NOAA FISHERIES

Biological reference points and projections

Black sea bass Research Track

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Outline

- General description of reference points in multi-stock extension of WHAM (TOR 5)
- BRPs for black sea bass application (TOR 5)
- Description of projections
- Example 3 year projection for black sea bass

Equilibrium SSB per recruit calculations

The $n_r \times n_r$ matrix of equilibrium spawning stock biomass per recruit for stock s in region r' (columns) given recruiting in region r (rows) as a function of a fully-selected F, $\widetilde{F}$, is defined as

$$\widetilde{\mathbf{O}}_s\left(\widetilde{F}\right) = \sum_{a=1}^{A} \mathbf{O}_{s,a}\left(\widetilde{F}\right) \mathbf{O}_{s,a}\left(\widetilde{F}, \delta_s\right) \operatorname{diag}\left(\mathbf{f}_{s,a}\right)$$

where $\mathbf{O}_{s,a}(\widetilde{F}, \delta_s)$ is $n_r \times n_r$ is the matrix of probabilities of surviving and occurring in region r' at age $a + \delta_s$ given starting in region r at age a. It is the upper left sub-matrix of the probability transition matrix defined over the same interval. Similarly,

$$\mathbf{O}_{s,a}\left(\widetilde{F}\right) = \begin{cases} \prod_{i=0}^{a-1} \mathbf{O}_{s,i}\left(\widetilde{F}\right) & 1 \leq a < A \\ \left[\prod_{i=0}^{a-1} \mathbf{O}_{s,i}\left(\widetilde{F}\right)\right] \mathbf{O}_{s,+}\left(\widetilde{F}\right) & a = A \end{cases}$$

is the upper left sub-matrix of the probability transition matrix of states at age a (columns) given being in each state (rows) at recruitment (age 1) where $\mathbf{O}_{s,0} = \mathbf{I}$. For the plus group $a = A$, $\mathbf{O}_{s,+} = \left(\mathbf{I} - \mathbf{O}_{s,A}\right)^{-1}$. $\mathbf{f}_{s,a}$ is the vector of fecundities (product of weight and maturity) at age a in each region.

Equilibrium Yield per recruit calculations

The matrix of equilibrium yield per recruit in each fleet (columns) as a function of $\widetilde{F}$ given recruiting in a given region (rows) is calculated as

$$\widetilde{\mathbf{Y}}_s\left(\widetilde{F}\right) = \sum_{a=1}^{A} \mathbf{O}_{s,a}\left(\widetilde{F}\right) \mathbf{H}_{s,a}\left(\widetilde{F}\right) \operatorname{diag}\left(\mathbf{c}_{s,a}\right)$$

where $\mathbf{c}_a$ is the vector of catch weight at age for each fleet, and $\mathbf{H}_{s,a}$ is the submatrix of $\mathbf{P}_{s,a}$ with the probabilities of being captured in each fleet over the interval from a to $a+1$.

- Currently, the model cannot distinguish catch weight at age by stock.
  - An empirical catch weight at age for the combined capture of all stocks is used.

Combining SSB/R across stocks to determine F_{40}

- To find F_{40}, we use a weighted average of stock-specific components of spawning biomass per recruit as a function of fully-selected F:

$$\widetilde{\mathcal{S}}\left(\widetilde{F}\right) = \sum_{i=1}^{n_S} \omega_i \widetilde{\mathbf{O}}_i \left(\widetilde{F}, r = r(s_i), r' = r(s_i)\right)$$

- weights can be user-specified or as a function of average recruitment for the different stocks:

$$\omega_i = \frac{\overline{R}_i}{\sum_{i=1}^{n_S} \overline{R}_i}$$

- F_{40} is the value $\widetilde{F}^*$ such that

$$\widetilde{\mathcal{S}}\left(\widetilde{F}^*\right) = 0.4\widetilde{\mathcal{S}}\left(\widetilde{F} = 0\right)$$

- Same Newton methods as the standard WHAM package are used to solve for F_{40} internally
  - Internal calculations allow propagation of parameter uncertainty into that of the reference points.

SSB and Yield at F_{40}

- An average recruitment is multiplied with SSB/R and Y/R for stock i

$$\widetilde{\mathrm{SSB}}_i = \overline{R}_i \widetilde{\mathbf{O}}_i \left(\widetilde{F}, r = r(s_i), r' = r(s_i) \right)$$

- For yield from stock i in fleet f:

$$\widetilde{Y}_{i,f} = \overline{R}_i \widetilde{\mathbf{Y}}_i \left(\widetilde{F}, r = r(s_i), f \right)$$

- The total yield for fleet f is just the sum across stocks:

$$\widetilde{Y}_f = \sum_{i=1}^{n_S} \widetilde{Y}_{i,f}$$

- User specifies the years to include for $\overline{R}_i$
  - We used years 2000-2021 for black sea bass as in previous assessments.

Average FAA for black sea bass BRPs

- All inputs to SSB/R and YPR/R are averaged over last five years
- FAA is averaged by fleet

	1	2	3	4	5	6	7	8+
North_Commercial	0.01	0.04	0.09	0.17	0.17	0.17	0.17	0.17
North_Recreational	0.01	0.09	0.10	0.15	0.26	0.40	0.56	0.56
South_Commercial	0.00	0.02	0.06	0.07	0.07	0.07	0.07	0.07
South_Recreational	0.03	0.08	0.15	0.21	0.25	0.26	0.26	0.26

Selectivity for black sea bass BRPs

- Average fishing mortality at age and fleet is divided by the maximum of the total average FAA.

