Application of the Woods Hole Assessment Model to Black Sea Bass

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Summary

The Woods Hole Assessment Model (WHAM) software package is maintained and developed at the Northeast Fisheries Science Center to enable state-space stock assessments, i.e. where processes such as the annual transitions in numbers-at-age (survival), natural mortality, selectivity, and catchability are treated as time- and, in some cases, age-varying random effects.

The current proposed model for management uses the Multi-WHAM version of WHAM (Miller, 2023) and models northern and souther components of the stock simultaneously. It includes movement of the northern stock to and from the southern region, VAST and Recreational CPA indices in the north and south, commercial and recreational fleets in the north and south and age composition observations for all fleets and indices. Process errors in recruitment, survival, and fleet and index selectivity are estimated.

The proposed model exhibits no retrospective patterns in fishing mortality or SSB and OSA residuals appear adequate for most of the data components.

1 Introduction

Black sea bass is currently assessed using ASAP, the Age-Structured Assessment Program (Legault and Restrepo, 1998; Miller and Legault, 2015). ASAP is a statistical catch-at-age (SCAA) model which estimates all model parameters as fixed effects.

We fit a series of models using the multi-stock, multi-region extension of WHAM for black sea bass (https://github.com/timjmiller/wham/tree/lab, Miller, 2023).

2 Methods

All code used for model fits along with results summaries can be found at https://github.com/kcurti/BSB.2023.RT.Modeling.

2.1 Early runs

The development of the multi-stock, multi-area version of WHAM was driven primarily by the needs of black sea bass and NEUS stocks of Atlantic cod. Because this extension to WHAM represents a major change to the code used to configure and estimate models, we compared results from fits of separate ASAP models, separate base WHAM models to the two regional components, as well as combined fits of these components in the new extension of WHAM without any movement (Figure 1). The latter fit will provide independent fits of the two components simultaneously.

Then we fit models treating recruitment as random effects and then also included random effects on survival for the older age classes.

Comparing separate fits for north and south using ASAP files from the last management track assessment in basic wham and multi-wham.

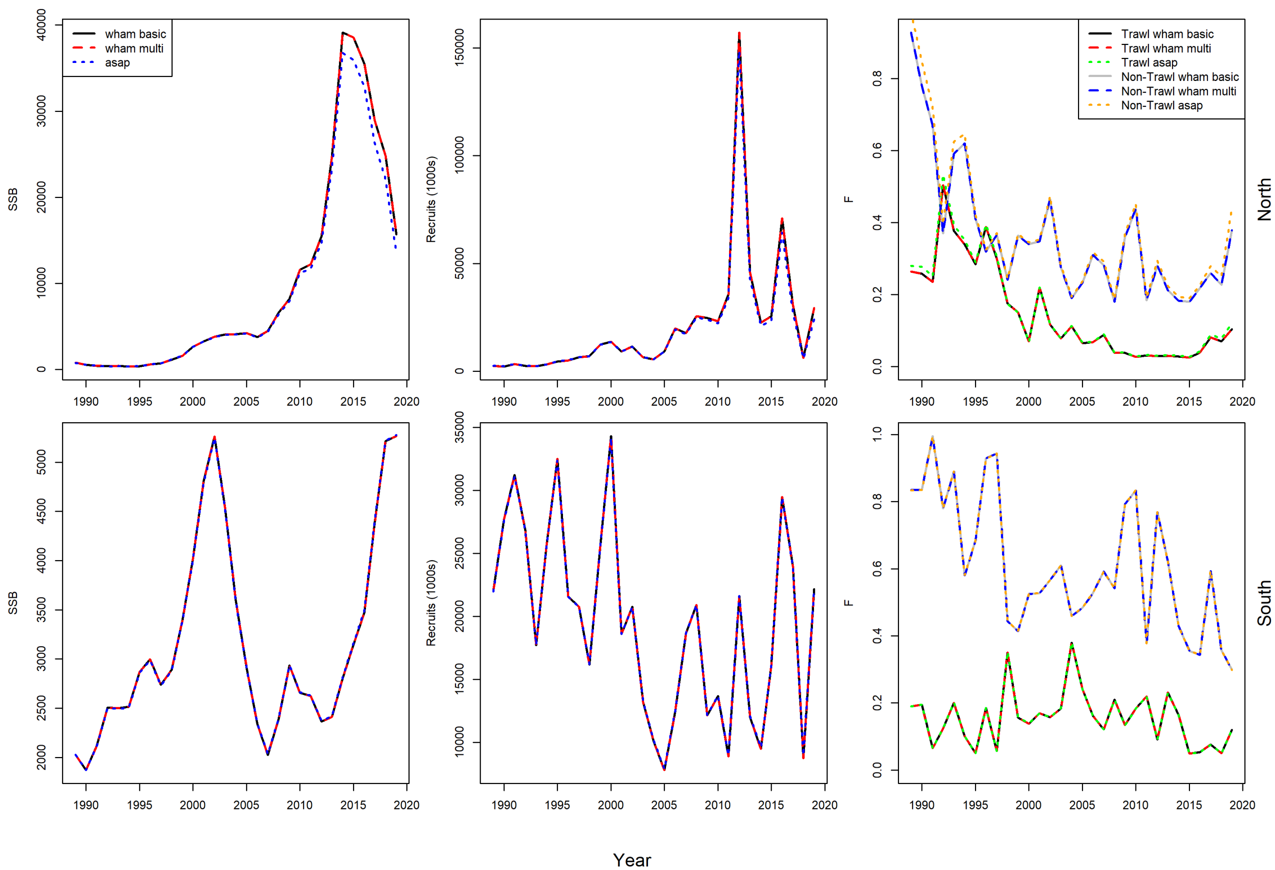

Figure 1: Comparison of recruitment, spawning stock biomass, and fishing mortality estimates from ASAP and WHAM fits to each regional component separately as well as simultaneoulsy in the multi-stock extension of WHAM using ASAP3 model input files from the most recent management track assessment.

