Projections of Black Sea Bass off the Southeastern United States

SEDAR 78 Assessment Addendum

Southeast Fisheries Science Center
National Marine Fisheries Service

Report issued: October 2023

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1 Introduction

In an email email dated 30 May 2023, from Dr. Chip Collier to Dr. Larry Massey, the SAFMS requested a series of projections for South Atlantic black sea bass on behalf of the Council and the SSC. Specifically, the request was for the following:

- Model specifications:
  - Fixed F for the interim years, with F being the average of the last three years of the time series
  - Projections using F0.1 instead of Fmax
  - Allow F from discard fleet to remain constant
- Projections:
  - 75%*F0.1 using recent (2014-2019) average recruitment
  - 10 year rebuilding projection using long-term average recruitment and F0.1

In the April 2023 SSC report additional recommendations for projections included considering all available information regarding landings and discards for 2022 and exploration of "sine-wave" increase in recruitment scenarios similar to the Scamp assessment projections.

During the review of the assessment, the SSC recommended research into the best measure of spawning biomass (females only, females plus males, etc.). As a result of this recommendation the SSB and stock status was recalculated using a number of different definitions of SSB.

Preliminary results of the projections were presented to the SSC during the July 2023 meeting. During the meeting, guidance on various aspects of the projections were sought by the SAFSC from the SSC. However, the SSC was unable to answer the various questions in the time alloted. Therefore, a working group on the black sea bass projections was convened on 2 October 2023. During this meeting, numerous decisions were made regarding the reference point to be used for calculation of stock status and for use in the projections. Thus, the reference point mentioned in the request for additional projections was no longer appropriate and was replaced in the projections presented.

1.1 Benchmark/Reference Point Methods

In the original SEDAR 76 assessment report a F_{MSY} was reported. However, the SSC identified that the value reported could not be a maximum sustainable yield because a mean recruitment model was used and the resulting curve would be the yield per recruit. The maximum identified in the YPR curve was the F that maximized the landed yield because it did not account for discards. Therefore, the SSC made the recommendation to use $F_{0.1}$ as the reference point because the spawning potential ratio could not be reduced to 40% using the female egg production as the defined SSB. Subsequent to the SSC review, the SPR was recalculated using multiple definitions of spawning stock biomass (Figure 1). The definitions of SSB were as follows: Eggs is female fecundity, Mature Weight is the sum of male and female mature biomass, Eggs*Male Wgt is the product of female fecundity and male mature biomass, Egg*Male N is the product of female fecundity and male mature abundance, Mature N is the abundance of mature fish, and Female*Male is the produce of female abundance and Male abundance. The black sea bass projection working group decided that the mature biomass (sum of male and female) was the most appropriate definition of SSB to be used for black sea bass. This decision was made as a result of concerns that metrics that used the product of males and females would over emphasize the influence of males in the population. Additionally, there was no information avilable regarding the potential for sperm limitation in this species. Other protogynous species, such as scamp, also used total mature biomass as the metric for calculating SSB and the precedent used by these species was followed. Changing the definition of the SSB to mature weight allowed for the calculation of $F_{40\%}$.

The quantities $F_{40\%}$, $\mathrm{SSB}_{\mathrm{F}40\%}$, $B_{\mathrm{F}40\%}$, and $L_{\mathrm{F}40\%}$ were estimated here and are recommended as proxies for MSY-based reference points. The value of $F_{40\%}$ is the F that provides 40% SPR. To compute biomass benchmarks, equilibrium recruitment was assumed equal to expected recruitment in arithmetic space (mean unbiased). However, in BAM, spawner-recruit parameters correspond to median-unbiased recruitment. Thus, on average, expected recruitment is higher than that estimated directly from the spawner-recruit model (i.e., R_0, when using the mean recruitment model), because of lognormal deviation in recruitment. Therefore, the method of benchmark estimation accounted for lognormal deviation by including a bias correction in equilibrium recruitment. The bias correction (ς) was computed from the variance (σ_R^2) of recruitment deviation in log space: $\varsigma = \exp(\sigma_R^2/2)$. Then, equilibrium recruitment (R_{eq}) associated with any F is, $R_{eq} = \varsigma R_0$ where R_0 is median-unbiased virgin recruitment. The R_{eq} and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of $F_{40\%}$ is the F giving 40% of the SPR, and the estimate of $L_{\mathrm{F}40\%}$ is that ASY. The estimates of $\mathrm{SSB}_{\mathrm{F}40\%}$ follows from the corresponding equilibrium age structure.

Estimates of $L_{\mathrm{F}40\%}$ and related benchmarks are conditional on selectivity pattern. The selectivity pattern used here was an average of terminal-year selectivities from each fleet, where each fleet-specific selectivity was weighted in proportion to its corresponding estimate of F averaged over the last three years (2019–2021). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of $L_{\mathrm{F}40\%}$ and related benchmarks.

The maximum fishing mortality threshold (MFMT) is defined here as $F_{40\%}$, and the minimum stock size threshold (MSST) as $(1 - M) * \mathrm{SSB}_{\mathrm{F}40\%}$. Overfishing is defined as $F >$ MFMT and overfished as SSB $<$ MSST. However, if the stock is overfished, the rebuilding target would be $\mathrm{SSB}_{\mathrm{F}40\%}$. Current status of the stock is represented by SSB in the latest assessment year (2021), and current status of the fishery is represented by the geometric mean of F from the latest three years (2019–2021). Generally, South Atlantic assessments have considered the mean over the terminal three years to be a more robust metric than that of a single, terminal year.

2 Biological reference points

The original assessment reported an "MSY" reference point, but this was identified to be a maximum landed yield (i.e., not an equilibrium landing due to assuming a mean stock-recruitment model). Instead, this assessment used a proxy for MSY, based on $F_{40\%}$. That is, biological reference points (benchmarks) were calculated based on the fishing rate that would allow a stock to attain 40% of the maximum spawning potential which would have been obtained in the absence of fishing mortality. The value of $F_{40\%}$ was chosen here because of its commonality in fishery management and because it has been shown to be an effective proxy (e.g., Legault and Brooks (2013); Hartford et al. (2019)). The proxy of $F_{30\%}$ has been shown to be appropriate only for very resilient stocks (Brooks et al. 2010), and even $F_{40\%}$ might be an aggressive benchmark for some stocks (Clark 2002; Hartford et al. 2019; Zhou et al. 2020). Computed benchmarks included the MSY proxy, fishing mortality rate at $F_{40\%}$, total biomass at $F_{40\%}$, and spawning stock at $F_{40\%}$ (Gabriel and Mace 1999). In this revised analysis, spawning stock measures total biomass of the mature stock (males + females). These benchmarks are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. The selectivity pattern used here was the effort-weighted selectivities at age, with effort from each fleet estimated as the full F averaged over the last three years of the assessment.

3 Projection Methods

Projections were run to predict stock status in years after the assessment as requested, but with changes regarding the fishing mortality reference point (i.e., using $F_{40\%}$). Additionally, these projections use the P^* of 35% or 30% based on recommendations from the October black sea bass projections working group. These long-term projections were run using $F = 0$ to determine a rebuilding time frame because the recalculated stock status is overfished with three different assumptions regarding recruitment: long-term average, recent mean (2014-2019), and autoregressive deviates around the long-term average starting at the recent mean value in 2021. Additional scenarios that set the fishing mortality for the discards at recent F levels and the F for landings to $F_{40\%}$, P^* multipliers of $F_{40\%}$, and values that resulted in $1 - P^*$ probabilities of rebuilding within 10 years.

The structure of the projection model was the same as that of the assessment model, and parameter estimates were those from the assessment. Any time-varying quantities, such as selectivity curves, were fixed to the most recent values of the assessment period. As in the assessment, projected removals include landings and dead discards.