1	2	3	4	5	6	7	8+
0.05	0.23	0.4	0.61	0.76	0.91	1.07	1.07

	1	2	3	4	5	6	7	8+
North_Commercial	0.01	0.04	0.08	0.16	0.16	0.16	0.16	0.16
North_Recreational	0.01	0.08	0.09	0.14	0.25	0.38	0.52	0.52
South_Commercial	0.00	0.02	0.06	0.07	0.07	0.07	0.07	0.07
South_Recreational	0.03	0.07	0.14	0.20	0.23	0.24	0.25	0.25

Weight at age for black sea bass BRPs

- Weight at age for SSB and fleets are averaged over last 5 years

	1	2	3	4	5	6	7	8+
BSB_North	0.11	0.20	0.37	0.54	0.75	0.99	1.19	1.53
BSB_South	0.09	0.19	0.35	0.48	0.63	0.81	0.93	1.50

	1	2	3	4	5	6	7	8+
North_Commercial	0.07	0.17	0.37	0.52	0.71	0.91	1.11	1.46
North_Recreational	0.11	0.20	0.37	0.54	0.75	0.99	1.19	1.53
South_Commercial	0.10	0.16	0.35	0.48	0.66	0.85	1.05	1.36
South_Recreational	0.09	0.19	0.35	0.48	0.63	0.81	0.93	1.50

Maturity, M, movement at age for black sea bass BRPs

	1	2	3	4	5	6	7	8+
BSB_North	0	0.48	0.98	1.00	1.00	1	1	1
BSB_South	0	0.34	0.82	0.98	0.97	1	1	1

	1	2	3	4	5	6	7	8+
BSB_North	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
BSB_South	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

	1	2	3	4	5	6	7	8+
North to South	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
South to North	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33

Unfished equlibrium survival for black sea bass BRPs (North)

$$\mathbf{O}_{s,a}\left(\widetilde{F}=0\right)$$

Recruits

	North	South
North	1	0
South	0	1

Age 2

	North	South
North	0.64	0.03
South	0.64	0.03

Age 3

	North	South
North	0.43	0.02
South	0.43	0.02

Age 4

	North	South
North	0.29	0.01
South	0.29	0.01

Unfished equlibrium survival for black sea bass BRPs (North)

$$\mathbf{O}_{s,a}\left(\widetilde{F}=0\right)$$

Age 5

	North	South
North	0.19	0.01
South	0.19	0.01

Age 6

	North	South
North	0.13	0.01
South	0.13	0.01

Age 7

	North	South
North	0.09	0
South	0.09	0

Age 8+

	North	South
North	0.18	0.01
South	0.18	0.01

Equlibrium survival at F_{40} for black sea bass BRPs (North)

Recruits

	North	South
North	1	0
South	0	1

Age 3

	North	South
North	0.37	0.02
South	0.37	0.02

Age 2

	North	South
North	0.63	0.03
South	0.63	0.03

Age 4

	North	South
North	0.21	0.01
South	0.21	0.01

Equlibrium survival at F_{40} for black sea bass BRPs (North)

$$\mathbf{O}_{s,a}\left(\widetilde{F}=0\right)$$

Age 5

	North	South
North	0.1	0
South	0.1	0

Age 6

	North	South
North	0.04	0
South	0.04	0

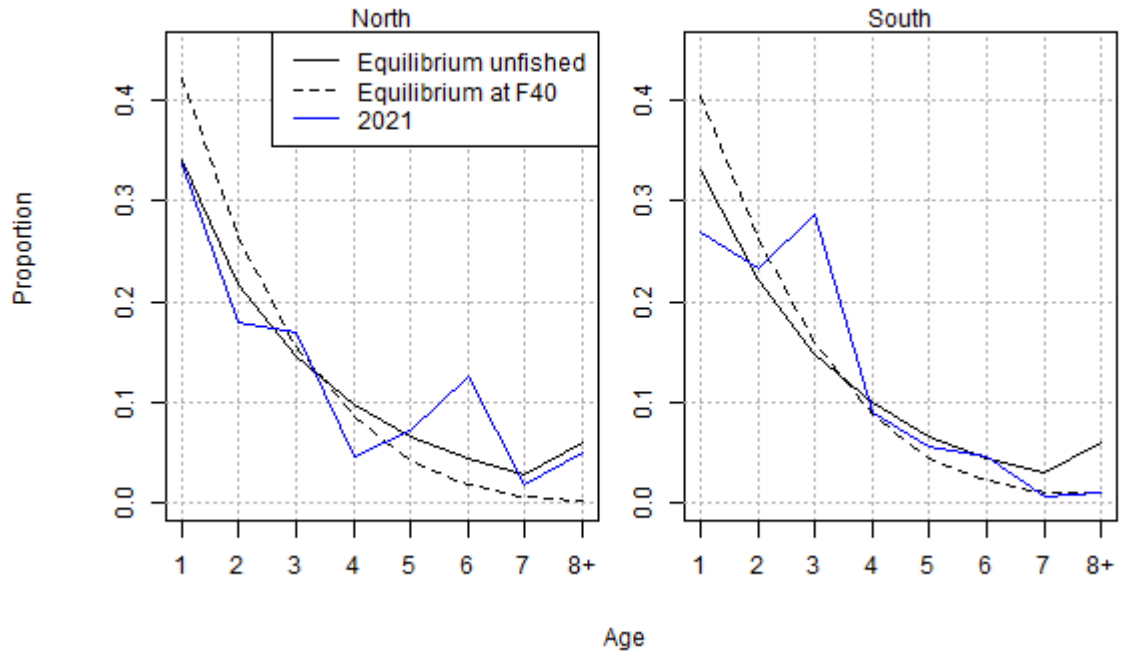
Age 7

	North	South
North	0.02	0
South	0.02	0

Age 8+

	North	South
North	0.01	0
South	0.01	0

January 1 proportions at age in spawning region



F_{40}

- Total FAA (across all 4 fleets) :

