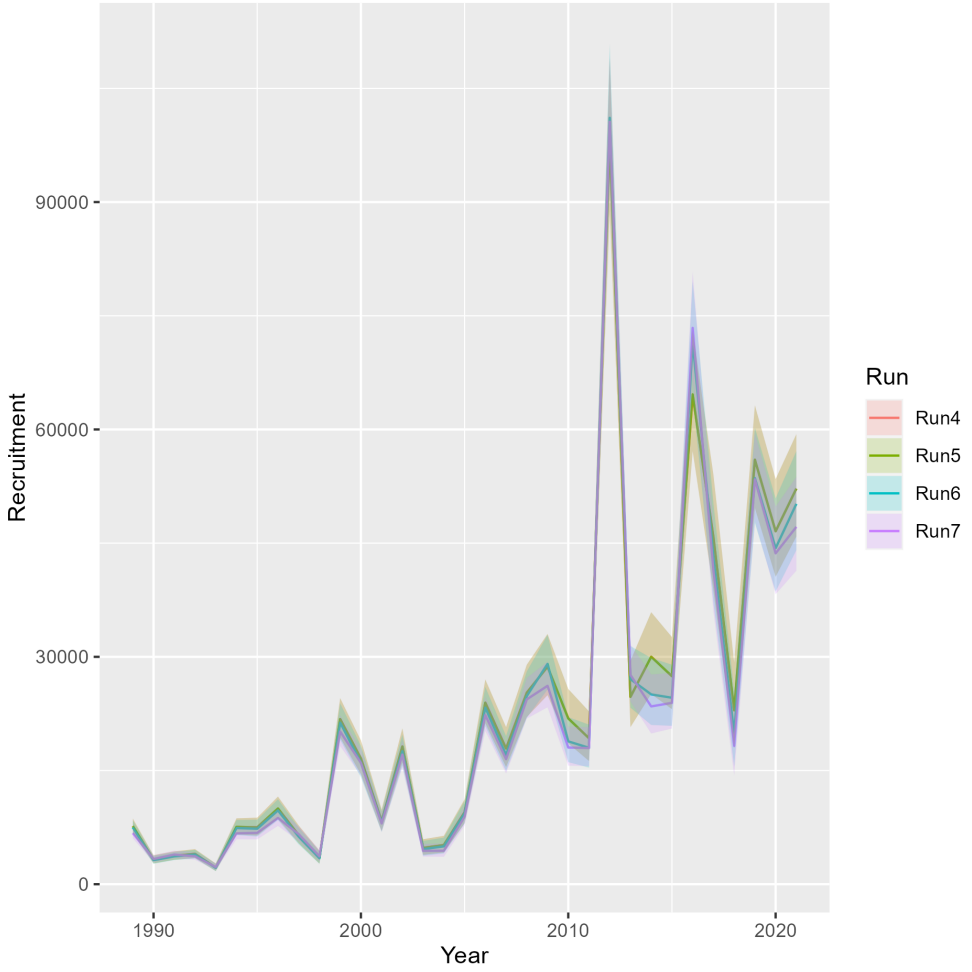


North

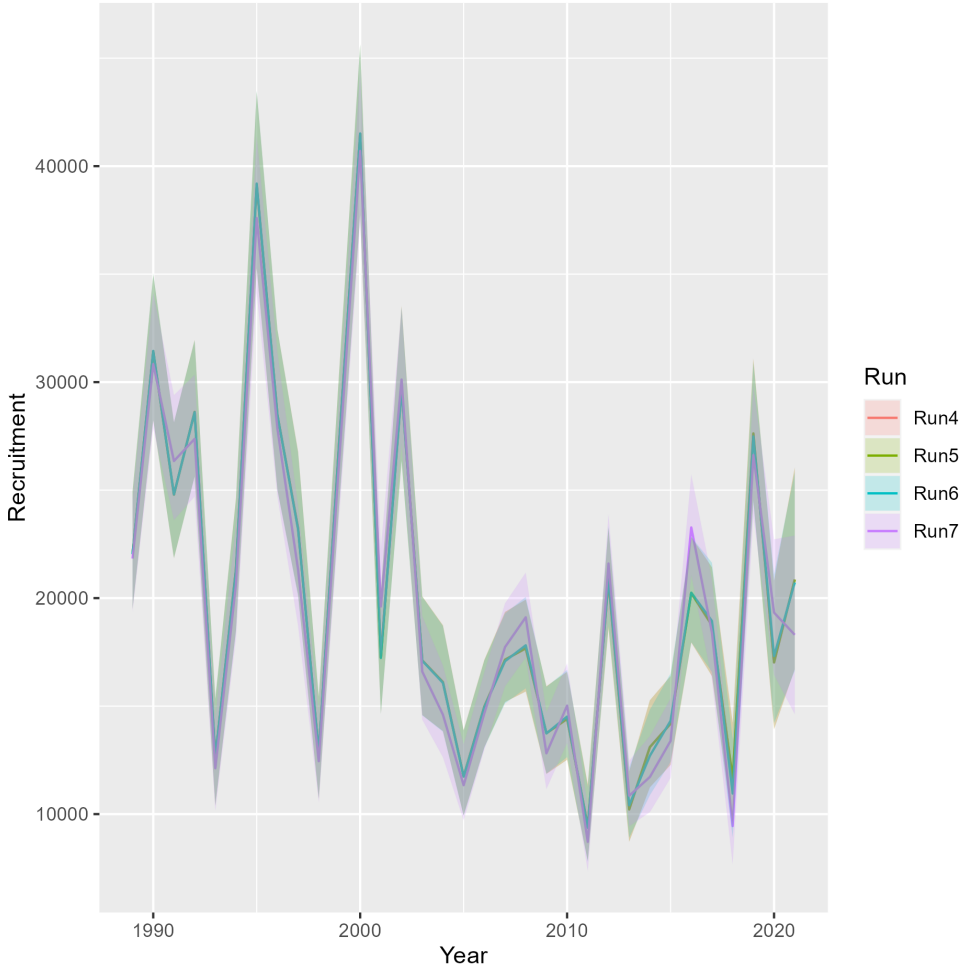


South

Bridge runs 4, 5, 6, and 7



North



South

Bridge runs