Expected values of SSB (time of peak spawning), F, recruits, removals, and the SERFS index were represented by deterministic projections using parameter estimates from the base run. These projections applied mean recruit with bias correction, and were thus consistent with estimated benchmarks in the sense that long-term fishing at $F_{40\%}$ would yield $L_{\mathrm{F40\%}}$ from a stock size at $\mathrm{SSB}_{\mathrm{F40\%}}$. Uncertainty in future time series was quantified through stochastic projections that extended the ensemble (MCBE) fits of the stock assessment model.

3.0.1 Landings and discards

Estimates of landings and discards from all fleets were obtained for 2022 using the same methods as in the assessment. Uncertainty in landings in 2022 were applied to projection calculations in the same manner as the MCBE analysis.

3.1 Initialization of projections

Initial age structure at the start of 2022 was computed by applying the 2021 age-dependent mortality (Z_a) to the 2021 abundance at age N_a, where both Z_a and N_a in 2021 were estimated by the assessment. The variability was added to the recent mean recruitment for 2020 and 2021 based on the recent standard deviation (2014-2019) from each MCBE iteration and carried forward to initialize the 2022 abundance at age using the estimated mortality.

Fishing rates that define the projections were assumed to start in 2025. Because the assessment period ended in 2021, the projections required an initialization period (2022–2024). Estimates of landings and discards for 2022 were used with the abundance in 2022, and selectivity estimates from the assessment to estimate the fishery specific fishing mortality rates. A maximum estimated fishing mortality of 5 was specified for each fleet. Fleet specific fishing mortalities were combined with natural mortality to progress the population to 2023. Recruitment in 2022 was assumed to equal either the long-term average, stayed at the recent average, or was an autoregressive deviate from depending on the scenario. Fishing mortality rates for the interim years 2023 and 2024 were set at the F that matched the current level of landings (arithmetic mean of 2019-2021).

3.2 Uncertainty of projections

To characterize uncertainty in future stock dynamics, stochasticity was included in replicate projections, each an extension of a single MCBE assessment model fit. Thus, projections carried forward uncertainties in natural mortality, indices, landings, discards, and discard mortality, as well as in estimated quantities such as mean recruitment, selectivity curves, and initial (start of 2022) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte-Carlo procedure, in which the estimated recruitment parameters (i.e. R_0, σ_R) of each MCBE fit was used to compute mean annual recruitment values ($\bar{R}_y = R_0$). Variability is added to the mean values by choosing multiplicative deviations at random from a lognormal distribution, $R_y = \bar{R}_y \exp(\epsilon_y)$. Here ϵ_y is drawn from a normal distribution with mean 0 and standard deviation σ_R, where σ_R is the standard deviation from the relevant MCBE fit.

The log deviates of the recruitment time series were fit to a first order autoregressive model that estimated the autocorrelation and the standard deviation for each MCBE model. Scenarios that assumed autoregressive recruitment deviates started from the deviate calculated for the mean recruitment value in 2021. $R_{y+1} = R_0 * \exp(\rho * \gamma_{y-1} + \delta_y)$. Here γ_{y-1} is the log-deviate from the previous year and R_0 is the assumed mean recruitment level, ρ is the MCBE estimated autocorrelation and δ_y is drawn from a normal distribution with mean 0 and standard deviation σ_R, where σ_R is the standard deviation from the relevant MCBE autocorrelated fit.

The procedure generated 20,000 replicate projections of MCBE model fits drawn at random (with replacement) from the MCBE runs. In cases where the same MCBE run was drawn, projections would still differ as a result of stochasticity in projected recruitment streams. Central tendencies were represented by the deterministic projections of the base run, as well as by medians of the stochastic projections. Precision of projections was represented graphically by the 5^{th} and 95^{th} percentiles of the replicate projections.

3.2.1 Rebuilding Time Frame and Generation Time

Based on the overfished stock status estimated by this assessment, black sea bass would enter a rebuilding plan. The projections with $F = 0$ are intended to help determine an appropriate rebuilding time-frame. In addition, the generation time was computed given the life-history characteristics of black sea bass and was found to be 6 years.

3.2.2 Projection Scenarios

Eleven projection scenarios are presented in this report. Three recruitment assumptions were modeled: long-term average recruitment (R0), recent mean recruitment (Rec-mu), and autoregressive recruitment deviates applied to the long-term average (AR). Two levels of discard were applied: proportional to landings (D_{prop}) and at current fishing mortality levels ($D_{current}$). The D_{current} is defined as the recent (2019–2021) average F estimated by the assessment multiplied by the selectivity for discard fleets. Fishing mortality for the landings was specified as 0, $F_{40\%}$, a P^* multiplier of $F_{40\%}$ ($P^*_{\%}$), or a fishing mortality that resulted in $1 - P^*$ probability of rebuilding in 10 years ($F_{R(1-P^*)\%}$). The F was then multiplied by the weighted landings selectivity from the assessment to calculate age specific fishing mortality to determine projection landings. Scenarios that assumed recent mean recruitment, current discard levels, and P^* multipliers of $F_{40\%}$ were created to be consistent with methods used to calculate ABC for scamp in SEDAR 68 and the requested projection scenario of $75\% F_{0.1}$. A scenario with long-term recruitment, current discard levels and $F_{40\%}$ was created to be used to calculate OFL levels in a manner consistent with scamp and the requested projections. The eleven scenarios presented are as follows:

- Scenario R0 D_{prop} F=0
- Scenario Rec-mu D_{prop} F=0
- Scenario AR D_{prop} F=0
- Scenario R0 $D_{current}$ F=0
- Scenario Rec-mu $D_{current}$ F=0
- Scenario AR $D_{current}$ F=0
- Scenario R0 $D_{current}$ $F = F_{R65\%}$
- Scenario R0 $D_{current}$ $F = F_{R70\%}$
- Scenario Rec-mu $D_{current}$ $F = P^{*}_{30} * F_{40\%}$
- Scenario Rec-mu $D_{current}$ $F = P^{*}_{35} * F_{40\%}$
- Scenario R0 $D_{current}$ $F = F_{40\%}$

4 Assessment and Projection Results

4.1 Benchmarks / Reference Points

As described in §1.1, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics and estimated selectivities. Reference points estimated were $F_{40\%}$, $L_{\mathrm{F40\%}}$, $B_{\mathrm{F40\%}}$, and $\mathrm{SSB}_{\mathrm{F40\%}}$. Based on $F_{40\%}$, an optimum yield (OY) was considered, $F_{\mathrm{OY}} = 75\% F_{40\%}$, and the corresponding yield was computed. Standard errors of benchmarks were approximated as those from MCBE analysis (See assessment report for description of methods).

Maximum likelihood estimates (base run) of benchmarks, as well as median values from MCBE analysis, are summarized in Table 1. Point estimates of reference points were $F_{40\%} = 1.18$ (y^{-1}), $L_{\mathrm{F40\%}} = 674.53$ (1000 lb), $B_{\mathrm{F40\%}} = 17688.58$ (mt), and $\mathrm{SSB}_{\mathrm{F40\%}} = 8736.42$ (mt). Median estimates were $F_{40\%} = 1.28$ (y^{-1}), $L_{\mathrm{F40\%}} = 492.38$ (1000 lb), $B_{\mathrm{F40\%}} = 22071.29$ (mt), and $\mathrm{SSB}_{\mathrm{F40\%}} = 10219.24$ (mt). Distributions of these benchmarks from the MCBE analysis are shown in Figure 4.

Reference points were also calculated for $F_{30\%}$ as a reference, but are not intended to be used for management purposes Table 2.