1	2	3	4	5	6	7	8+
0.05	0.22	0.39	0.59	0.73	0.88	1.03	1.03

- FAA by region

1	2	3	4	5	6	7	8+
0.02	0.13	0.18	0.32	0.42	0.56	0.71	0.71
0.03	0.09	0.20	0.28	0.31	0.32	0.32	0.32

F_{40}

- FAA by region

1	2	3	4	5	6	7	8+
0.02	0.13	0.18	0.32	0.42	0.56	0.71	0.71
0.03	0.09	0.20	0.28	0.31	0.32	0.32	0.32

- FAA by fleet

1	2	3	4	5	6	7	8+
0.01	0.04	0.09	0.17	0.17	0.17	0.17	0.17
0.01	0.09	0.10	0.15	0.26	0.39	0.54	0.54
0.00	0.02	0.06	0.07	0.07	0.07	0.07	0.07
0.03	0.08	0.15	0.21	0.24	0.25	0.25	0.25

F_{40}

- FAA by fleet

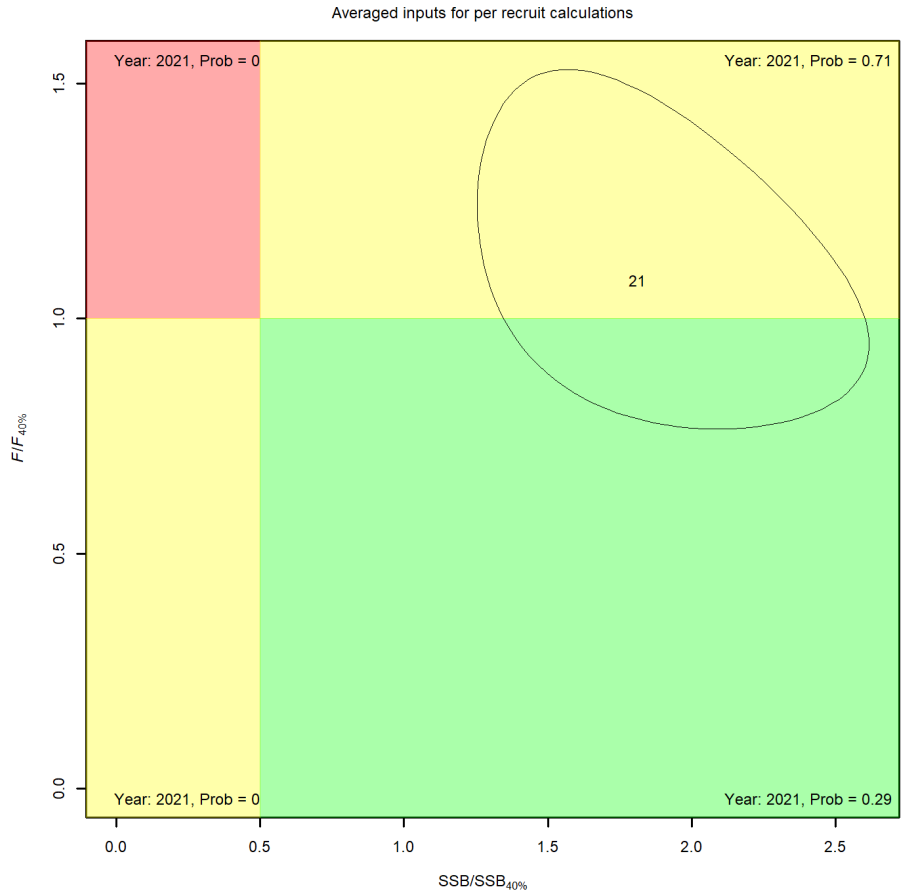
1	2	3	4	5	6	7	8+
0.01	0.04	0.09	0.17	0.17	0.17	0.17	0.17
0.01	0.09	0.10	0.15	0.26	0.39	0.54	0.54
0.00	0.02	0.06	0.07	0.07	0.07	0.07	0.07
0.03	0.08	0.15	0.21	0.24	0.25	0.25	0.25

- $\mathbf{FAA}/(F_{40} = \mathbf{1.03})$ = selectivity

1	2	3	4	5	6	7	8+
0.01	0.04	0.08	0.16	0.16	0.16	0.16	0.16
0.01	0.08	0.09	0.14	0.25	0.38	0.52	0.52
0.00	0.02	0.06	0.07	0.07	0.07	0.07	0.07
0.03	0.07	0.14	0.20	0.23	0.24	0.25	0.25