2.2 Model configurations

We compared the base models for each stock in the single-stock and multi-stock versions of wham.

2.3 Configuring selectivity of fleets and indices

Early model runs kept the same selectivity blocks for the fleets as in latest management track assessment, but we found substantial patterns in OSA residuals for age composition observations for some fleets and/or indices. Furthermore, it is possible to estimate time-varying selectivity in WHAM, so we explored alternative configurations of mean selectivity models, selectivity random effects, and age composition likelihoods. We did these explorations in separate models for the north and south components of the stock for efficiency reasons (i.e., faster run times and iterating through models).

These explorations culminated in configurations in Table 1.

Table 1: Configuration of Age composition likelihood, mean selectivity model, and selectivity random effects for each age composition data component in Run 34.

Data component	Age Composition Likelihood	Mean Selectivity model	Random effects configuration
North Commercial	Dirichlet-Multinomial	age-specific (flat-topped at ages > 3)	2D-AR1 (age and year)
North Recreational	Logistic-normal (0s as missing)	age-specific (flat-topped at ages > 6)	2D-AR1 (age and year)
South Commercial	Logistic-normal (AR1, 0s as missing)	logistic	None
South Recreational	Logistic-normal (AR1, 0s as missing)	logistic	None
North Recreational CPA	Logistic-normal (0s as missing)	age-specific (flat-topped at ages > 1)	AR1 (year)
North VAST	Dirichlet-Multinomial	age-specific (flat-topped at ages > 4)	2D-AR1 (age and year)
South Recreational CPA	Logistic-normal (AR1, 0s as missing)	age-specific (flat-topped at ages > 2)	None
South VAST	Logistic-normal (AR1, 0s as missing)	age-specific (flat-topped at ages > 1)	None

2.4 Seasonality and movement

The WHAM model assumes 11 intervals within each calendar year: 5 monthly time intervals from Jan 1 to May 31, a spawning season from June 1 to July 31, and 5 monthly intervals from August 1 to December 31. All southern fish are assumed to never move to the northern region. Northern fish are all in the northern region during the spawning period. A proportion p_1 of northern fish can move to the south each month during the last 5 months of the year, but no movement is allows from the south to the north during this period. For the first 4 months of the year a proportion p_2 of northern fish in the south can move back to the north, but no movement from the north to south is allowed during this period. In the fifth month any northern fish still in the south are assumed to move back to the north for the subsequent spawning period. We configured survival and movement to occur sequentially in each interval. Each of the two proportions are assumed constant across intervals, age, and year.

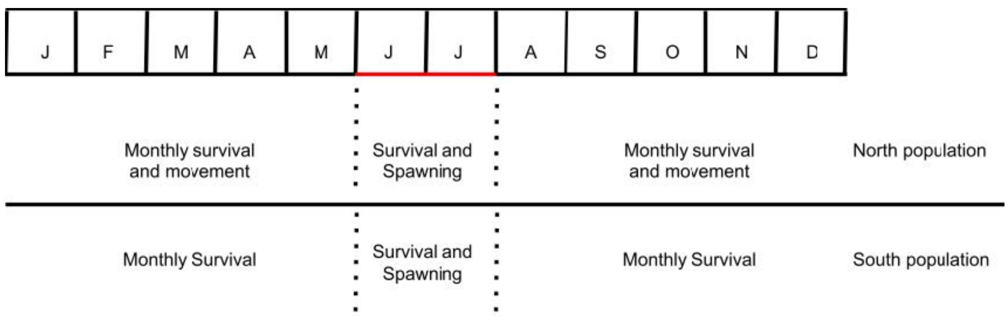

Figure 2: Diagram of intervals within the year and configuation of the dynamics of each component of the BSB population.

The monthly movement matrices are

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

for portion of the year after spawning and

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

for portion of the year before spawning.

2.4.1 Prior distribution for movement rates

The Stock Synthesis model has 2 seasons (6 months each) where a 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 is

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

and

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

We approximate the monthly movement matrices as the roots $\mathbf{P}_1$ and $\mathbf{P}_2$ defined by the number of months of movement for each season (5 and 4, respectively): $\mathbf{p}_1 = \mathbf{P}_1^{\frac{1}{5}}$ and $\mathbf{p}_2 = \mathbf{P}_2^{\frac{1}{4}}$. Given the proportion parameter, the eigen decomposition of the matricies can be used to define the roots

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

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

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. Note, for diagonal matrices, $\mathbf{D}_i^k$ is equal to the diagonal matrix with the elements raised to the power k.

We used a parametric bootstrap approach to determine an appropriate standard deviation for the prior distribution for the movement parameters. The actual parameters x_1 and x_2 estimated in the SS model are transformations of P_1 and P_2 such that

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

In WHAM a logit transformation is used

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

We simulated 1000 values from a normal distribution with mean and standard deviation defined by the SS parameter estimate and standared error $\tilde{x}_i \sim N(x_i, SE(x_i))$. For each simulated value we constructed $\mathbf{P}_i$, took the appropriate root and calculated inverse logit for $\tilde{y}_i$. We calculated the mean and standard deviation of the values y_i. The mean values did not differ meaningfully from the transformation of the original estimates and the standard deviation was approximately 0.2 for both parameters.