4.1.1 Status of the Stock and Fishery

Estimated time series of stock status (SSB/MSST and $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{F40\%}}$) showed general decline until the mid-1990s, followed by a marginal increase until 2012 and since then decreased to below 1 (Figure 5 and Table 1). The increase in stock status appears to have been initiated by strong year classes in 2008 to 2010. The decline in stock status since appears to be due to decreased recruitment but coincides with changes in management regulations. Base-run estimates of spawning biomass have remained above MSST and $\mathrm{SSB}_{\mathrm{MSY}}$ since the early 1990s, increased slightly from 2008 to 2011, and then decreased substantially in the last ten years. Current stock status was estimated in the base run to be $\mathrm{SSB}_{2021}/\mathrm{MSST} = 0.57$ and $\mathrm{SSB}_{2021}/\mathrm{SSB}_{\mathrm{MSY}} = 0.36$ (Table 1), indicating that the stock is overfished. Uncertainty from the MCBE analysis suggested that the estimate of SSB relative to $\mathrm{SSB}_{\mathrm{MSY}}$ is robust but that the status relative to MSST is less certain (Figures 6 and 7). More specifically, 100% of MCBE runs indicate the stock is below $\mathrm{SSB}_{\mathrm{F40\%}}$, while 69.6% are below MSST indicating an overfished status.

The estimated time series of $F/F_{40\%}$ are highly uncertain and have a small probability that overfishing has been occurring throughout the assessment period (Figure 5). The new reference point of $F_{40\%}$ suggest that the stock has approached overfishing in recent years but has only occasionally exceeded it (Table 1). However, the fishery benchmark is based on the last three years of selectivity and fishing mortality, and may not be appropriate to compare to earlier years as the selectivity and the proportional contributions of the fleets to the total fishing mortality have changed through time. Current fishery status in the terminal year, with current F represented by the geometric mean from 2019–2021, was estimated by the base run to be $F_{2019-2021}/F_{\text{MSY}} = 0.79$ (Table 1), and only 37.1% of MCBE trials indicated there is a chance overfishing is occurring (Figures 6 and 7). However, 62.9% of the MCBE runs agree with the base model suggesting that overfishing is not occurring.

4.2 Projections

Projections based on $F = 0$ with long-term, average recruitment or autocorrelated recruitment deviates allowed the spawning stock to increase quickly, achieving greater than 70% chance of recovery by 2027 and greater than 95% chance by 2031 (Figures 8, 9, 12 and 13 and Tables 3 and 5). Thus, given that the stock can recover (probabilistically) within 10 years under $F = 0$, the rebuilding time-frame would equal 10 years. Assuming that the start year of a recovery plan would be 2025, the time frame of rebuilding would last until the end of 2034. However, based on $F = 0$ and recent average recruitment the spawning stock is never able to rebuild to long-term average reference levels (Figures 10 and 11 and Table 4). For the scenario that assumes the discard levels remain at current fishing levels, but no landed fish, and long-term average recruitment the population is able to rebuild with above 70% probability by 2031 (Figures 14 and 15 and Table 6). However, for similar scenarios that assume recent mean recruitment or autocorrelated deviates the population cannot recover with above 70% probability, though the latter does exceed 50% recovery probability after 10 years (Figures 16 to 19 and Tables 7 and 8).

The scenarios that assume long-term average recruitment and recent discard fishing levels that rebuild with 70% and 65% probability within 10 years allow for a 13% and 33% multiplier on $F_{40\%}$ for the landed fish (Figures 20 to 23 and Tables 9 and 10).

Scenarios designed to calculate ABC levels for different P-Stars (30 and 35%) were conducted. These scenarios never exceeded more than a 1% probability of rebuilding and had a wide range of fishing mortality (Figures 26 to 29 and Tables 11 and 12).

The scenario that was created to calculate OFL consistent with the methods used for scamp is shown in Figures 28 and 29 and Table 13. This scenarios resulted in a 57.2% probability of rebuilding within 10 years.

5 Discussion

5.1 Comments on the Projections

As usual, projections should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.

- Landings and discarding rates were assumed to continue at their estimated current selectivity patterns. New management regulations that alter selectivities would likely affect projection results.
- The projections assumed no change in the selectivity applied to discards. As stock increase generally begins with the smallest size classes, management action may be needed to meet that assumption.
- Projections apply the Baranov catch equation to relate F and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures are in effect, introducing additional and unquantified uncertainty into the projection results.
- Changing the proportion of discards to landings in the projections will ultimately result in a change in reference point due to changes in the weighted selectivity. However, changes to the reference points were not calculated and benchmarks in figures were those estimated for the last 3 years of the assessment.
- Projection results were highly dependent on assumptions regarding future recruitment. The recent average recruitment scenarios implicitly assume a regime shift in the productivity of the stock, but there is currently not sufficient evidence to support such a conclusion. However, whether recruitment can return to long-term average levels quickly is unknown. The scenarios with the autoregressive recruitment were proposed as an option that allows for a transition from recent low levels to long-term average based on the observed data.

6 References

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7 Tables

Table 1. Estimated status indicators, benchmarks, and related quantities for $F_{40\%}$ from the base run of the BAM, conditional on estimated current selectivities averaged across fleets. Also presented are median values and measures of precision (standard errors, SE) from the Monte Carlo/Bootstrap ensemble analysis. Rate estimates (F) are in units of y^{-1}; status indicators are dimensionless; biomass estimates are in units of thousands of pounds, as indicated. Spawning stock biomass (SSB) is measured as weight of mature fish in thousands of pounds. L_{current} and D_{current} are the average landings and discards from 2019–2021, respectively. Estimates of yield do not include discards; $D_{\mathrm{F40\%}}$ represents discard mortalities expected when fishing at $F_{40\%}$.

Quantity	Units	Estimate	Median	SE
$F_{40\%}$	y^{-1}	1.18	1.28	1.36
$B_{\mathrm{F40\%}}$	1000 lb	17688.58	22071.29	18851.44
$\mathrm{SSB}_{\mathrm{F40\%}}$	1000 lb	8736.42	10219.24	1951.55
MSST	1000 lb	5460.26	5807.19	1152.61
$L_{\mathrm{F40\%}}$	1000 lb	674.53	492.38	367.25
$L_{75\%\mathrm{F40\%}}$	1000 lb	808.39	633.13	356.01
L_{current}	1000 lb	544.23	536.40	65.80
$D_{\mathrm{F40\%}}$	1000 dead fish	4530.85	6599.32	7825.67
$D_{\mathrm{F40\%}}$ klb	1000 lb	1901.63	2655.96	2374.23
$D_{75\%\mathrm{F40\%}}$	1000 dead fish	3678.27	2285.27	2220.61
$D_{75\%\mathrm{F40\%}}$ klb	1000 lb	1592.67	2285.27	2220.61
D_{current}	1000 dead fish	935.34	1242.30	530.60
D_{current} klb	1000 lb	437.42	575.19	234.03
$F_{2019-2021}/F_{40\%}$	—	0.79	0.61	1.14
$\mathrm{SSB}_{2021}/\mathrm{MSST}$	—	0.57	0.72	0.41
$\mathrm{SSB}_{2021}/\mathrm{SSB}_{\mathrm{F40\%}}$	—	0.36	0.42	0.27

Table 2. Estimated status indicators, benchmarks, and related quantities for $F_{30\%}$ from the base run of the BAM, conditional on estimated current selectivities averaged across fleets. Also presented are median values and measures of precision (standard errors, SE) from the Monte Carlo/Bootstrap ensemble analysis. Rate estimates (F) are in units of y^{-1}; status indicators are dimensionless; biomass estimates are in units of thousands of pounds, as indicated. Spawning stock biomass (SSB) is measured as weight of mature fish in thousands of pounds. L_{current} and D_{current} are the average landings and discards from 2019–2021, respectively. Estimates of yield do not include discards; $D_{\mathrm{F30\%}}$ represents discard mortalities expected when fishing at $F_{30\%}$.