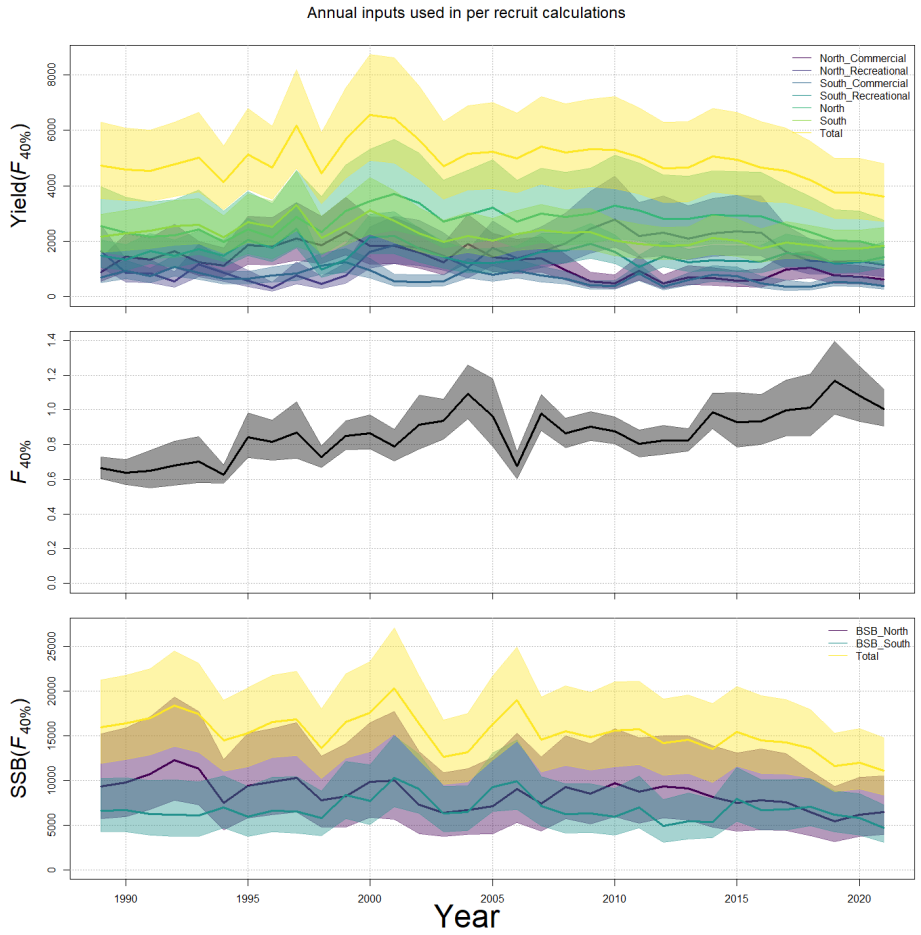
Status relative to reference points

- WHAM and Mult-WHAM can calculate joint uncertainty of status of current F and SSB relative to reference points

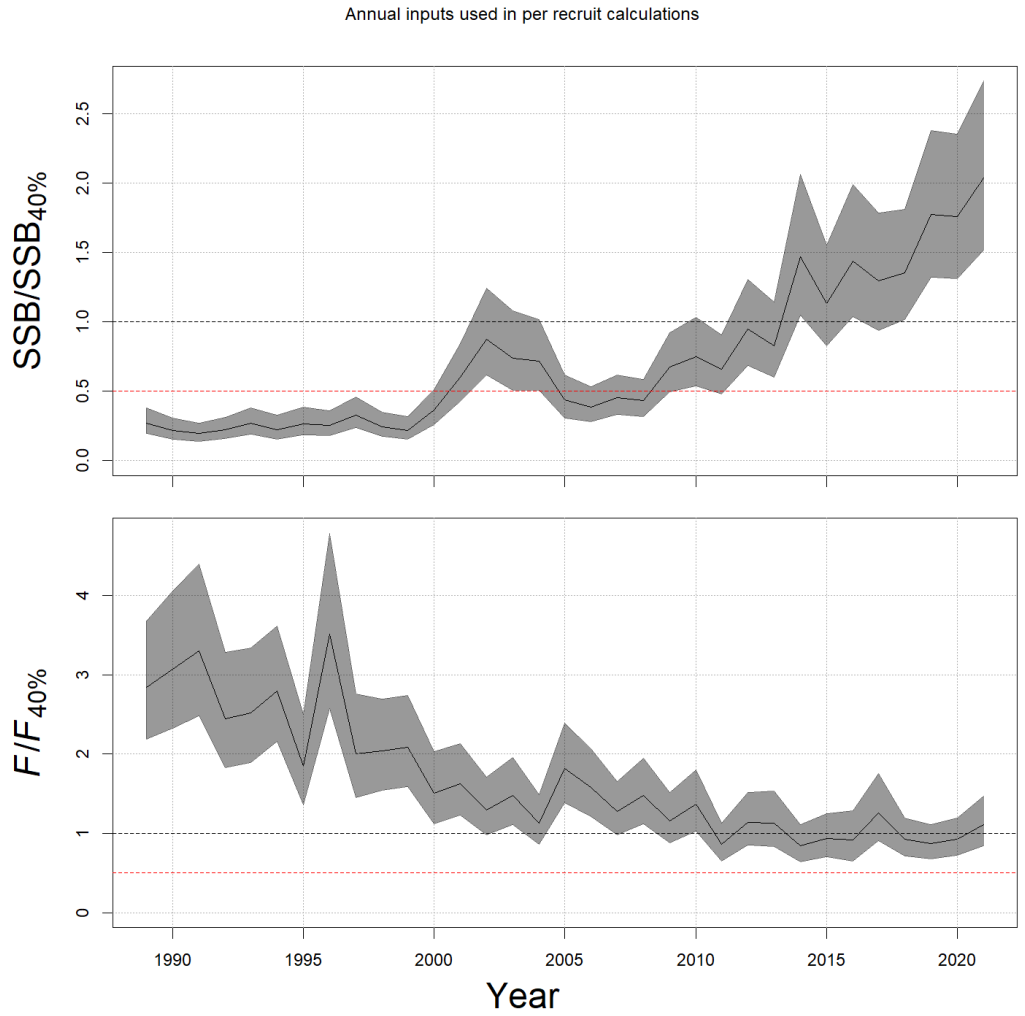


Annual reference points

- Can calculate reference points every year using annual inputs instead of last 5 years.