Separate fits for north and south regions

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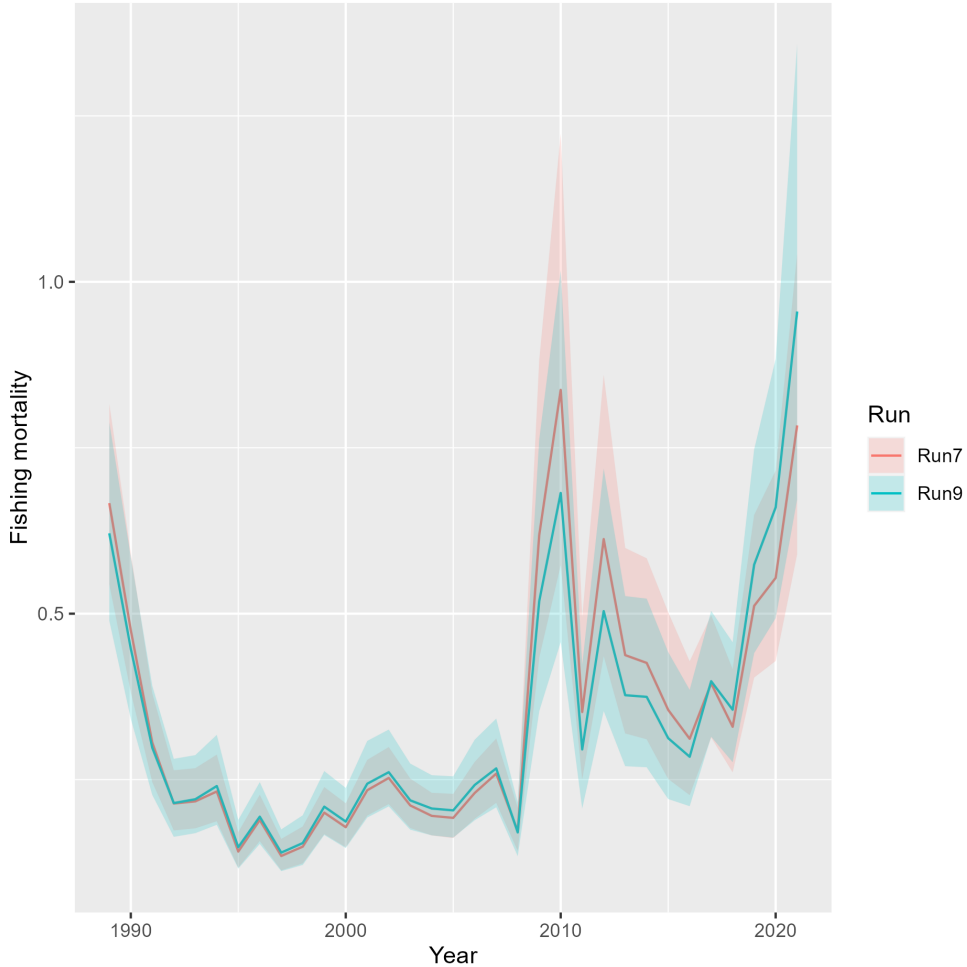
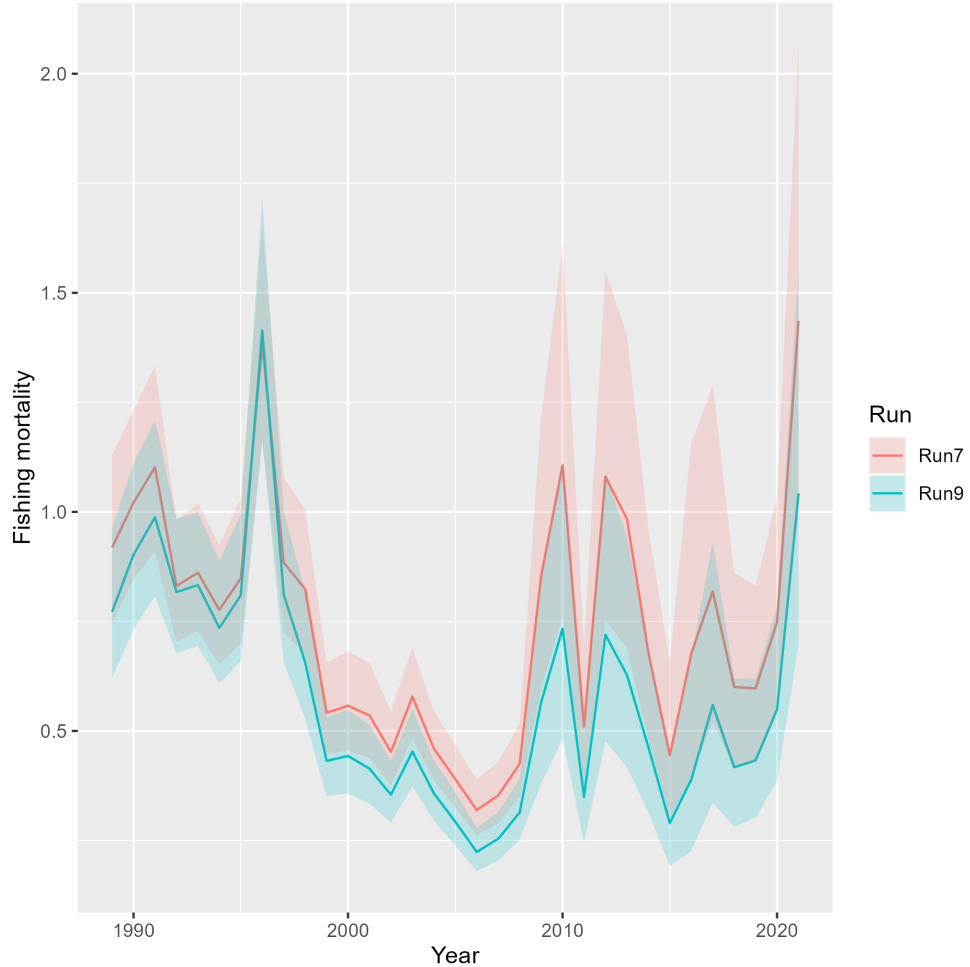
Bridge runs 7 and 9