Quantity	Units	Estimate	Median	SE
$F_{30\%}$	y^{-1}	2.11	2.38	1.71
$B_{\mathrm{F30\%}}$	1000 lb	15362.20	19631.47	19323.52
$\mathrm{SSB}_{\mathrm{F30\%}}$	1000 lb	6552.58	7730.90	2327.61
MSST	1000 lb	4095.36	4556.86	933.88
$F_{30\%}$	1000 lb	363.87	243.58	316.19
$L_{75\%\mathrm{F30\%}}$	1000 lb	516.47	369.24	355.25
L_{current}	1000 lb	544.23	536.40	65.80
$D_{\mathrm{F30\%}}$	1000 dead fish	6519.88	9280.22	9131.64
$D_{\mathrm{F30\%}}$ klb	1000 lb	2503.50	3343.97	2464.99
$D_{75\%\mathrm{F30\%}}$	1000 dead fish	5502.56	3033.90	2345.73
$D_{75\%\mathrm{F30\%}}$ klb	1000 lb	2218.17	3033.90	2345.73
D_{current}	1000 dead fish	935.34	1242.30	530.60
D_{current} klb	1000 lb	437.42	575.19	234.03
$F_{2019-2021}/F_{30\%}$	—	0.44	0.33	0.70
$\mathrm{SSB}_{2021}/\mathrm{MSST}$	—	0.76	0.95	0.46
$\mathrm{SSB}_{2021}/\mathrm{SSB}_{\mathrm{F30\%}}$	—	0.47	0.54	0.17

Table 3. Projection results with fishing mortality rate fixed at $F = 0$ starting in 2025 and longterm recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F40\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	71	116	3.235	2.315	2287	2995	452	421	534	487	1215	1621	432	563	0.002
2023	71	115	0.936	0.801	3403	4659	105	113	106	119	1458	1910	497	624	0.080
2024	71	114	0.936	0.801	5262	7178	135	133	130	133	2472	3291	885	1154	0.286
2025	71	116	0.000	0.000	7079	9597	0	0	0	0	0	0	0	0	0.486
2026	71	114	0.000	0.000	9419	12675	0	0	0	0	0	0	0	0	0.697
2027	71	115	0.000	0.000	11418	15194	0	0	0	0	0	0	0	0	0.843
2028	71	114	0.000	0.000	13070	17311	0	0	0	0	0	0	0	0	0.937
2029	71	115	0.000	0.000	14408	19014	0	0	0	0	0	0	0	0	0.982
2030	71	114	0.000	0.000	15476	20394	0	0	0	0	0	0	0	0	0.996
2031	71	115	0.000	0.000	16319	21526	0	0	0	0	0	0	0	0	1.000
2032	71	116	0.000	0.000	16977	22361	0	0	0	0	0	0	0	0	1.000
2033	71	115	0.000	0.000	17487	23077	0	0	0	0	0	0	0	0	1.000
2034	71	115	0.000	0.000	17868	23704	0	0	0	0	0	0	0	0	1.000
2035	71	115	0.000	0.000	18148	24121	0	0	0	0	0	0	0	0	1.000
2036	71	115	0.000	0.000	18353	24434	0	0	0	0	0	0	0	0	1.000
2037	71	115	0.000	0.000	18503	24684	0	0	0	0	0	0	0	0	1.000
2038	71	115	0.000	0.000	18614	24892	0	0	0	0	0	0	0	0	1.000
2039	71	114	0.000	0.000	18694	25025	0	0	0	0	0	0	0	0	1.000

Table 4. Projection results with fishing mortality rate fixed at $F = 0$ starting in 2025 and recent average recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F40\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	25	44	3.247	2.356	2276	2978	451	420	534	489	1215	1627	460	604	0.002
2023	25	43	0.936	0.801	2471	3377	106	115	107	120	60	159	9	22	0.007
2024	25	43	0.936	0.801	3152	4414	160	158	154	160	63	166	10	25	0.017
2025	25	43	0.000	0.000	3756	5351	0	0	0	0	64	170	12	29	0.032
2026	25	43	0.000	0.000	4355	6226	0	0	0	0	65	173	13	33	0.054
2027	25	43	0.000	0.000	4842	6962	0	0	0	0	66	175	15	35	0.082
2028	25	43	0.000	0.000	5230	7529	0	0	0	0	67	176	15	38	0.109
2029	25	43	0.000	0.000	5537	7985	0	0	0	0	67	178	16	40	0.140
2030	25	43	0.000	0.000	5777	8349	0	0	0	0	67	177	17	41	0.172
2031	25	43	0.000	0.000	5963	8629	0	0	0	0	68	178	17	43	0.198
2032	25	43	0.000	0.000	6102	8843	0	0	0	0	68	179	18	43	0.225
2033	25	43	0.000	0.000	6205	8990	0	0	0	0	68	178	18	44	0.247
2034	25	44	0.000	0.000	6280	9115	0	0	0	0	68	179	18	45	0.267
2035	25	43	0.000	0.000	6335	9214	0	0	0	0	68	178	18	45	0.280
2036	25	43	0.000	0.000	6375	9291	0	0	0	0	68	179	18	45	0.293
2037	25	43	0.000	0.000	6404	9328	0	0	0	0	68	178	18	46	0.299
2038	25	44	0.000	0.000	6426	9368	0	0	0	0	68	179	18	46	0.308
2039	25	43	0.000	0.000	6441	9396	0	0	0	0	68	179	18	46	0.312

Table 5. Projection results with fishing mortality rate fixed at $F = F0$ starting in 2025 and autocorrelated recruitment deviates starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F40\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	71	55	3.235	2.381	2287	2972	452	420	534	487	1215	1625	432	598	0.002
2023	71	65	0.936	0.801	3403	3385	105	109	106	116	1458	1451	497	544	0.005
2024	71	75	0.936	0.801	5262	4240	135	122	130	127	2472	1885	885	723	0.029
2025	71	83	0.000	0.000	7079	5513	0	0	0	0	0	0	0	0	0.114
2026	71	90	0.000	0.000	9419	7589	0	0	0	0	0	0	0	0	0.278
2027	71	96	0.000	0.000	11418	9656	0	0	0	0	0	0	0	0	0.449
2028	71	99	0.000	0.000	13070	11667	0	0	0	0	0	0	0	0	0.603
2029	71	102	0.000	0.000	14408	13497	0	0	0	0	0	0	0	0	0.727
2030	71	105	0.000	0.000	15476	15152	0	0	0	0	0	0	0	0	0.814
2031	71	107	0.000	0.000	16319	16636	0	0	0	0	0	0	0	0	0.870
2032	71	108	0.000	0.000	16977	17905	0	0	0	0	0	0	0	0	0.907
2033	71	109	0.000	0.000	17487	19020	0	0	0	0	0	0	0	0	0.932
2034	71	111	0.000	0.000	17868	20011	0	0	0	0	0	0	0	0	0.949
2035	71	111	0.000	0.000	18148	20920	0	0	0	0	0	0	0	0	0.959
2036	71	112	0.000	0.000	18353	21605	0	0	0	0	0	0	0	0	0.966
2037	71	113	0.000	0.000	18503	22168	0	0	0	0	0	0	0	0	0.972
2038	71	114	0.000	0.000	18614	22633	0	0	0	0	0	0	0	0	0.975
2039	71	113	0.000	0.000	18694	22971	0	0	0	0	0	0	0	0	0.978