Annual status



Projections (TOR 6)

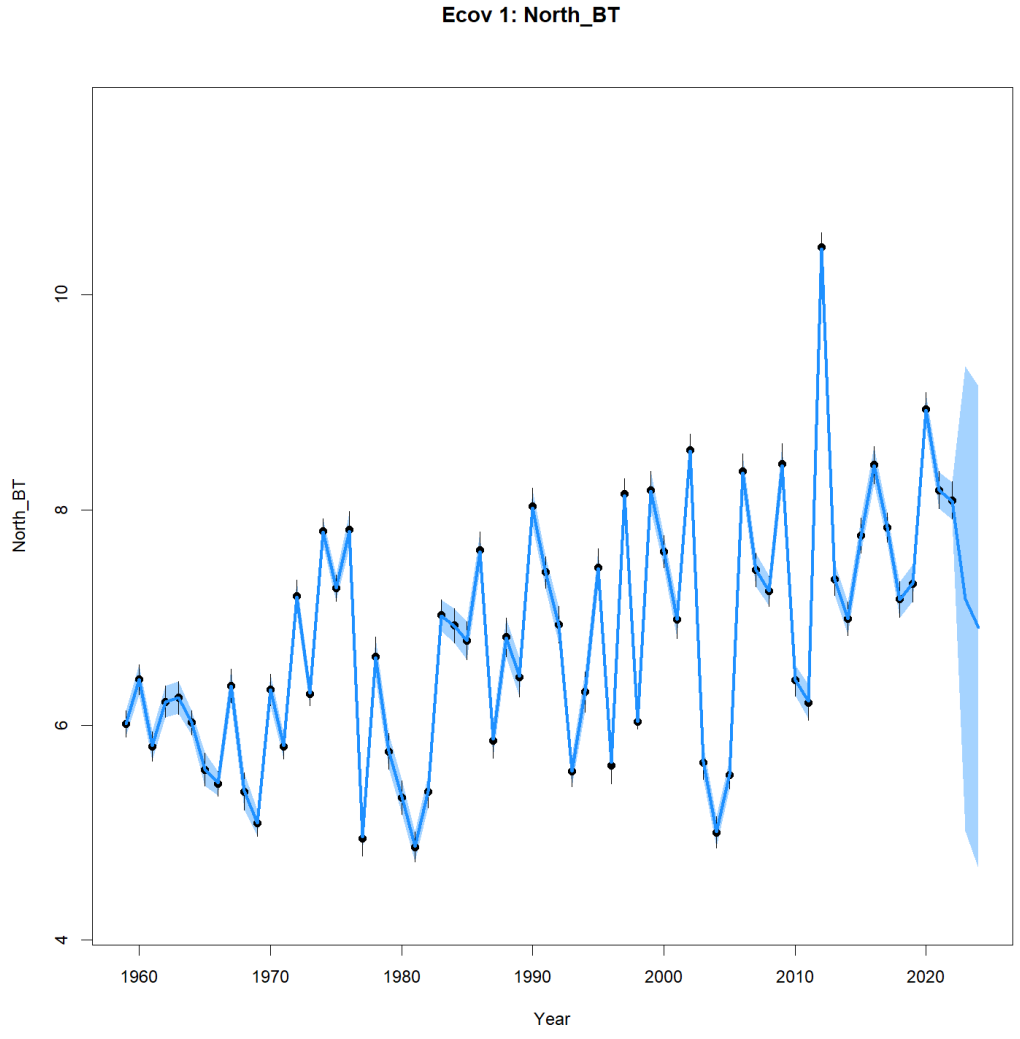
Projection options

- Multi-WHAM has the same options as the standard WHAM package
- Continues time series models for some random effects:
  - Recruitment
  - Survival/movement transitions
  - Environmental covariates
  - Optional for M, and movement
  - Uncertainty in these estimates grows in projection years moving away from observations
  - **Under AR1 model projected random effects converge to the mean of the process**
- For other dynamics user specifies years to average (default is the same as that for prevailing BRPs).
- Various options for projected (year-specific) fully-selected F or FAA:
  - Status quo
  - F_{40} (or some other percentage)
  - F_{MSY} (if a S-R function is used)
  - user-specified fully-selected F
  - user-specified total Catch (appropriate FAA is calculated internally)