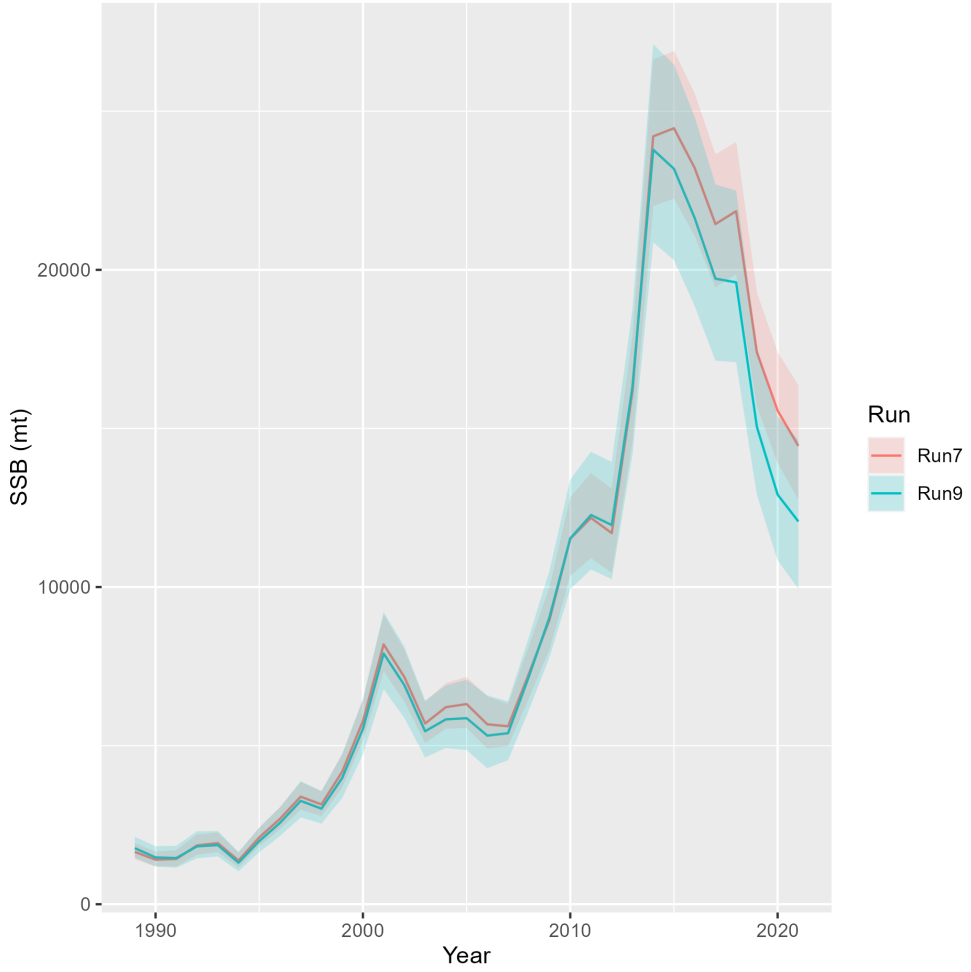


North



South

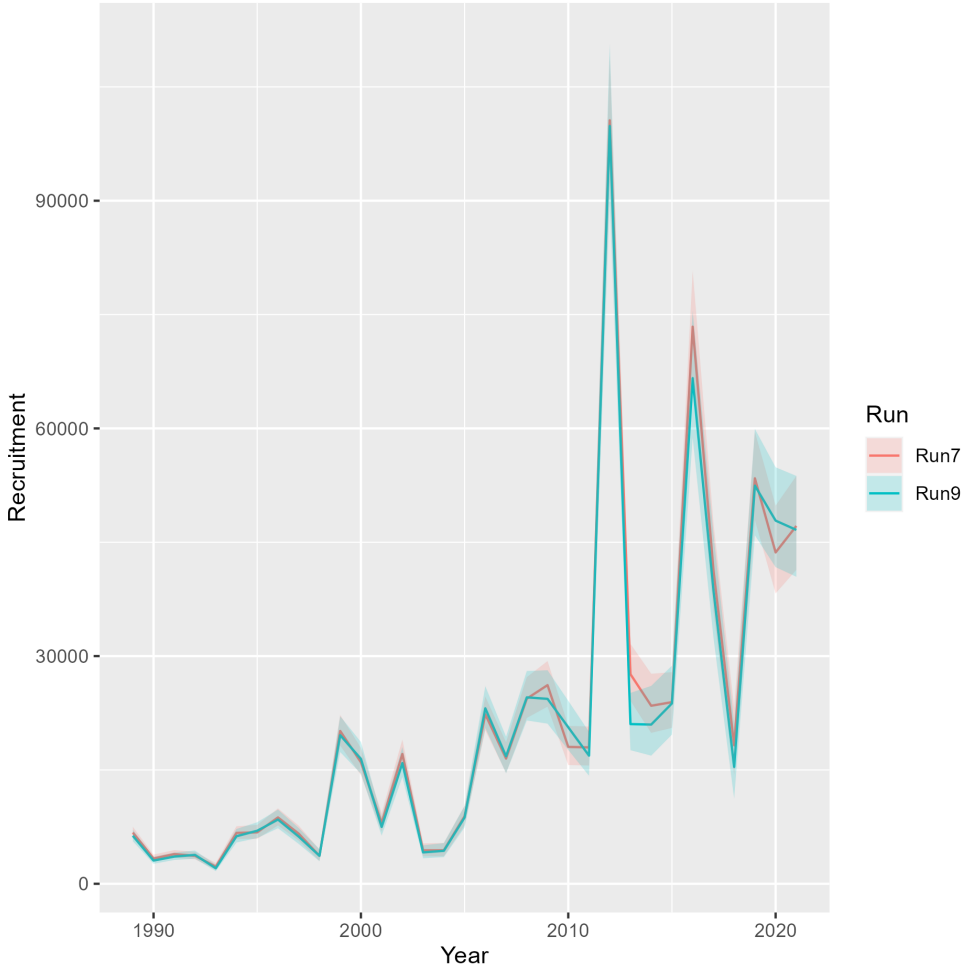
Bridge runs 7 and 9



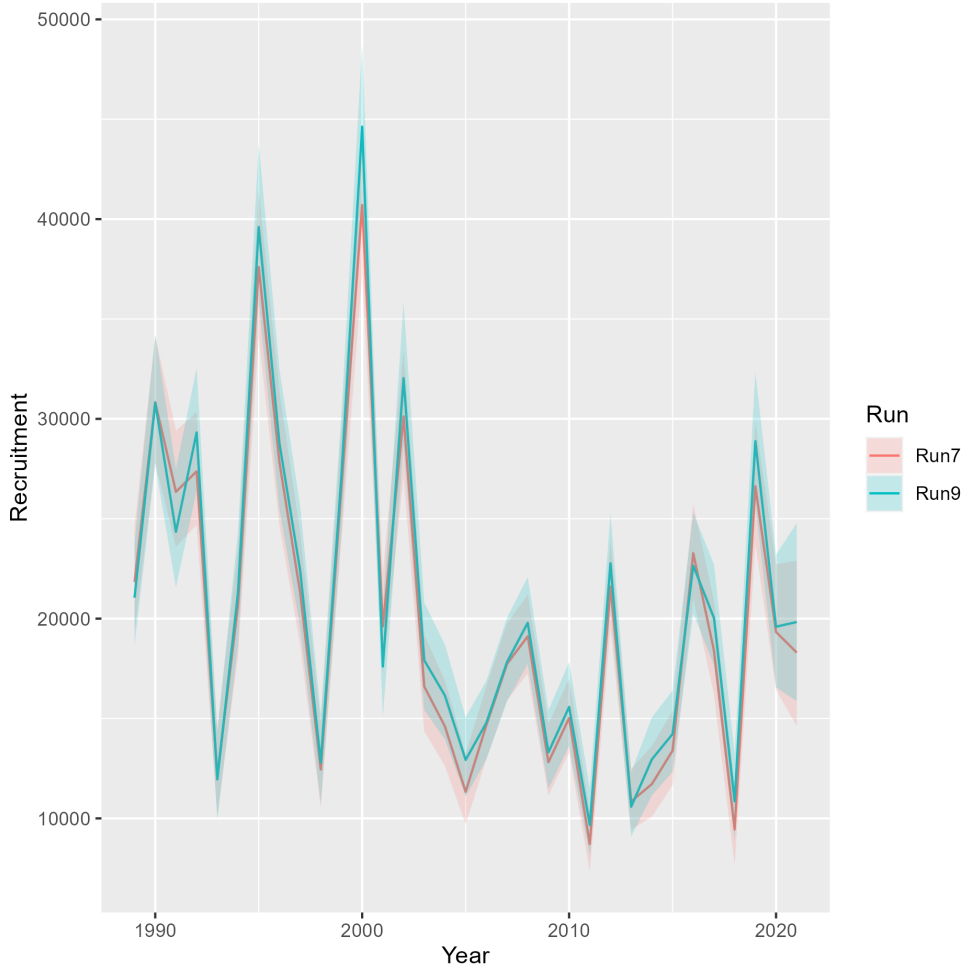
North

South

Bridge runs 7 and 9

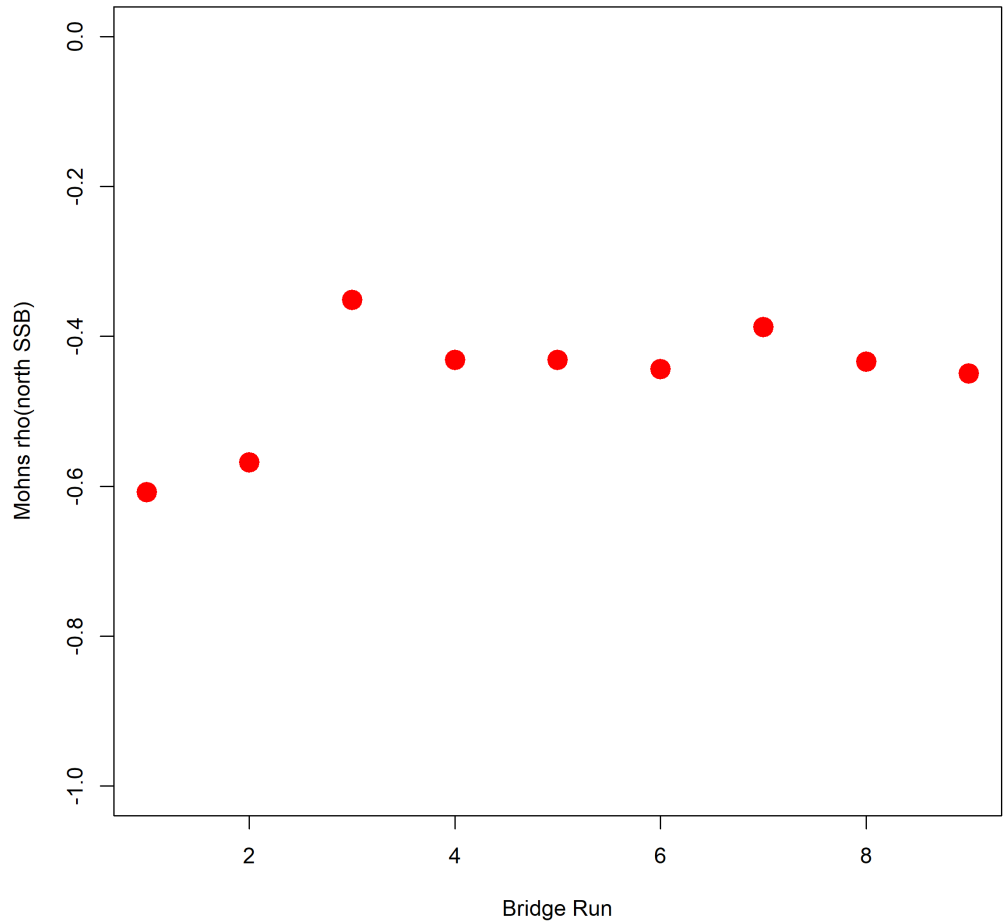


North



South

Retrospective patterns for north remained



Early research track runs (1-18)

- See table in the working paper
- Used updated and new observations