Table 6. Projection results with fishing mortality rate fixed at $F_{\text{Landed}} = 0$ and $F_{\text{Discard}} = F_{\text{current}}$ starting in 2025 and longterm recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\text{SSB} \geq \text{SSB}_{\text{F40\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	71	115	3.235	2.352	2287	2986	452	422	534	489	1215	1626	432	566	0.002
2023	71	115	0.938	0.803	3534	4773	110	119	109	122	155	375	17	39	0.057
2024	71	114	0.938	0.803	5964	7837	174	171	161	166	170	404	23	51	0.321
2025	71	114	0.003	0.004	8322	10728	0	0	0	0	178	422	29	63	0.556
2026	71	115	0.003	0.004	10468	13302	0	0	0	0	184	435	34	73	0.727
2027	71	115	0.003	0.004	12253	15484	0	0	0	0	188	444	38	82	0.837
2028	71	114	0.003	0.004	13704	17340	0	0	0	0	190	448	41	89	0.901
2029	71	114	0.003	0.004	14866	18756	0	0	0	0	192	454	44	95	0.936
2030	71	114	0.003	0.004	15785	19932	0	0	0	0	193	453	46	100	0.954
2031	71	114	0.003	0.004	16504	20876	0	0	0	0	194	454	48	104	0.965
2032	71	114	0.003	0.004	17060	21559	0	0	0	0	195	456	49	106	0.972
2033	71	114	0.003	0.004	17485	22075	0	0	0	0	195	456	50	109	0.976
2034	71	114	0.003	0.004	17795	22503	0	0	0	0	195	457	51	111	0.979
2035	71	114	0.003	0.004	18022	22928	0	0	0	0	196	457	52	112	0.980
2036	71	114	0.003	0.004	18188	23226	0	0	0	0	196	458	52	114	0.981
2037	71	115	0.003	0.004	18309	23347	0	0	0	0	196	459	52	115	0.982
2038	71	115	0.003	0.004	18398	23528	0	0	0	0	196	463	53	115	0.982
2039	71	114	0.003	0.004	18463	23598	0	0	0	0	196	460	53	116	0.983

Table 7. Projection results with fishing mortality rate fixed at $F_{\mathrm{Landed}} = 0$ and $F_{\mathrm{Discard}} = F_{\mathrm{current}}$ starting in 2025 and recent average recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F40\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	25	44	3.247	2.363	2276	2971	451	419	534	488	1215	1627	460	603	0.002
2023	25	43	0.938	0.803	2471	3371	106	114	107	120	60	159	9	21	0.007
2024	25	43	0.938	0.803	3152	4410	160	158	154	160	63	166	10	25	0.017
2025	25	43	0.003	0.004	3756	5349	0	0	0	0	64	170	12	29	0.032
2026	25	43	0.003	0.004	4355	6227	0	0	0	0	65	173	13	33	0.055
2027	25	43	0.003	0.004	4842	6961	0	0	0	0	66	176	15	35	0.081
2028	25	43	0.003	0.004	5230	7532	0	0	0	0	67	176	15	38	0.109
2029	25	43	0.003	0.004	5537	7988	0	0	0	0	67	178	16	40	0.140
2030	25	43	0.003	0.004	5777	8347	0	0	0	0	67	177	17	41	0.171
2031	25	43	0.003	0.004	5963	8627	0	0	0	0	68	178	17	43	0.197
2032	25	43	0.003	0.004	6102	8844	0	0	0	0	68	179	18	43	0.225
2033	25	43	0.003	0.004	6205	8988	0	0	0	0	68	178	18	44	0.247
2034	25	44	0.003	0.004	6280	9115	0	0	0	0	68	179	18	45	0.267
2035	25	43	0.003	0.004	6335	9215	0	0	0	0	68	178	18	45	0.279
2036	25	43	0.003	0.004	6375	9292	0	0	0	0	68	179	18	45	0.293
2037	25	43	0.003	0.004	6404	9330	0	0	0	0	68	178	18	46	0.299
2038	25	44	0.003	0.004	6426	9368	0	0	0	0	68	179	18	46	0.308
2039	25	43	0.003	0.004	6441	9397	0	0	0	0	68	179	18	46	0.312

Table 8. Projection results with fishing mortality rate fixed at $F_{\mathrm{Landed}} = 0$ and $F_{\mathrm{Discard}} = F_{\mathrm{current}}$ with autocorrelated recruitment starting in 2025 and autocorrelated deviates around the long-term average recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F40\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	71	55	3.235	2.389	2287	2973	452	421	534	488	1215	1621	432	595	0.002
2023	71	65	0.936	0.801	3403	3386	105	109	106	116	1458	1453	497	544	0.005
2024	71	75	0.936	0.801	5262	4246	135	122	130	127	2472	1886	885	723	0.029
2025	71	83	0.380	0.403	6710	5216	0	0	0	0	3174	2308	1299	912	0.101
2026	71	90	0.380	0.403	7730	6234	0	0	0	0	3336	2687	1433	1079	0.194
2027	71	96	0.380	0.403	8485	7233	0	0	0	0	3360	3012	1459	1231	0.278
2028	71	99	0.380	0.403	9081	8092	0	0	0	0	3363	3269	1462	1352	0.350
2029	71	102	0.380	0.403	9557	8868	0	0	0	0	3363	3477	1462	1447	0.412
2030	71	105	0.380	0.403	9935	9546	0	0	0	0	3363	3666	1462	1531	0.463
2031	71	107	0.380	0.403	10230	10124	0	0	0	0	3363	3798	1462	1598	0.503
2032	71	108	0.380	0.403	10459	10690	0	0	0	0	3363	3891	1462	1637	0.537
2033	71	109	0.380	0.403	10634	11162	0	0	0	0	3363	3960	1462	1670	0.566
2034	71	111	0.380	0.403	10763	11510	0	0	0	0	3363	4039	1462	1701	0.587
2035	71	111	0.380	0.403	10857	11814	0	0	0	0	3363	4079	1462	1732	0.602
2036	71	112	0.380	0.403	10926	12055	0	0	0	0	3363	4139	1462	1755	0.617
2037	71	113	0.380	0.403	10976	12298	0	0	0	0	3363	4164	1462	1773	0.630
2038	71	114	0.380	0.403	11013	12488	0	0	0	0	3363	4175	1462	1776	0.643
2039	71	113	0.380	0.403	11041	12599	0	0	0	0	3363	4207	1462	1785	0.653

Table 9. Projection results with fishing mortality rate fixed at $F_{\text{Landed}} = F_{\text{Rebuild65\%}}$ *and* $F_{\text{Discard}} = F_{\text{current}}$ *starting in 2025 and longterm recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000* lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\text{SSB} \geq \text{SSB}_{\text{F40\%}}$*. The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	71	116	3.235	2.330	2287	2988	452	422	534	489	1215	1618	432	560	0.002
2023	71	115	0.936	0.801	3403	4656	105	112	106	119	1458	1912	497	624	0.080
2024	71	114	0.936	0.801	5262	7176	135	133	130	132	2472	3291	885	1155	0.286
2025	71	116	0.389	0.659	6685	9003	88	109	82	102	3168	4255	1295	1701	0.444
2026	71	114	0.389	0.659	7618	10118	149	179	146	171	3324	4459	1424	1870	0.525
2027	71	115	0.389	0.659	8238	10807	222	262	232	265	3345	4486	1447	1894	0.578
2028	71	114	0.389	0.659	8641	11260	302	350	341	381	3347	4489	1449	1904	0.610
2029	71	115	0.389	0.659	8873	11438	350	398	416	456	3347	4483	1449	1895	0.629
2030	71	114	0.389	0.659	8999	11579	374	423	457	497	3347	4488	1449	1902	0.639
2031	71	115	0.389	0.659	9066	11618	386	433	479	519	3347	4475	1449	1894	0.645
2032	71	116	0.389	0.659	9101	11626	391	440	491	530	3347	4464	1449	1893	0.646
2033	71	115	0.389	0.659	9120	11700	394	445	497	537	3347	4457	1449	1894	0.647
2034	71	115	0.389	0.659	9129	11704	396	444	500	539	3347	4462	1449	1888	0.650
2035	71	115	0.389	0.659	9133	11745	396	443	502	543	3347	4480	1449	1903	0.649
2036	71	115	0.389	0.659	9136	11685	397	445	503	543	3347	4464	1449	1897	0.652
2037	71	115	0.389	0.659	9137	11719	397	446	503	545	3347	4486	1449	1904	0.653
2038	71	115	0.389	0.659	9137	11723	397	445	503	546	3347	4462	1449	1889	0.652
2039	71	114	0.389	0.659	9138	11774	397	445	503	546	3347	4490	1449	1895	0.654