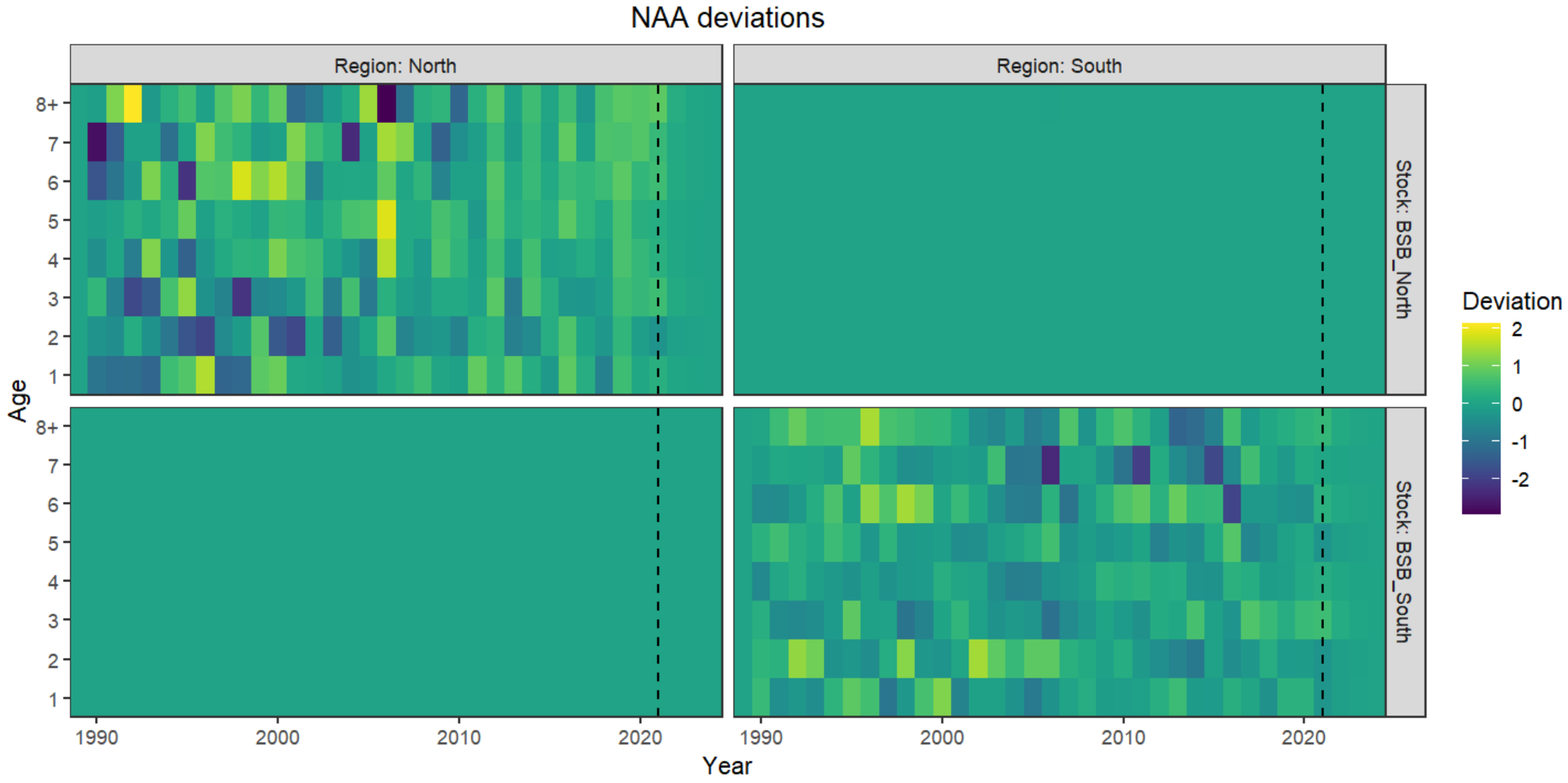
3-year projection example:

- Total Catch = 10 kmt in 2022
- Fully-selected total F = F_{40} in 2023, 2024
- Bottom temperature:
  - AR1 process random effects are forecast for 2022 and 2024 (observations end after 2022)
- 2DAR1 process random effects for recruitment and survival are forecast