- **included random effects on recruitment and survival/movement transitions of older ages**
  - **random effects for the transitions was a minimum requirement to remove retro for northern component**
- 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.**

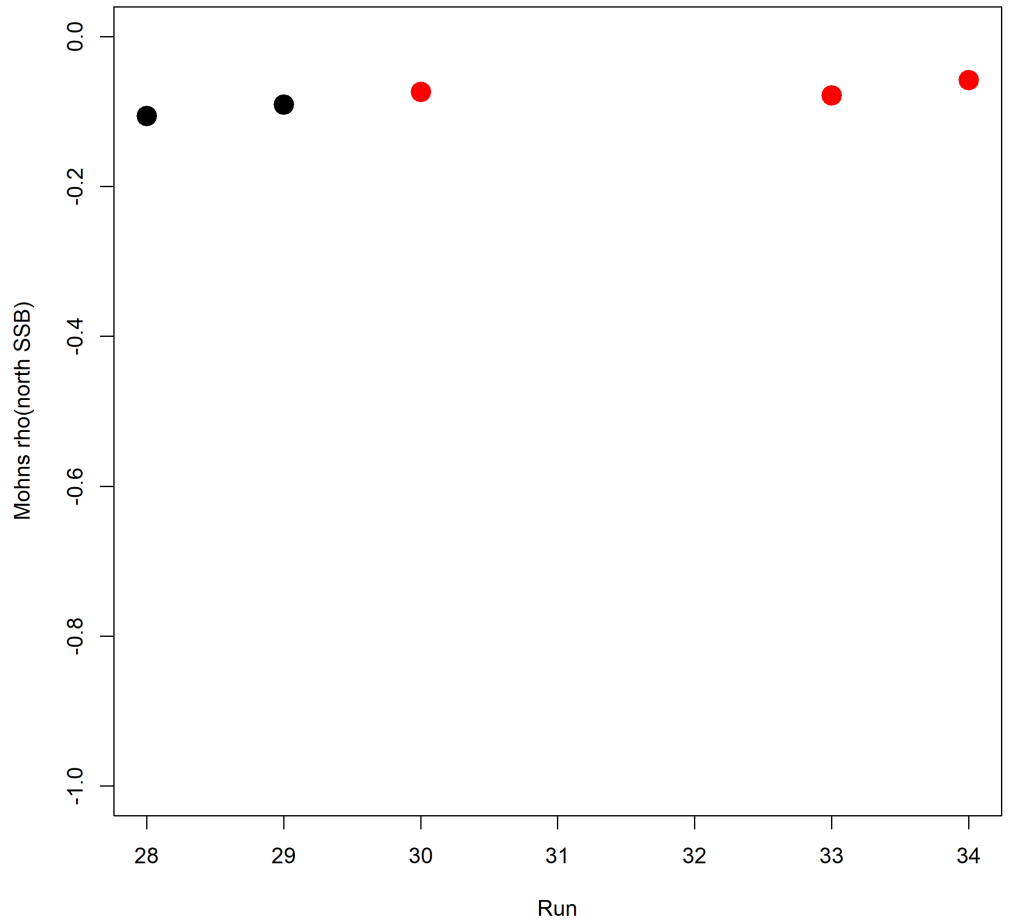
Middle runs (19-27)

- 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.