2.5 Recruitment and Survival

For the northern population abundance at age 1 on January 1 (recruitment) is only allowed in the northern region, but given the monthly movement described above, older individuals that previously recruited in the northern region may occur in the southern region on January 1. Therefore, a model with survival random effects will model the transitions (survival/movement) of abundances at age of northern origin fish in each region. All of the initial runs assumed variance parameters for these random effects to be the same for northern origin fish occurring in both regions on January 1. The base model assumes very small variance for the transitions of northern fish in the southern region, which is essentially the same as the deterministic transition assumptions of a statistical catch at age model. We also allow 2DAR1 correlation for recruitment and survival for both the northern and southern components. Variance and correlation parameters for the recruitment and survival random effects are different for the northern and southern components.

2.5.1 Uncertainty recreational CPA index observations

The CVs provided by the analyses for the recreational catch per angler ranged between 0.02 and 0.06 which the working group felt did not capture the true uncertainty in the index with regard to its relationship to stock abundance. In many of the initial runs as well as the base model we allowed a scalar multiple of the standard deviation of the log aggregate index to be estimated for these indices in the northern and southern regions. Models that successfully estimated these scalars indicated standard deviations for these surveys to be approximately 5 times the input value and this value was fixed in many preliminary runs to avoid dealing with convergence problems. However, the base model successfully estimated these scalars. The model estimates are negligibly affected by estimating these scalars, but we felt estimating these parameters allowed uncertainty in model output to be more properly conveyed.

Table 2: Comparison of AIC and estimates of standard deviation of recruitment for the northern stock component with and without bottom temperature effects on northern recruitment for Run 33.

	AIC	North $\widehat{\sigma}_R$
No effect	-1591.34	0.91
With temperature effect	-1601.84	0.72

2.6 Bottom Temperature effects on recruitment

We have bottom temperature observations for the northern and southern regions from 1963 to 2021 and estimated standard errors of those observations. We assumed AR1 models for the latent bottom temperature covariates in each region. We fit models with the bottom temperature covariate observations in the model, but without effects on recruitment. This is the null model which can be compared with models with effects on recruitment using AIC because the observations included in each model are the same. We also fit a model with effects of the regional bottom temperatures on the respective stock components. The hypothesis is that bottom temperature affects overwinter survival of fish where the fish turn from age 0 to age 1 on January 1.

We assume the covariate in year y affects recruitment in the same years because the covariate observations are from months January to March. The fish are technically already 1 year old, but there are no observations of these individuals until later in the year except possibly in fishery catches which are accumulated over the whole year. Expected log-recruitment is a linear function of log-recruitment at the previous time step and bottom temperature

$$\log R_y = \mu_R + \beta x_y + \epsilon_y \tag{1}$$

Comparison of the base model to one with the bottom temperature effect on natural mortality at age 1 might be of interest in the future.

2.7 Dead End Runs

We attenmpted a few further extensions of the base model. First we fit models that assumed Beverton-Holt stock recruit relationships for the north and south components. Although this fit converged nominally, the α and β parameters tended toward infinity (equivalent to steepness tending toward 1). We also fit a model with AR1 annual random effects in the movement rates from the north to the south for the northern stock component. This run did not converge.

2.8 self tests

2.9 Jitter analysis

2.10 Reference points

Because

2.10.1 Projections

2.11 Results

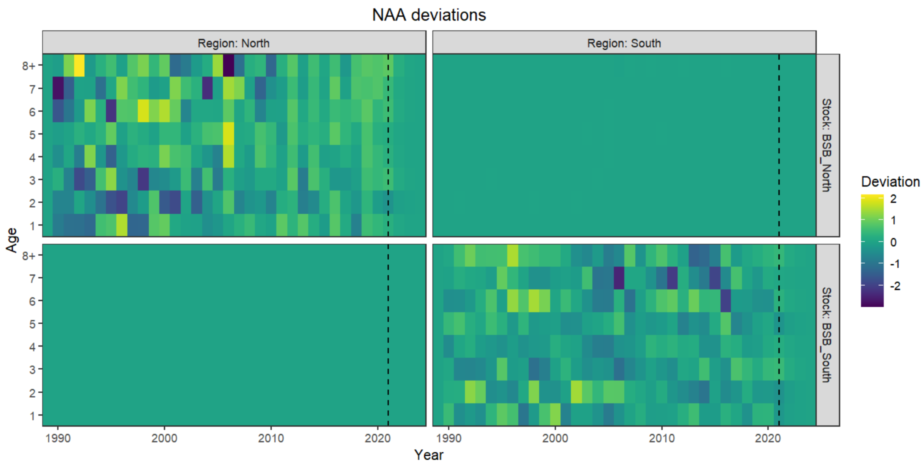

Figure 3: Estimated survival deviations from the proposed base model.