Table 10. Projection results with fishing mortality rate fixed at $F_{\mathrm{Landed}} = F_{\mathrm{Rebuild70\%}}$ and $F_{\mathrm{Discard}} = F_{\mathrm{current}}$ starting in 2025 and longterm recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb*), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000* lb*), pr.reb = proportion of stochastic projection replicates with* $\mathrm{SSB} \geq \mathrm{SSB}_{\mathrm{F40\%}}$. *The extension* b *indicates expected values (deterministic) from the base run; the extension* med *indicates median values from the stochastic projections.*

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	71	116	3.235	2.355	2287	2986	452	422	534	488	1215	1617	432	561	0.002
2023	71	115	0.936	0.801	3403	4661	105	113	106	118	1458	1913	497	623	0.080
2024	71	114	0.936	0.801	5262	7180	135	133	130	133	2472	3288	885	1154	0.286
2025	71	116	0.383	0.474	6700	9022	36	45	34	42	3172	4258	1298	1706	0.446
2026	71	114	0.383	0.474	7683	10215	63	76	64	75	3331	4470	1429	1879	0.533
2027	71	115	0.383	0.474	8378	10990	98	116	106	121	3354	4500	1454	1906	0.590
2028	71	114	0.383	0.474	8883	11541	139	161	163	183	3356	4505	1456	1917	0.628
2029	71	115	0.383	0.474	9238	11852	169	193	210	231	3356	4497	1457	1906	0.654
2030	71	114	0.383	0.474	9480	12116	188	212	243	265	3356	4501	1457	1914	0.671
2031	71	115	0.383	0.474	9643	12240	199	223	265	288	3356	4491	1457	1906	0.681
2032	71	116	0.383	0.474	9751	12338	206	231	280	301	3356	4482	1457	1904	0.691
2033	71	115	0.383	0.474	9823	12467	211	235	290	311	3356	4473	1457	1907	0.695
2034	71	115	0.383	0.474	9868	12478	214	237	296	316	3356	4477	1457	1900	0.700
2035	71	115	0.383	0.474	9896	12548	215	239	300	320	3356	4495	1457	1915	0.705
2036	71	115	0.383	0.474	9914	12516	217	240	302	322	3356	4480	1457	1909	0.706
2037	71	115	0.383	0.474	9925	12569	217	241	304	323	3356	4503	1457	1916	0.710
2038	71	115	0.383	0.474	9932	12582	218	241	305	326	3356	4480	1457	1902	0.709
2039	71	114	0.383	0.474	9936	12607	218	240	305	327	3356	4504	1457	1909	0.712

Table 11. Projection results with fishing mortality rate fixed at $F_{\text{Landed}} = F_{\text{PStar30\%}}$ and $F_{\text{Discard}} = F_{\text{current}}$ starting in 2025 and recent average recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.reb = proportion of stochastic projection replicates with SSB $\geq$ $\text{SSB}_{\text{F40\%}}$. The extension b indicates expected values (deterministic) from the base run; the extension med indicates median values from the stochastic projections.

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	25	44	3.247	2.380	2276	2970	451	420	534	488	1215	1625	460	602	0.002
2023	25	43	0.936	0.801	2350	3187	101	108	104	115	1066	1371	432	532	0.005
2024	25	43	0.936	0.801	2609	3610	123	120	124	126	1139	1580	483	643	0.008
2025	25	43	0.671	0.852	2784	3863	115	139	117	141	1157	1667	498	698	0.010
2026	25	43	0.671	0.852	2907	4025	149	173	161	181	1160	1700	501	715	0.010
2027	25	43	0.671	0.852	2968	4095	169	197	190	212	1161	1701	501	720	0.009
2028	25	43	0.671	0.852	2994	4145	178	209	204	230	1161	1694	501	719	0.011
2029	25	43	0.671	0.852	3005	4169	181	215	210	238	1161	1691	501	716	0.011
2030	25	43	0.671	0.852	3010	4185	182	217	213	242	1161	1699	501	718	0.011
2031	25	43	0.671	0.852	3011	4173	183	219	213	245	1161	1687	501	717	0.011
2032	25	43	0.671	0.852	3012	4178	183	219	214	246	1161	1683	501	714	0.011
2033	25	43	0.671	0.852	3012	4184	183	219	214	246	1161	1682	501	714	0.010
2034	25	44	0.671	0.852	3012	4173	183	219	214	247	1161	1687	501	715	0.011
2035	25	43	0.671	0.852	3012	4178	183	218	214	247	1161	1691	501	718	0.011
2036	25	43	0.671	0.852	3012	4184	183	219	214	247	1161	1694	501	717	0.010
2037	25	43	0.671	0.852	3012	4188	183	218	214	247	1161	1692	501	719	0.011
2038	25	44	0.671	0.852	3012	4174	183	218	214	246	1161	1685	501	713	0.010
2039	25	43	0.671	0.852	3012	4178	183	219	214	247	1161	1692	501	714	0.009

Table 12. Projection results with fishing mortality rate fixed at $F_{\text{Landed}} = F_{\text{PStar35\%}}$ and $F_{\text{Discard}} = F_{\text{current}}$ starting in 2025 and recent average recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.reb = proportion of stochastic projection replicates with $\text{SSB} \geq \text{SSB}_{\text{F40\%}}$. The extension b indicates expected values (deterministic) from the base run; the extension med indicates median values from the stochastic projections.

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	25	44	3.247	2.370	2276	2975	451	420	534	489	1215	1622	460	601	0.002
2023	25	43	0.936	0.801	2350	3186	101	108	104	115	1066	1372	432	532	0.005
2024	25	43	0.936	0.801	2609	3607	123	121	124	127	1139	1579	483	642	0.008
2025	25	43	0.794	0.936	2778	3857	133	161	135	162	1156	1664	497	696	0.010
2026	25	43	0.794	0.936	2885	3994	168	196	180	201	1159	1698	499	713	0.009
2027	25	43	0.794	0.936	2933	4057	187	218	207	231	1159	1698	500	718	0.009
2028	25	43	0.794	0.936	2953	4104	194	230	219	247	1159	1692	500	716	0.010
2029	25	43	0.794	0.936	2960	4119	197	235	223	254	1159	1688	500	714	0.011
2030	25	43	0.794	0.936	2962	4131	197	237	225	258	1159	1696	500	717	0.010
2031	25	43	0.794	0.936	2963	4121	198	238	225	260	1159	1684	500	715	0.010
2032	25	43	0.794	0.936	2964	4121	198	238	225	261	1159	1680	500	712	0.010
2033	25	43	0.794	0.936	2964	4128	198	238	225	261	1159	1679	500	712	0.010
2034	25	44	0.794	0.936	2964	4115	198	238	225	262	1159	1684	500	712	0.010
2035	25	43	0.794	0.936	2964	4117	198	238	225	262	1159	1689	500	715	0.011
2036	25	43	0.794	0.936	2964	4126	198	238	225	261	1159	1692	500	715	0.010
2037	25	43	0.794	0.936	2964	4130	198	237	225	262	1159	1689	500	717	0.011
2038	25	44	0.794	0.936	2964	4119	198	237	225	261	1159	1683	500	712	0.010
2039	25	43	0.794	0.936	2964	4117	198	237	225	262	1159	1689	500	712	0.009