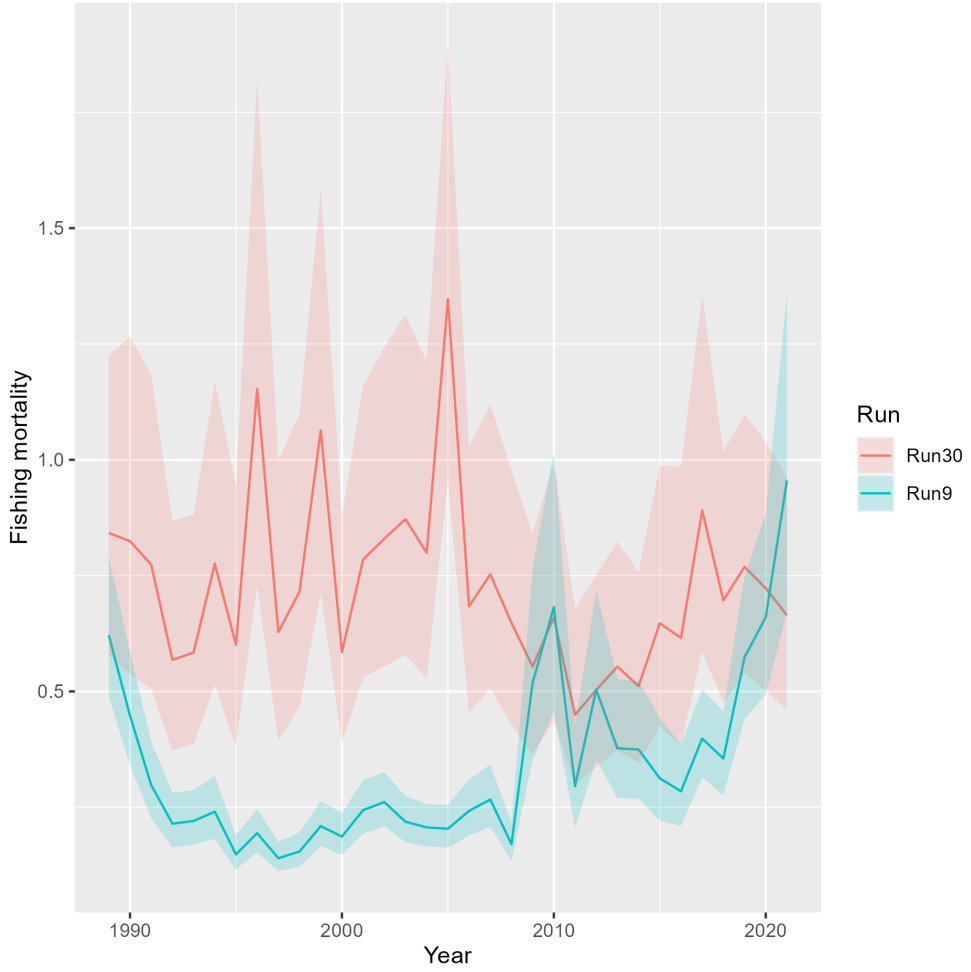
Late runs (28-34)

- 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 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.