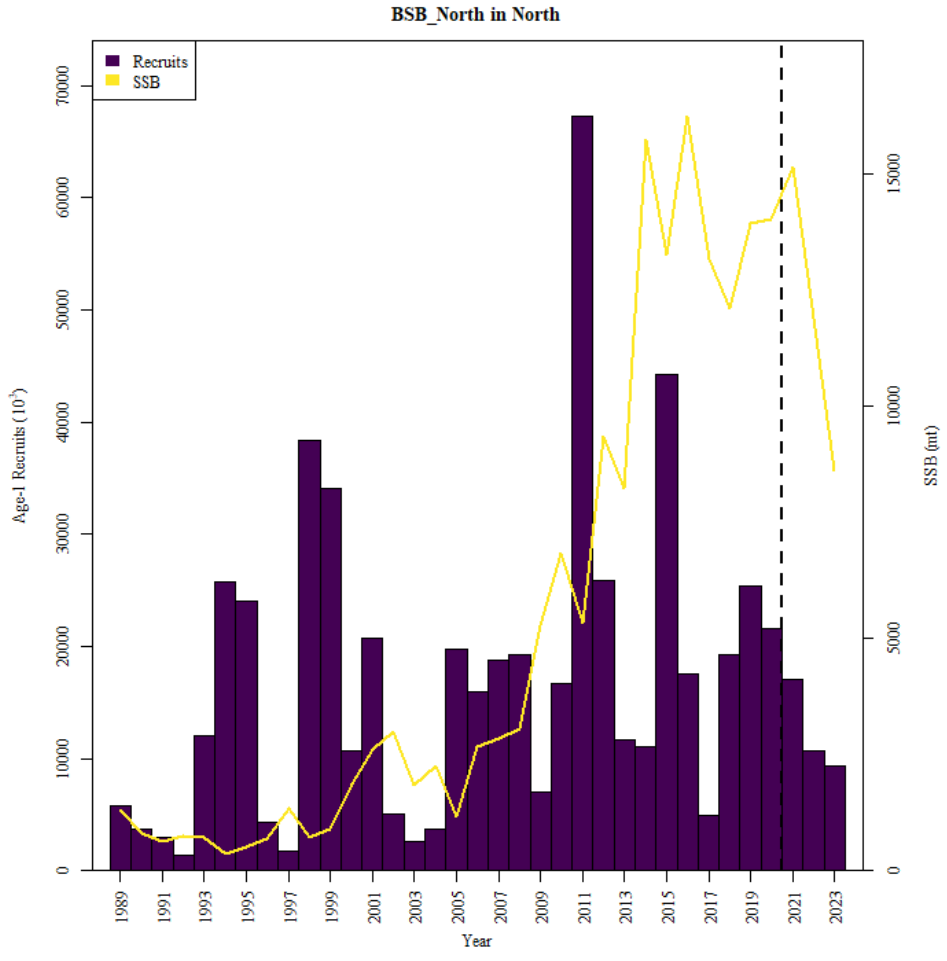
Bottom temperature in the North

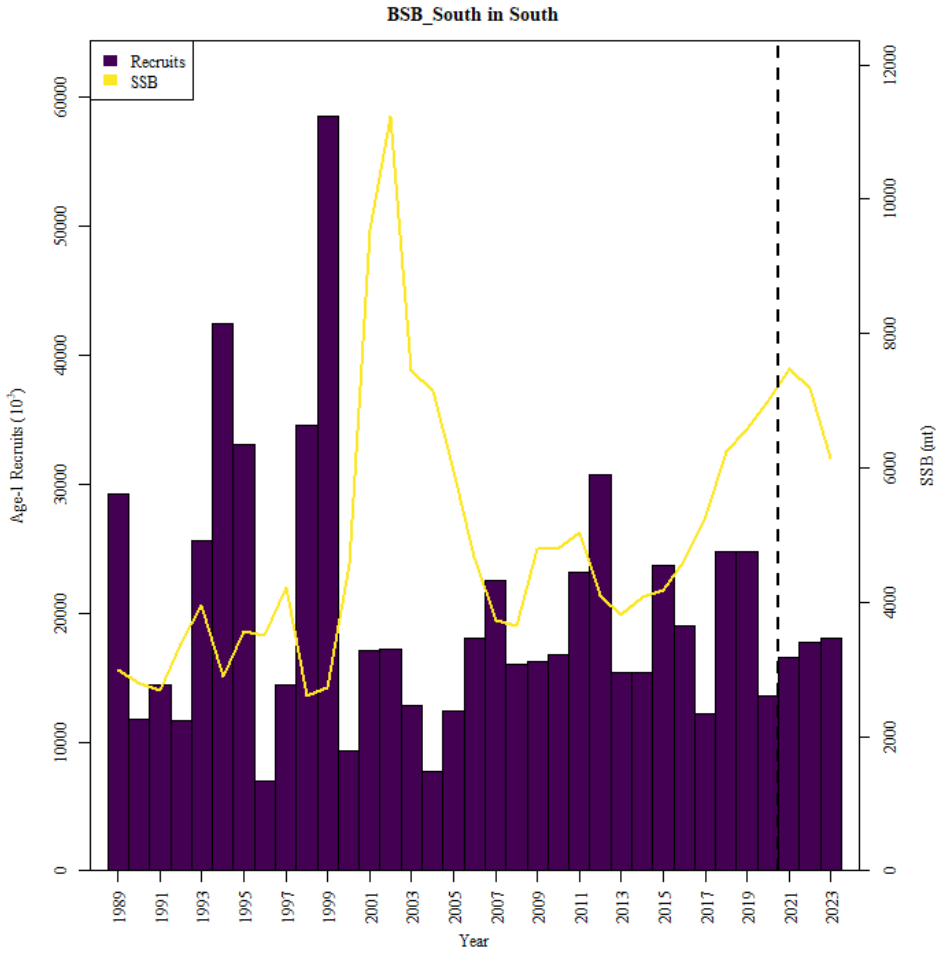


Survival/movement deviation random effects

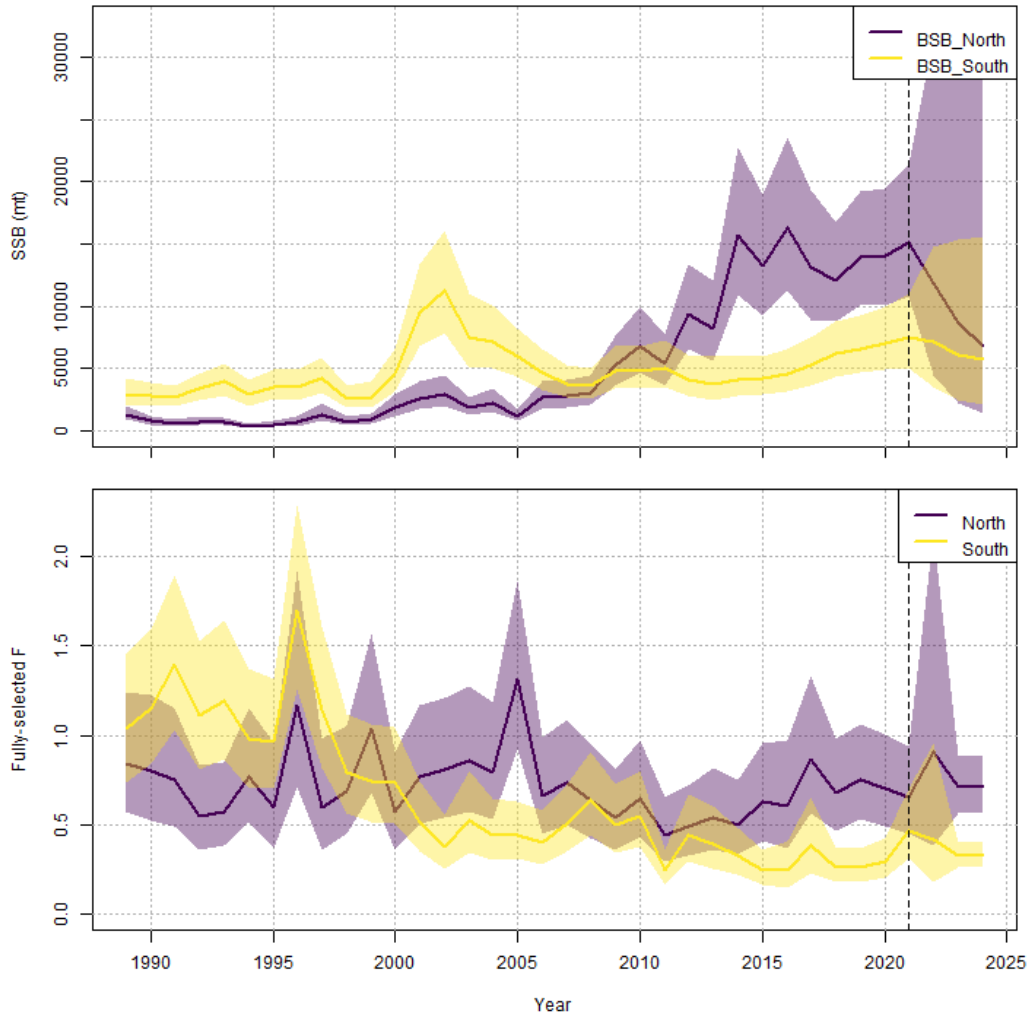


SSB and recruitment