Table 13. Projection results with fishing mortality rate fixed at $F_{\text{Landed}} = F_{40\%}$ and $F_{\text{Discard}} = F_{\text{current}}$ starting in 2025 and longterm recruitment starting in 2023. R = number of age-0 recruits (in millions), F = fishing mortality rate (per year), S = spawning stock (1000 lb), L = landings and D = discards expressed in numbers (n, in 1000s) or whole weight (w, in 1000 lb), pr.reb = proportion of stochastic projection replicates with $\text{SSB} \geq \text{SSB}_{\text{F40\%}}$. The extension b indicates expected values (deterministic) from the base run; the extension med indicates median values from the stochastic projections.

Year	R.b	R.med	F.b	F.med	S.b	S.med	L.b(n)	L.med(n)	L.b(w)	L.med(w)	D.b(n)	D.med(n)	D.b(w)	D.med(w)	pr.reb
2022	71	116	3.235	2.330	2287	2988	452	421	534	489	1215	1621	432	562	0.002
2023	71	115	0.936	0.801	3403	4657	105	113	106	118	1458	1910	497	624	0.080
2024	71	114	0.936	0.801	5262	7185	135	133	130	132	2472	3290	885	1155	0.287
2025	71	116	1.178	1.286	6639	8924	242	299	219	268	3156	4234	1287	1688	0.436
2026	71	114	1.178	1.286	7441	9875	367	442	334	389	3300	4420	1406	1843	0.507
2027	71	115	1.178	1.286	7906	10375	510	605	492	562	3317	4442	1424	1859	0.550
2028	71	114	1.178	1.286	8122	10609	628	732	647	725	3318	4440	1426	1867	0.568
2029	71	115	1.178	1.286	8186	10665	665	766	702	779	3318	4437	1426	1858	0.572
2030	71	114	1.178	1.286	8202	10703	673	775	717	797	3318	4441	1426	1866	0.576
2031	71	115	1.178	1.286	8206	10679	675	782	720	806	3318	4431	1426	1858	0.572
2032	71	116	1.178	1.286	8207	10644	675	780	721	806	3318	4423	1426	1856	0.571
2033	71	115	1.178	1.286	8207	10703	675	781	721	808	3318	4416	1426	1858	0.572
2034	71	115	1.178	1.286	8207	10684	675	778	721	811	3318	4415	1426	1855	0.572
2035	71	115	1.178	1.286	8207	10715	675	779	721	805	3318	4435	1426	1866	0.572
2036	71	115	1.178	1.286	8207	10680	675	784	721	806	3318	4422	1426	1861	0.574
2037	71	115	1.178	1.286	8207	10699	675	780	721	809	3318	4442	1426	1867	0.573
2038	71	115	1.178	1.286	8207	10694	675	781	721	808	3318	4415	1426	1854	0.573
2039	71	114	1.178	1.286	8207	10727	675	781	721	807	3318	4438	1426	1859	0.576

8 Figures

*Figure 1. Estimated time series of static spawning potential ratio, the annual equilibrium spawners per recruit relative to that at the unfished level for various ways to calculate spawning potential. The vertical lines indicate fishing mortality rates where 40% of unfished SPR is obtained. Eggs is female fecundity, Mature Weight is the sum of male and female mature biomass, Eggs*Male Wgt is the product of female fecundity and male mature biomass, Egg*Male N is the product of female fecundity and male mature abundance, Mature N is the abundance of mature fish, and Female*Male is the produce of female abundance and Male abundance.*

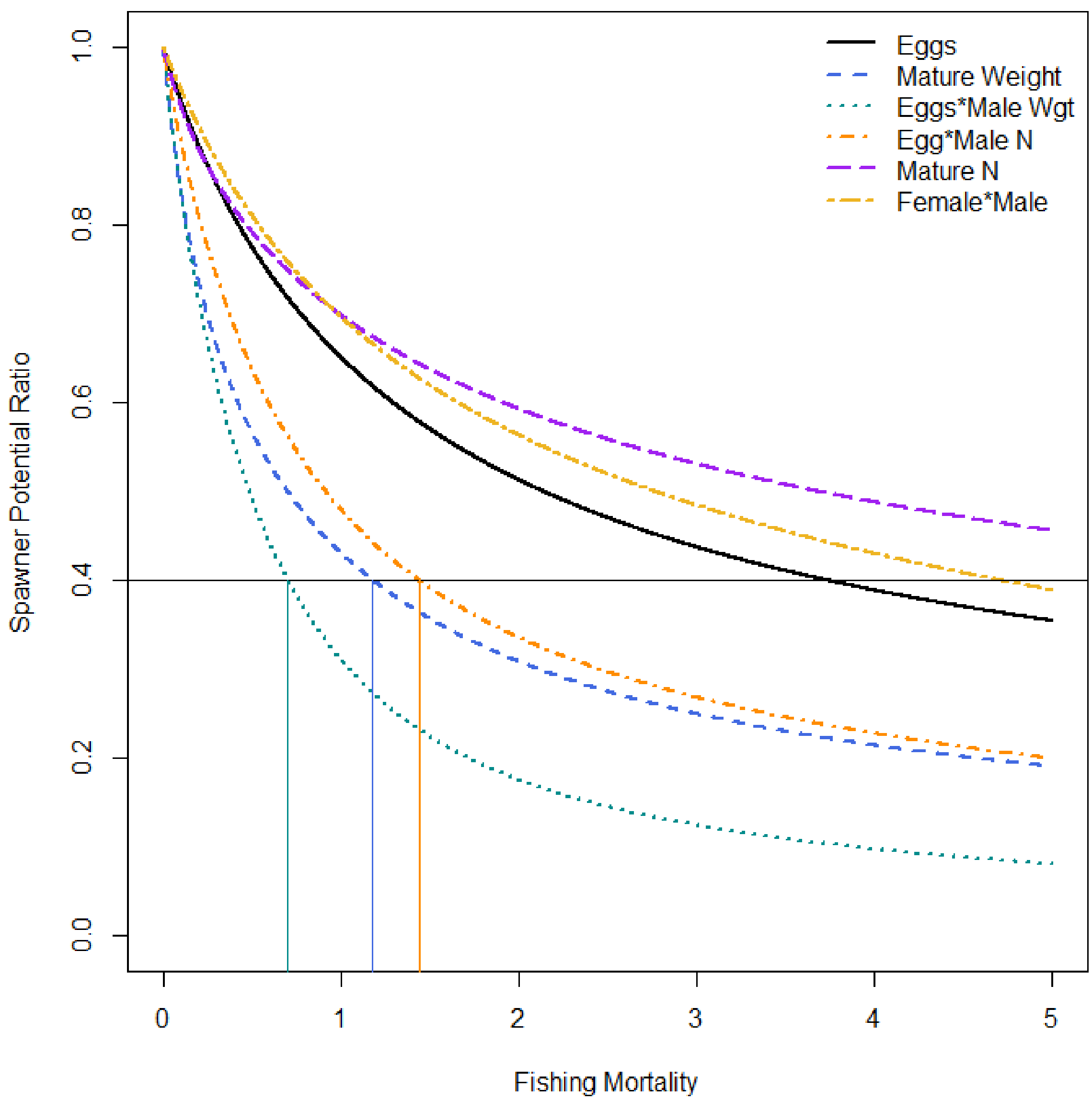


*Figure 2. Time series of spawning stock calculated by various metrics of spawning potential. Eggs is female fecundity, Mature Weight is the sum of male and female mature biomass, Eggs*Male Wgt is the product of female fecundity and male mature biomass, Egg*Male N is the product of female fecundity and male mature abundance, Mature N is the abundance of mature fish, and Female*Male is the produce of female abundance and Male abundance.*