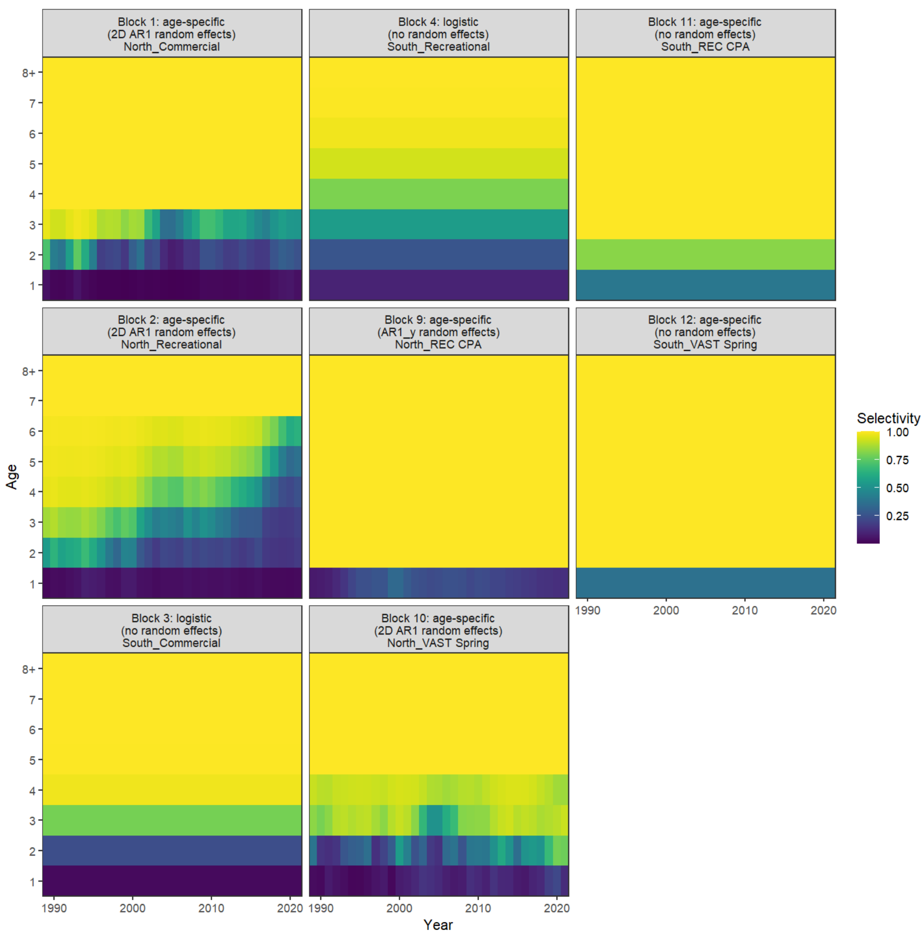

Figure 4: Estimated selectivity for indices and fleets from the proposed base model.

Table 3: Parameter estimates, standard errors, and confidence intervals. Rounded to 3 decimal places.

	Estimate	Std. Error	95% CI lower	95% CI upper
BSB North mean log(R) intercept	5.835	0.954	3.965	7.704
BSB North in North NAA σ (age 1)	0.721	0.101	0.548	0.949
BSB North in North NAA σ (ages 2-8+)	0.807	0.047	0.721	0.904
BSB North in South NAA σ (age 1)	0.721	0.101	0.548	0.949
BSB North in North NAA AR1 ρ age	0.089	0.094	-0.097	0.269
BSB North in North NAA AR1 ρ year	0.261	0.079	0.101	0.408
BSB South Mean Recruitment	21254.097	4468.727	14075.875	32092.969
BSB South in North NAA σ (age 1)	0.518	0.079	0.384	0.700
BSB South in North NAA σ (ages 2-8+)	0.614	0.070	0.490	0.769
BSB South in South NAA σ (age 1)	0.518	0.079	0.384	0.700
BSB South in South NAA σ (ages 2-8+)	0.614	0.070	0.490	0.769
BSB South in North NAA AR1 ρ age	-0.108	0.114	-0.323	0.118
BSB South in North NAA AR1 ρ year	0.318	0.101	0.109	0.501
BSB South in South NAA AR1 ρ age	-0.108	0.114	-0.323	0.118
BSB South in South NAA AR1 ρ year	0.318	0.101	0.109	0.501
North REC CPA fully selected q	1.021×10^{-4}	1.508×10^{-5}	7.648×10^{-5}	1.364×10^{-4}
North VAST Spring fully selected q	0.016	0.002	0.012	0.021
South REC CPA fully selected q	1.521×10^{-4}	2.024×10^{-5}	1.171×10^{-4}	1.974×10^{-4}
South VAST Spring fully selected q	0.015	0.002	0.011	0.019
Block 1: North Commercial Mean Selectivity for age 1	0.019	0.015	0.004	0.089
Block 1: North Commercial Mean Selectivity for age 2	0.327	0.174	0.094	0.696
Block 1: North Commercial Mean Selectivity for age 3	0.815	0.128	0.454	0.959
Block 1: North Commercial Mean Selectivity for age 4	1.000			
Block 1: North Commercial Mean Selectivity for age 5	1.000			
Block 1: North Commercial Mean Selectivity for age 6	1.000			
Block 1: North Commercial Mean Selectivity for age 7	1.000			
Block 1: North Commercial Mean Selectivity for age 8+	1.000			
Block 2: North Recreational Mean Selectivity for age 1	0.029	0.026	0.005	0.154
Block 2: North Recreational Mean Selectivity for age 2	0.325	0.200	0.075	0.741
Block 2: North Recreational Mean Selectivity for age 3	0.558	0.227	0.172	0.884
Block 2: North Recreational Mean Selectivity for age 4	0.787	0.157	0.370	0.959
Block 2: North Recreational Mean Selectivity for age 5	0.888	0.097	0.540	0.982
Block 2: North Recreational Mean Selectivity for age 6	0.950	0.050	0.708	0.993

Table 3: Parameter estimates, standard errors, and confidence intervals. Rounded to 3 decimal places. *(continued)*