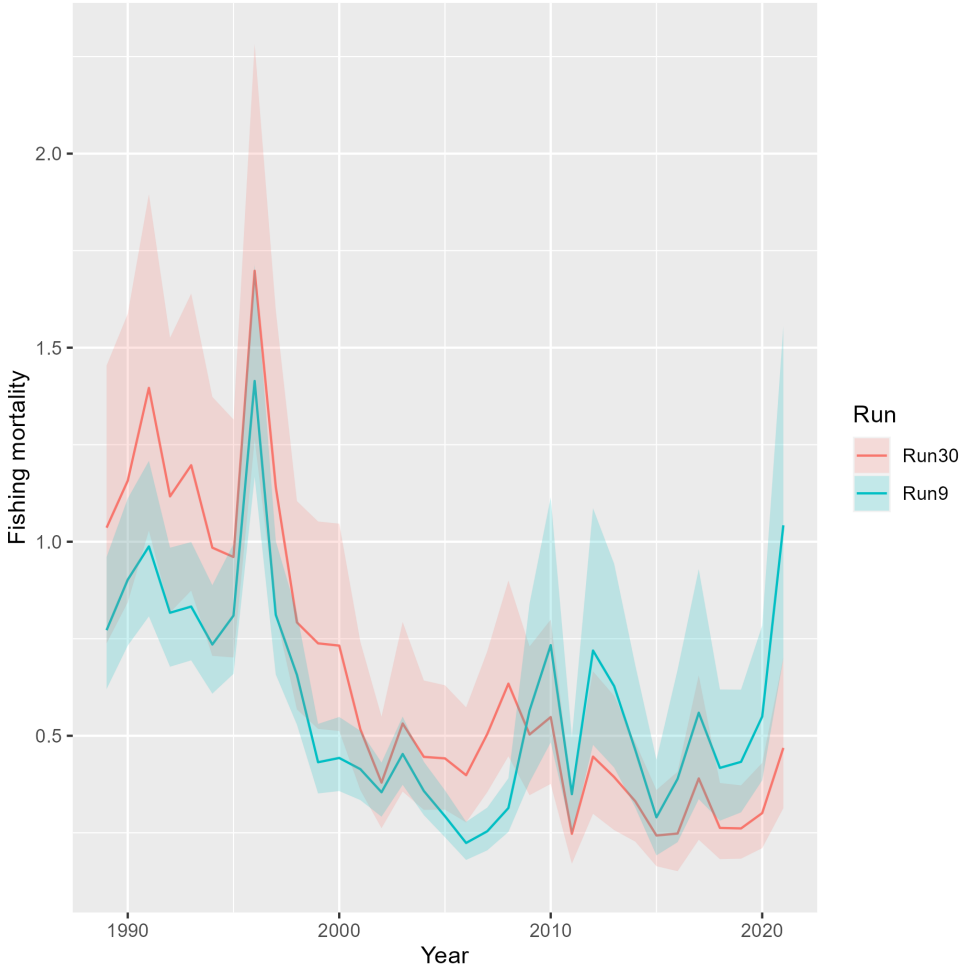
North Retros patterns neglibile



Bridge run 9 and RT run 30

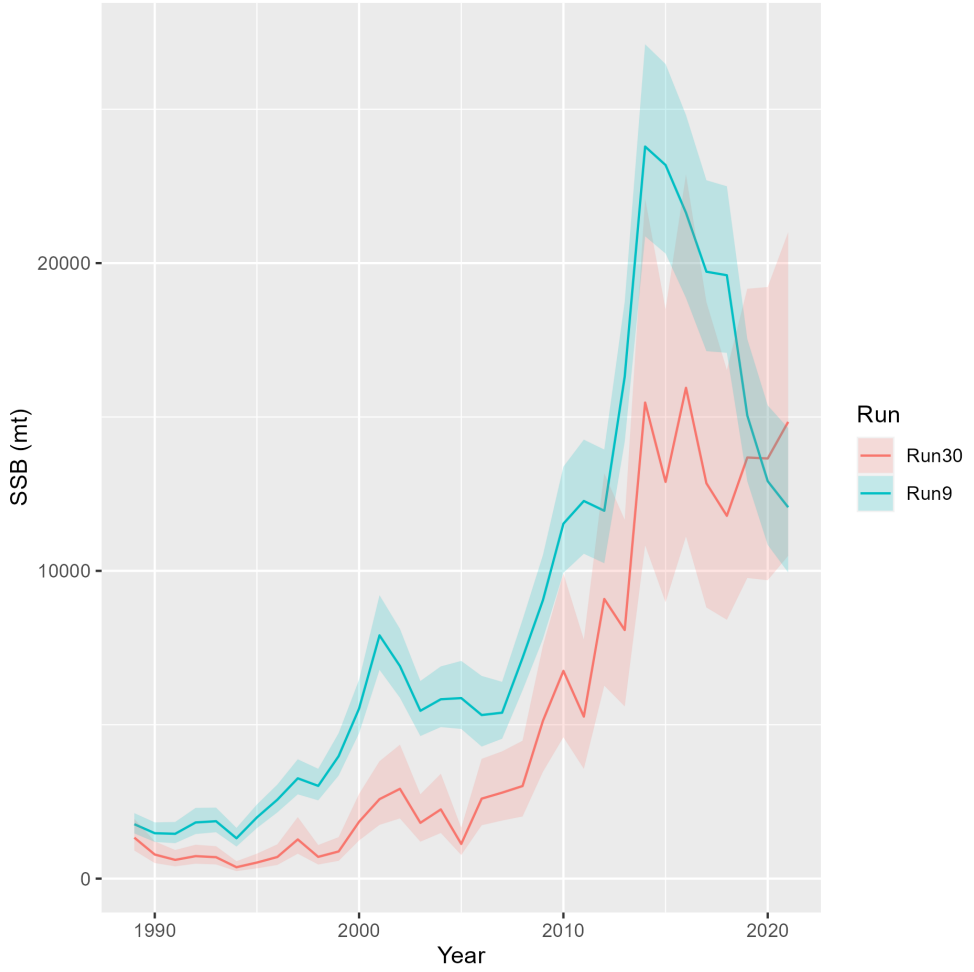


North

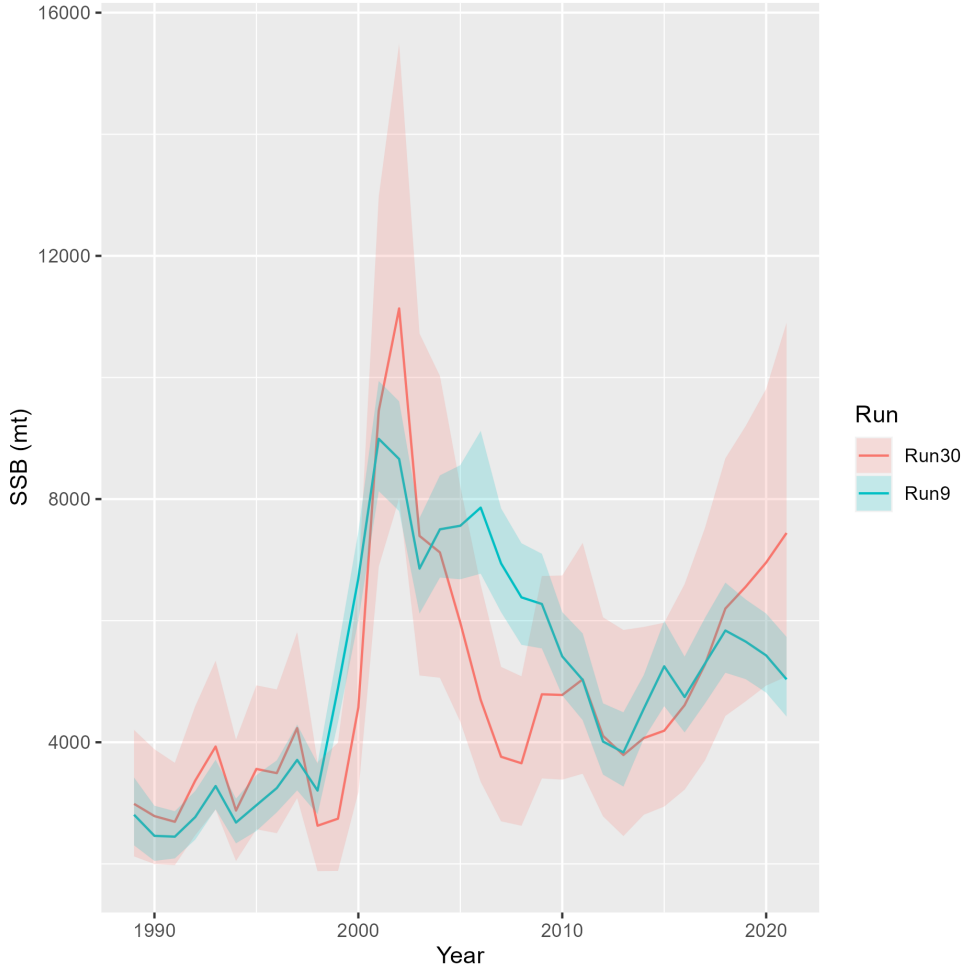


South

Bridge run 9 and RT run 30

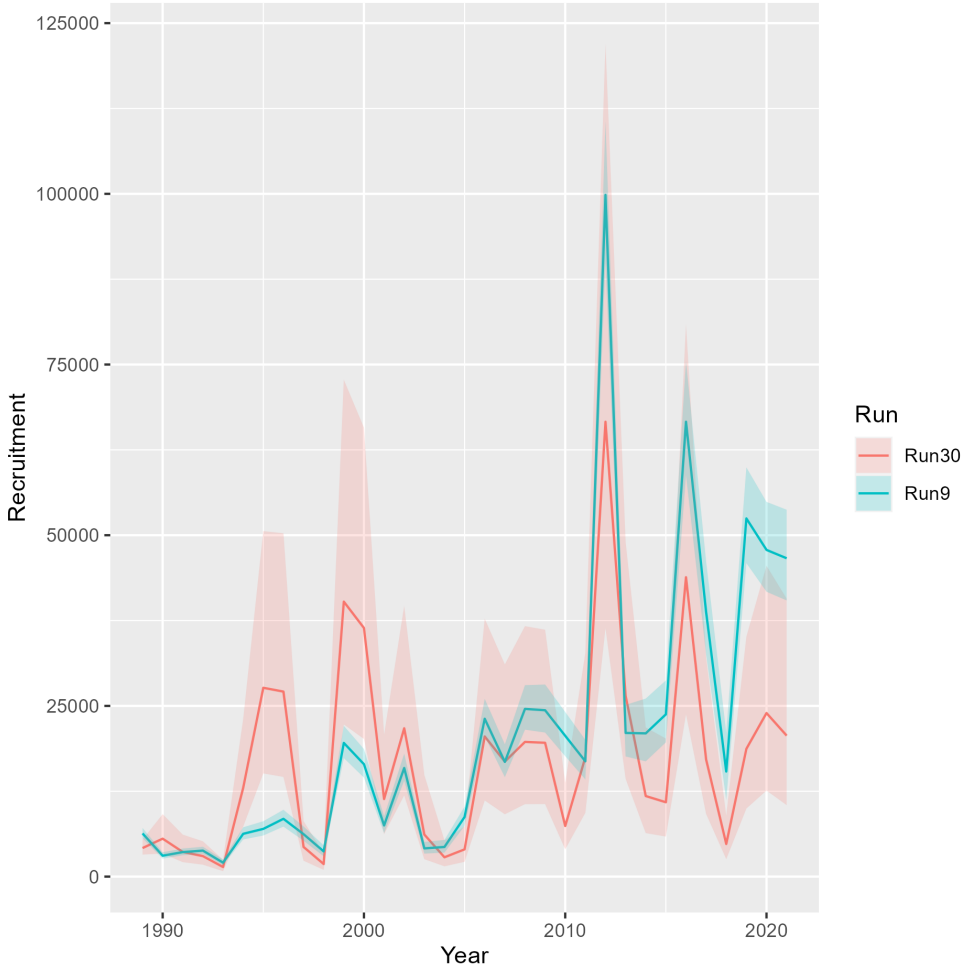


North

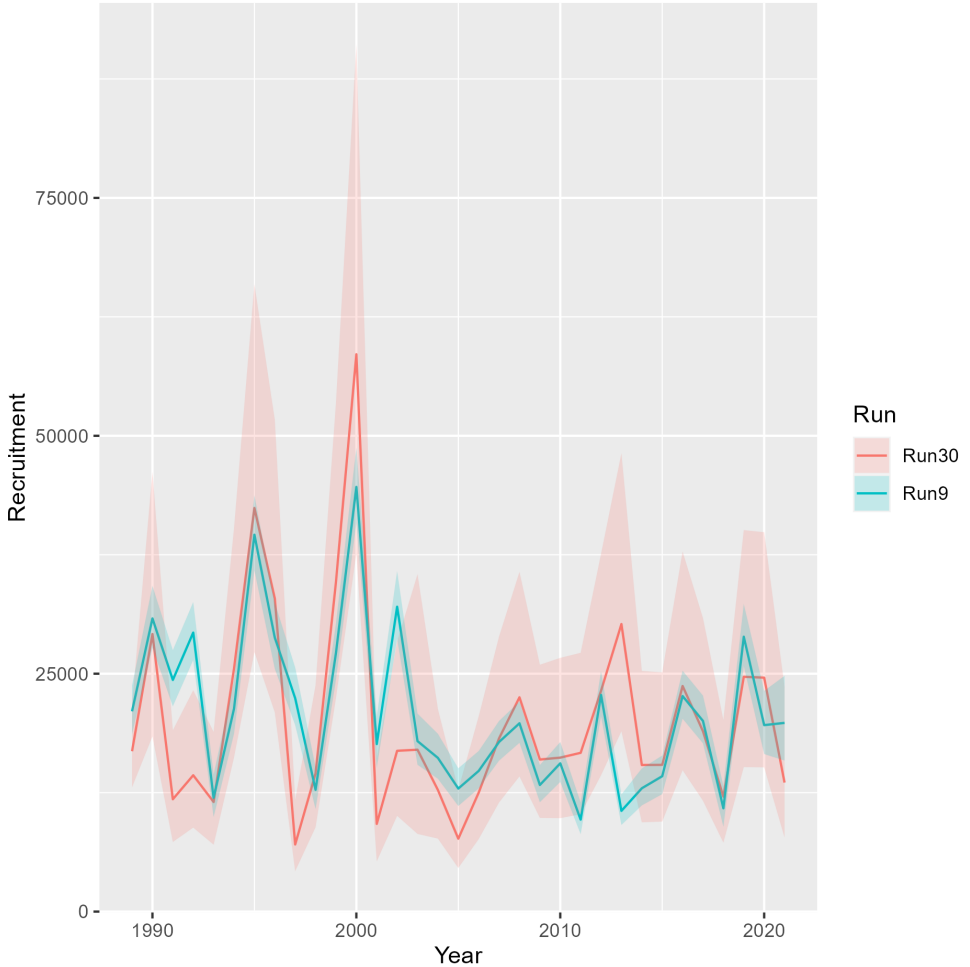


South

Bridge run 9 and RT run 30



North



South

Evidence for bottom temperature effects on recruitment

	AIC	North `$\widehat{\sigma}_R$`
No effect	-1551.79	0.92
North temperature effect only	-1562.14	0.74
Both temperature effects	-1561.61	0.74

Peel	No effect	North only	North and South
0	10.35	0.00	0.53
1	10.17	0.00	0.38
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