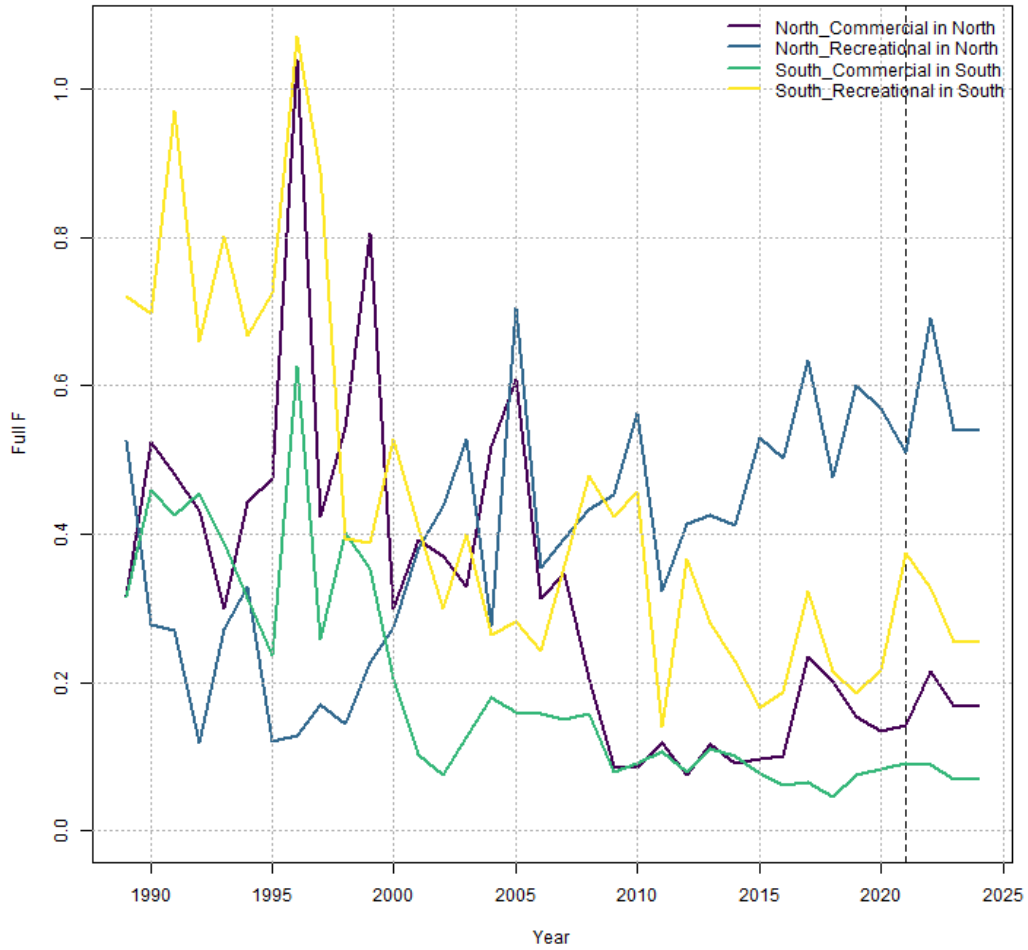




SSB and F


BSB_North
BSB_South
SSB (mt)
0
5000
10000
20000
30000
North
South
Fully-selected F
0.0
0.5
1.0
1.5
2.0
1990
1995
2000
2005
2010
2015
2020
2025
Year

fleet-specific F



Projected status