	Estimate	Std. Error	95% CI lower	95% CI upper
Block 2: North Recreational Mean Selectivity for age 7	1.000			
Block 2: North Recreational Mean Selectivity for age 8+	1.000			
Block 3: South Commercial a_{50}	2.465	0.124	2.229	2.713
Block 3: South Commercial 1/slope (increasing)	0.401	0.034	0.340	0.472
Block 4: South Recreational a_{50}	2.843	0.233	2.405	3.314
Block 4: South Recreational 1/slope (increasing)	0.822	0.101	0.645	1.042
Block 9: North REC CPA Mean Selectivity for age 1	0.158	0.067	0.065	0.335
Block 9: North REC CPA Mean Selectivity for age 2	1.000			
Block 9: North REC CPA Mean Selectivity for age 3	1.000			
Block 9: North REC CPA Mean Selectivity for age 4	1.000			
Block 9: North REC CPA Mean Selectivity for age 5	1.000			
Block 9: North REC CPA Mean Selectivity for age 6	1.000			
Block 9: North REC CPA Mean Selectivity for age 7	1.000			
Block 9: North REC CPA Mean Selectivity for age 8+	1.000			
Block 10: North VAST Spring Mean Selectivity for age 1	0.073	0.027	0.035	0.148
Block 10: North VAST Spring Mean Selectivity for age 2	0.404	0.092	0.242	0.590
Block 10: North VAST Spring Mean Selectivity for age 3	0.893	0.060	0.710	0.966
Block 10: North VAST Spring Mean Selectivity for age 4	0.927	0.039	0.805	0.975
Block 10: North VAST Spring Mean Selectivity for age 5	1.000			
Block 10: North VAST Spring Mean Selectivity for age 6	1.000			
Block 10: North VAST Spring Mean Selectivity for age 7	1.000			
Block 10: North VAST Spring Mean Selectivity for age 8+	1.000			
Block 11: South REC CPA Selectivity for age 1	0.399	0.070	0.273	0.541
Block 11: South REC CPA Selectivity for age 2	0.824	0.076	0.626	0.929
Block 11: South REC CPA Selectivity for age 3	1.000			
Block 11: South REC CPA Selectivity for age 4	1.000			
Block 11: South REC CPA Selectivity for age 5	1.000			
Block 11: South REC CPA Selectivity for age 6	1.000			
Block 11: South REC CPA Selectivity for age 7	1.000			
Block 11: South REC CPA Selectivity for age 8+	1.000			
Block 12: South VAST Spring Selectivity for age 1	0.370	0.080	0.231	0.535
Block 12: South VAST Spring Selectivity for age 2	1.000			
Block 12: South VAST Spring Selectivity for age 3	1.000			

Table 3: Parameter estimates, standard errors, and confidence intervals. Rounded to 3 decimal places. *(continued)*

	Estimate	Std. Error	95% CI lower	95% CI upper
Block 12: South VAST Spring Selectivity for age 4	1.000			
Block 12: South VAST Spring Selectivity for age 5	1.000			
Block 12: South VAST Spring Selectivity for age 6	1.000			
Block 12: South VAST Spring Selectivity for age 7	1.000			
Block 12: South VAST Spring Selectivity for age 8+	1.000			
Block 1: North Commercial Selectivity RE σ	0.407	0.116	0.233	0.710
Block 1: North Commercial Selectivity RE AR1 ρ (age)	0.479	0.139	0.338	0.940
Block 1: North Commercial Selectivity RE AR1 ρ (year)	0.591	0.082	0.584	0.967
Block 2: North Recreational Selectivity RE σ	0.208	0.030	0.156	0.277
Block 2: North Recreational Selectivity RE AR1 ρ (age)	0.520	0.063	0.651	0.910
Block 2: North Recreational Selectivity RE AR1 ρ (year)	0.733	0.024	0.875	0.983
Block 9: North REC CPA Selectivity RE σ	0.256	0.067	0.154	0.427
Block 9: North REC CPA Selectivity RE AR1 ρ (year)	0.658	0.078	0.539	0.988
Block 10: North VAST Spring Selectivity RE σ	0.746	0.152	0.500	1.111
Block 10: North VAST Spring Selectivity RE AR1 ρ (age)	0.118	0.249	-0.273	0.637
Block 10: North VAST Spring Selectivity RE AR1 ρ (year)	0.341	0.168	0.182	0.845
North Commercial in North age comp, Dirichlet-multinomial: dispersion (ϕ)	54.871	7.002	42.729	70.462
North Recreational in North age comp, logistic-normal: σ	2.832	0.337	2.243	3.576
South Commercial in South age comp, logistic-normal: σ	33.924	3.453	27.789	41.414
South Commercial in South age comp, logistic-normal: ρ	0.719	0.061	0.585	0.823
South Recreational in South age comp, logistic-normal: σ	27.912	4.330	20.594	37.830
South Recreational in South age comp, logistic-normal: ρ	0.910	0.027	0.842	0.951
North REC CPA in North age comp, logistic-normal: σ	4.298	0.395	3.590	5.146
North VAST Spring in North age comp, Dirichlet-multinomial: dispersion (ϕ)	28.552	3.236	22.864	35.655
South REC CPA in South age comp, logistic-normal: σ	27.464	4.520	19.892	37.920
South REC CPA in South age comp, logistic-normal: ρ	0.927	0.024	0.864	0.962
South VAST Spring in South age comp, logistic-normal: σ	48.175	3.878	41.144	56.409
South VAST Spring in South age comp, logistic-normal: ρ	0.661	0.057	0.542	0.762
stock BSB North μ from North to South (intercept)	0.009	0.001	0.006	0.011
stock BSB North μ from South to North (intercept)	0.332	0.043	0.253	0.421
North REC CPA log-index observation SD scalar	4.757	1.429	2.641	8.569
South REC CPA log-index observation SD scalar	5.306	1.270	3.319	8.483
Ecov North BT: μ	6.754	0.176	6.409	7.099
Ecov North BT: σ	1.062	0.104	0.876	1.286