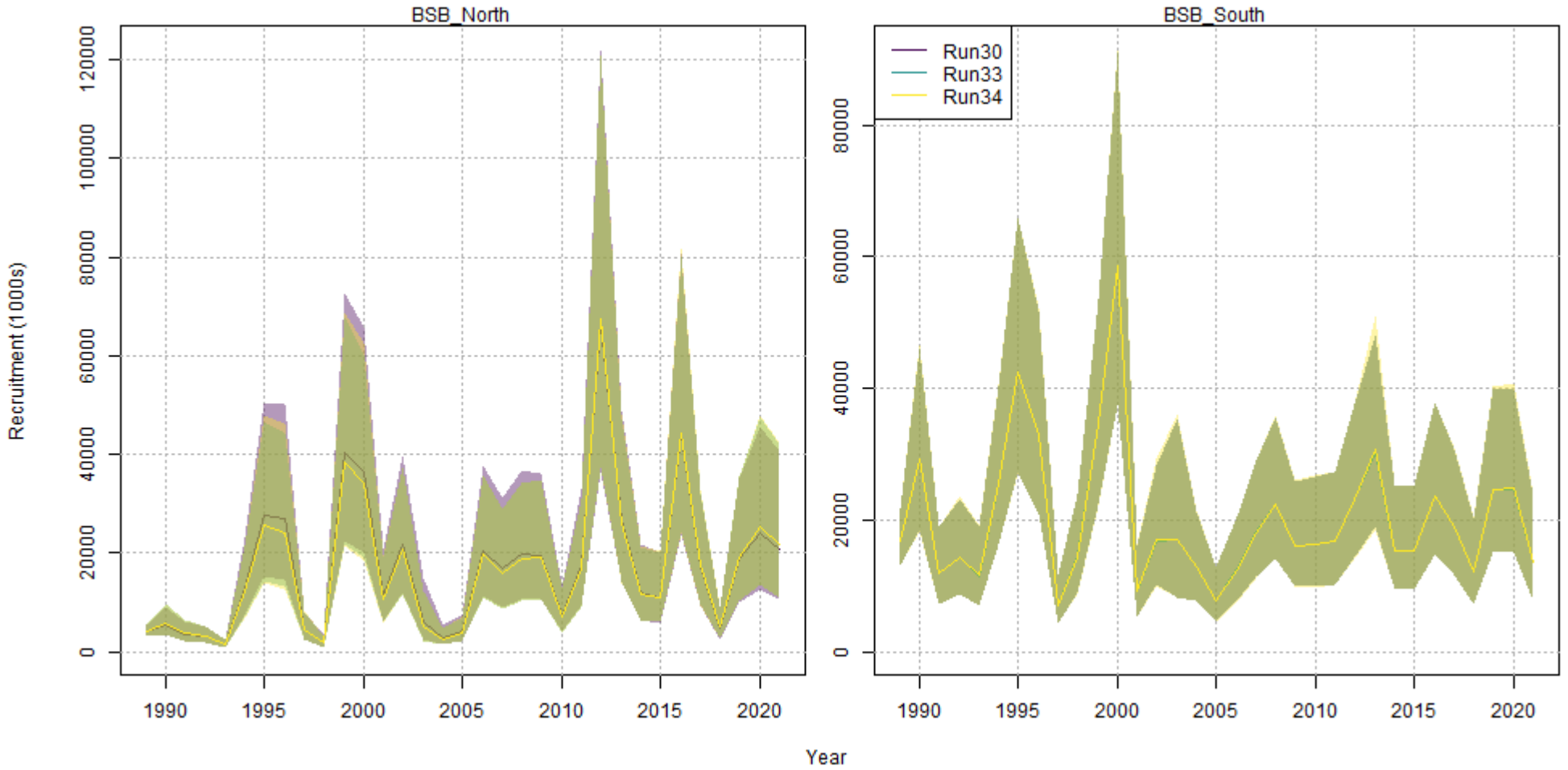
Comparison of Runs 30, 33 and 34

- 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

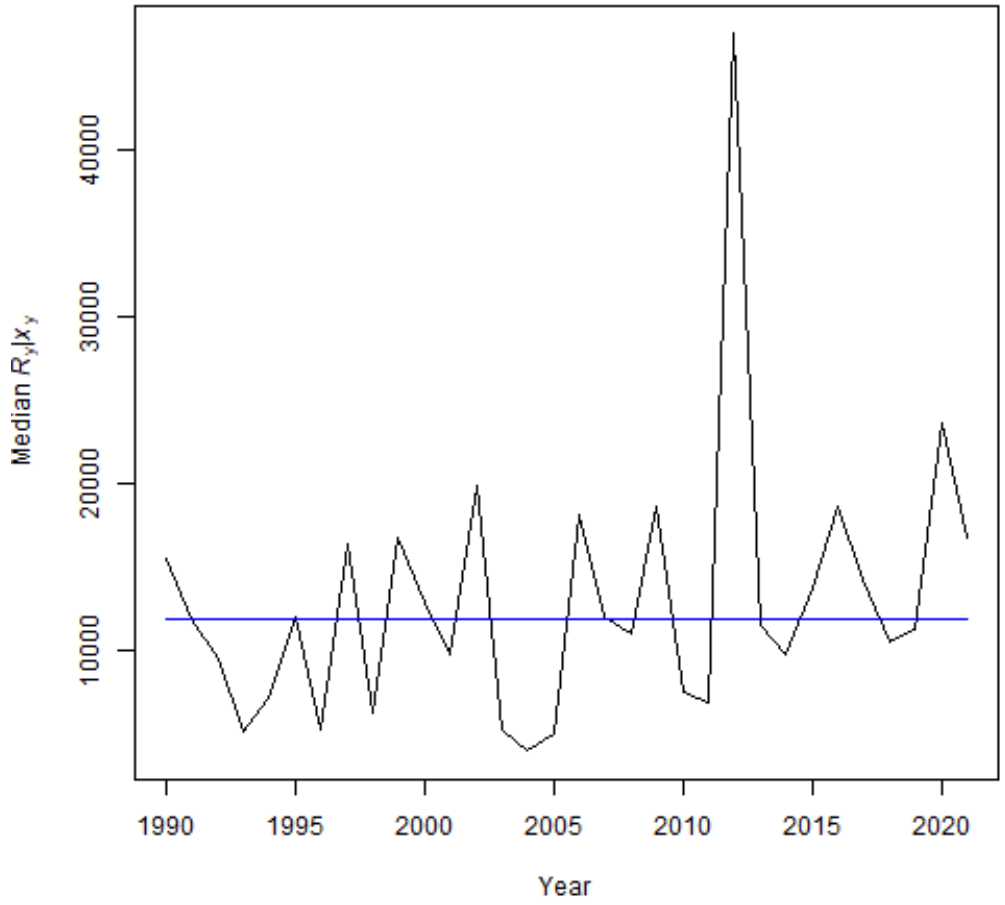
Comparison of Runs 30, 33 and 34: SSB

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 (SE_1) and without (SE_2) the scalar of the Recreational CPA index standard errors estimated.