Table 3: Parameter estimates, standard errors, and confidence intervals. Rounded to 3 decimal places. *(continued)*

	Estimate	Std. Error	95% CI lower	95% CI upper
Ecov North BT: AR1 ρ	0.241	0.128	-0.020	0.471
Ecov South BT: μ	6.843	0.157	6.536	7.151
Ecov South BT: σ	1.023	0.097	0.849	1.232
Ecov South BT: AR1 ρ	0.164	0.130	-0.095	0.403
BSB North Recruitment Ecov: North BT β_1	0.492	0.126	0.244	0.740

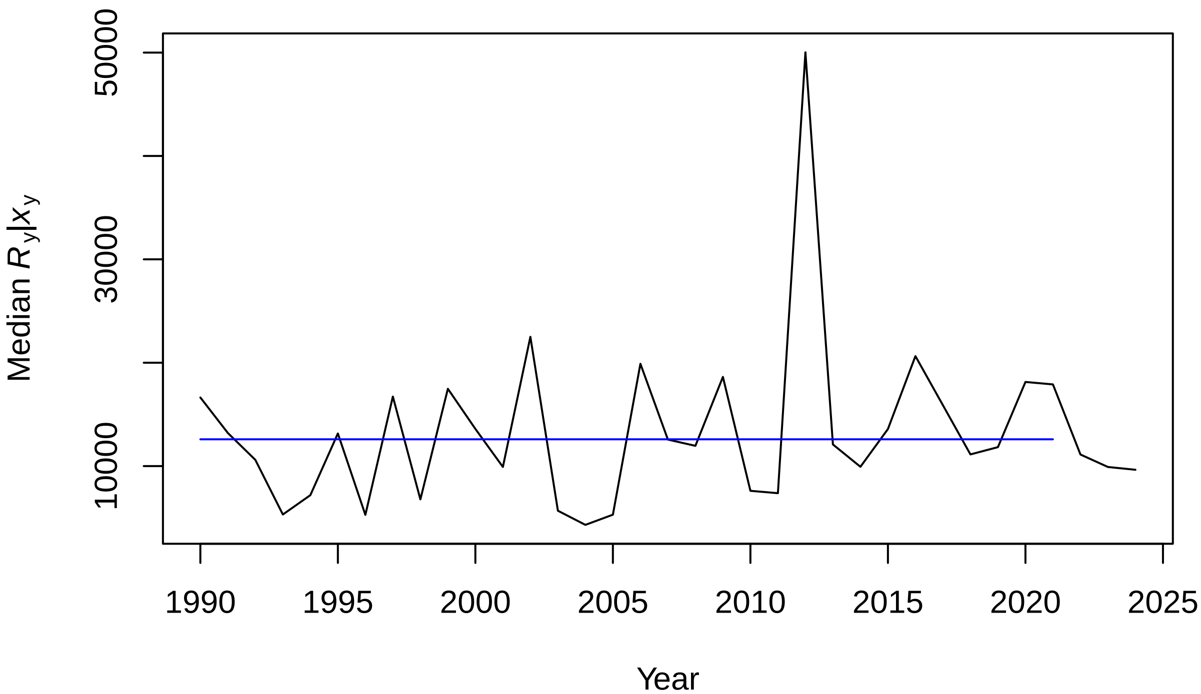

Figure 5: Median recruitment with and without temperature (x) effects.

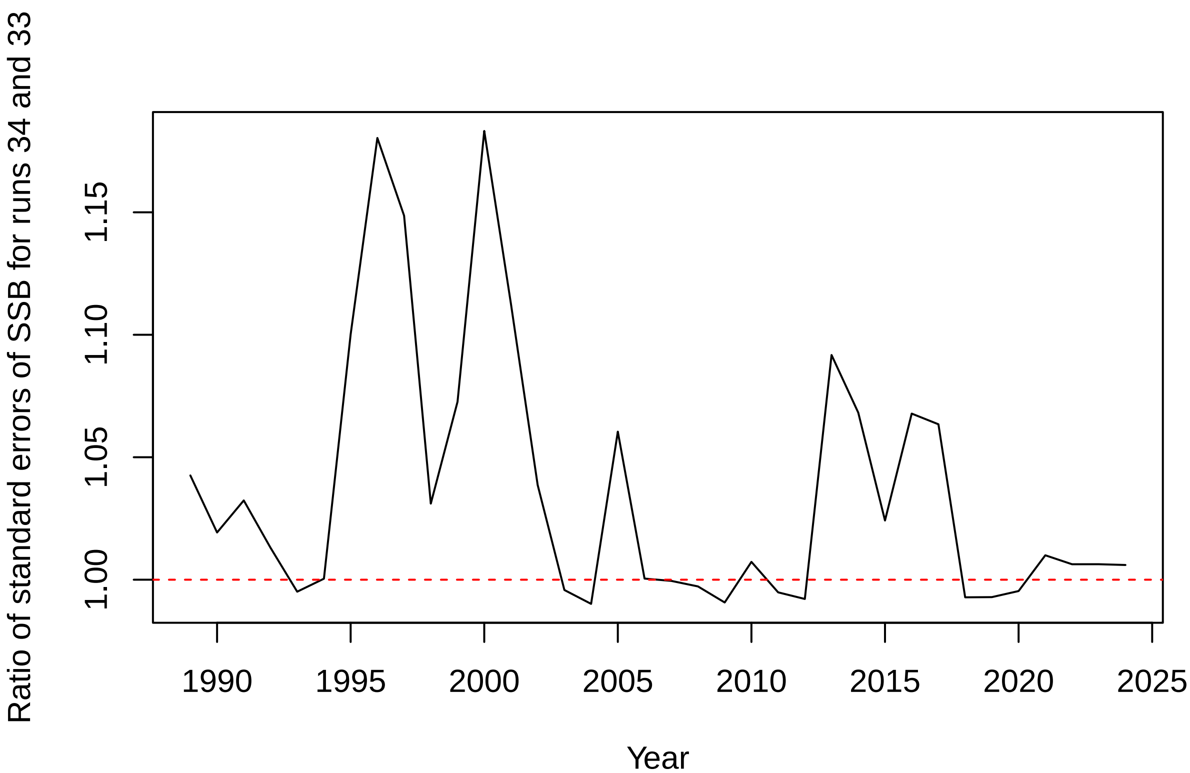

Figure 6: Ratio of standard errors of Northern component SSB with and without the scalar of the Recreational CPA index standard errors estimated.

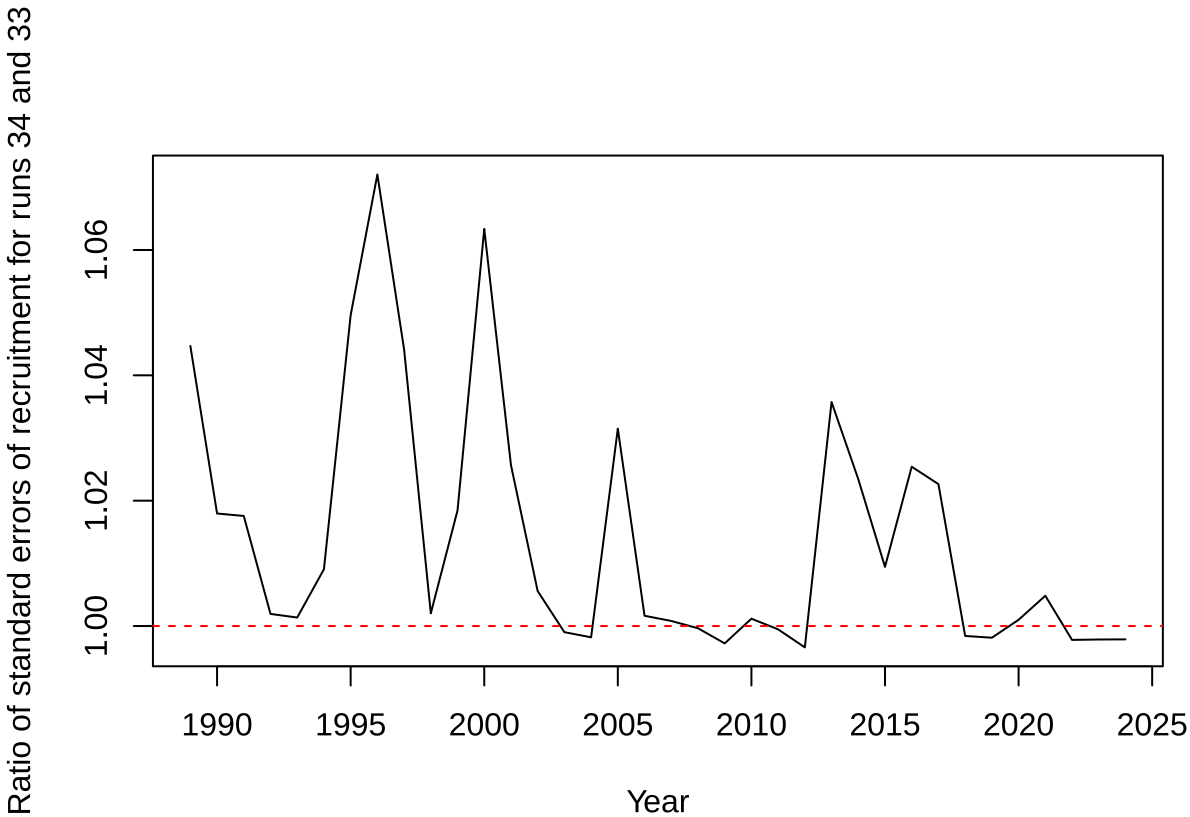

Figure 7: Ratio of standard errors of Northern component recruitment with and without the scalar of the Recreational CPA index standard errors estimated.

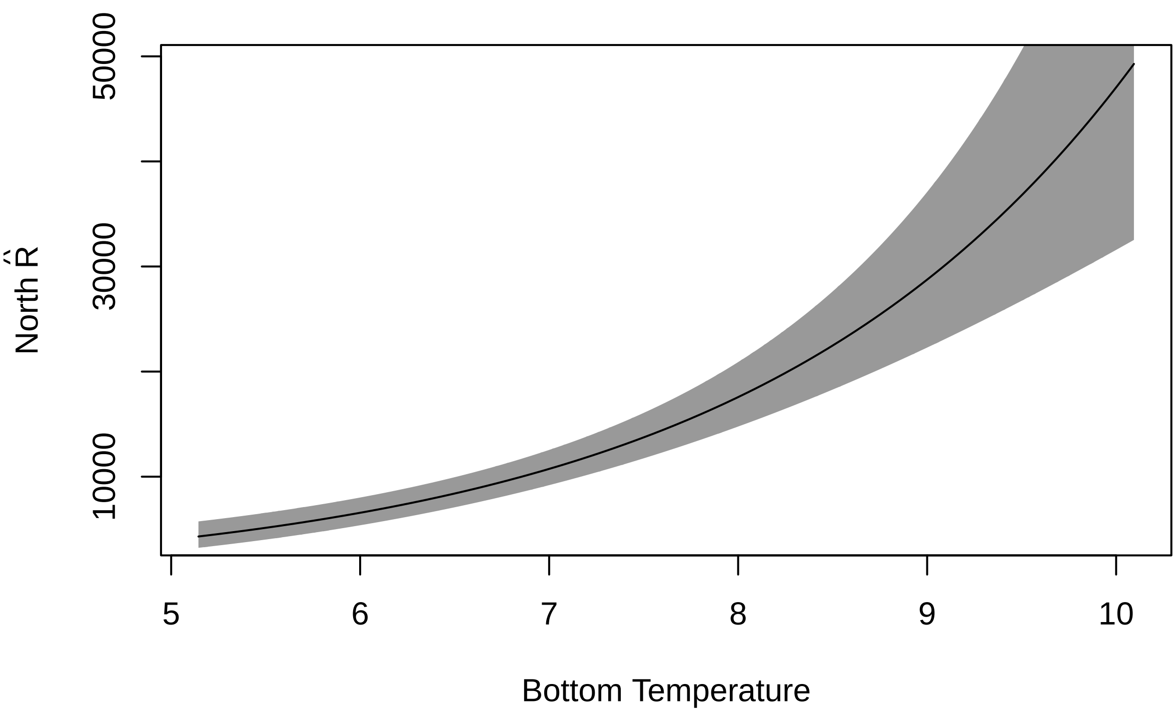

Figure 8: Expected recruitment for the northern component of the black sea bass stock as a function of bottom temperature

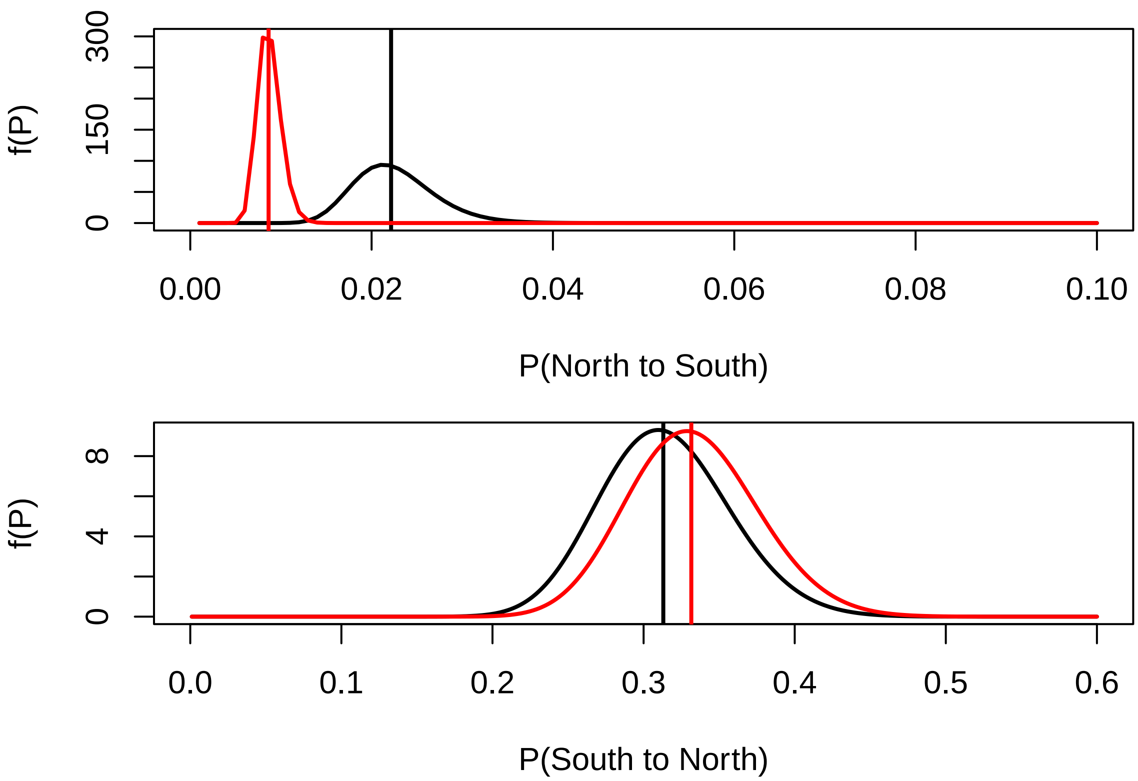

Figure 9: Prior (black) and posterior (red) distributions of movement of northern component stock from north to south (top) and south to north (bottom)

2.12 Projections

References

Legault, C.M., Restrepo, V.R., 1998. A Flexible Forward Age-Structured Assessment Program (No. 49).

Miller, T.J., 2023. Multi-WHAM: A multi-stock, multi-region extension of the woods hole assessment model. Working paper for the 2023 black sea bass research track assessment peer review.

Miller, T.J., Legault, C.M., 2015. Technical details for ASAP version 4 (No. Ref Doc. 15-17). US Dept Commer, Northeast Fish Sci Cent.