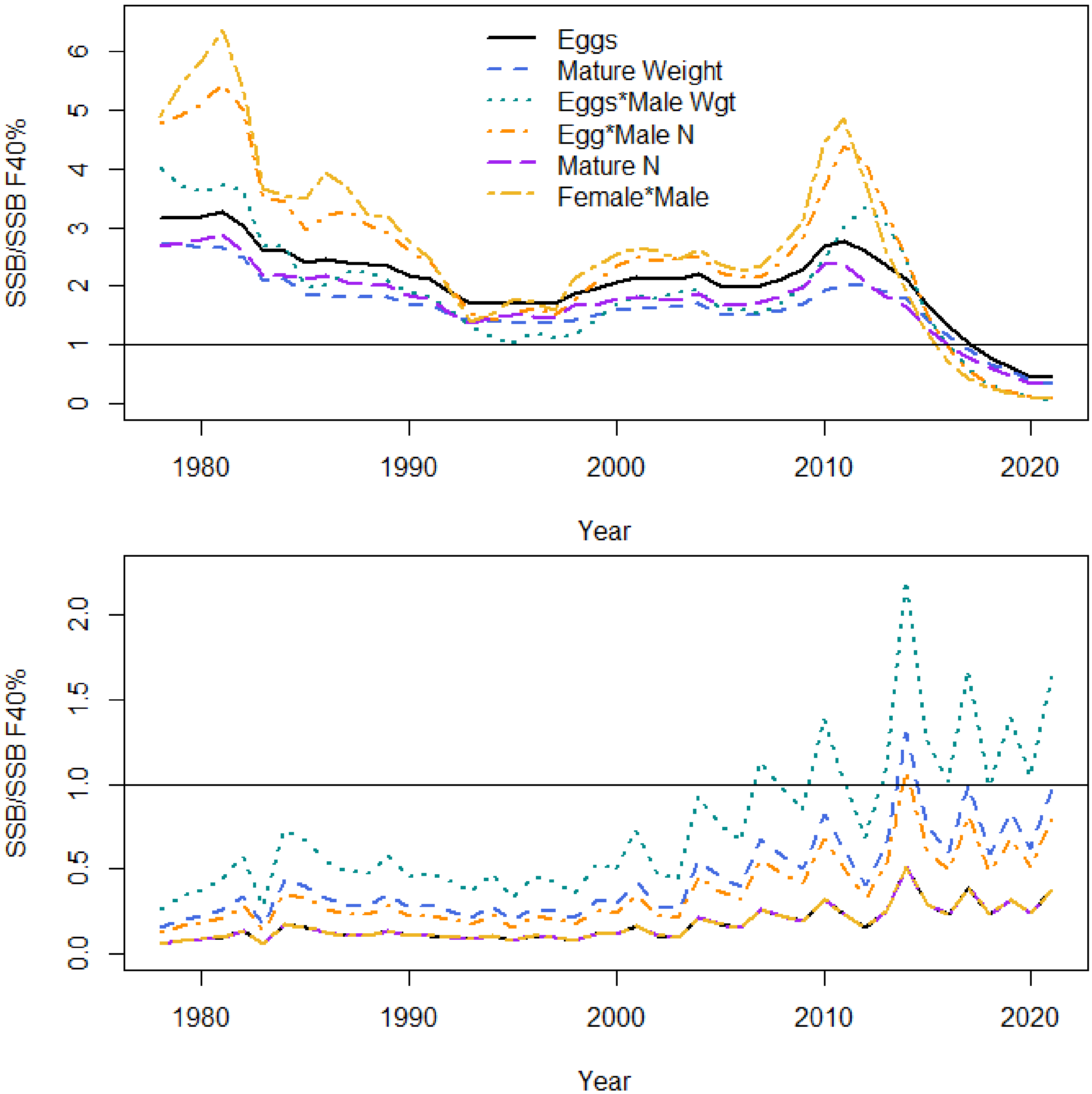


*Figure 3. Left panel: yield per recruit in landed pounds. middle panel: yield per recruit in discarded pound. right panel: yield per recruit in total pounds. All curves are based on average selectivity from the end of the assessment period. Vertical lines are drawn for various reference points where F_{MLY} is the fishing mortality that maximizes landed yield, Mature Weight $F_{40\%}$ is the fishing mortality that gives 40% mature biomass per recruit relative to that at the unfished level, while Eggs*Male Wgt $F_{40\%}$ is the fishing mortality that gives 40% SPR for the product of female egg production and mature male weight.*

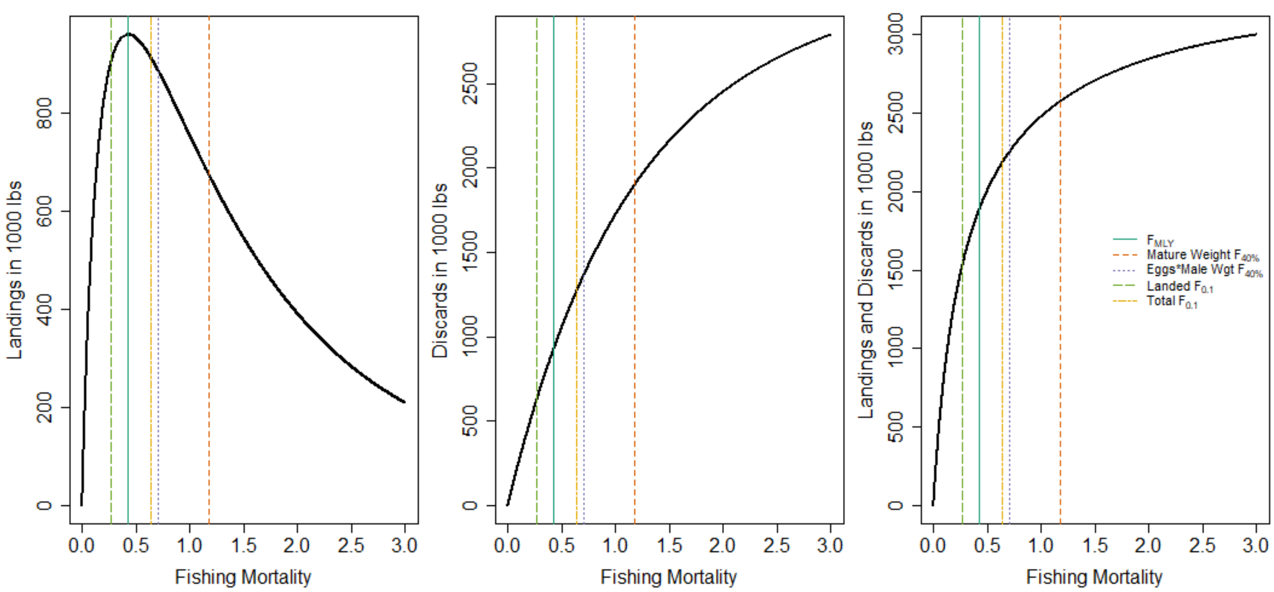


Figure 4. Probability densities of $F_{40\%}$-related benchmarks from the MCBE of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run and dashed vertical lines represent medians from the MCBE.

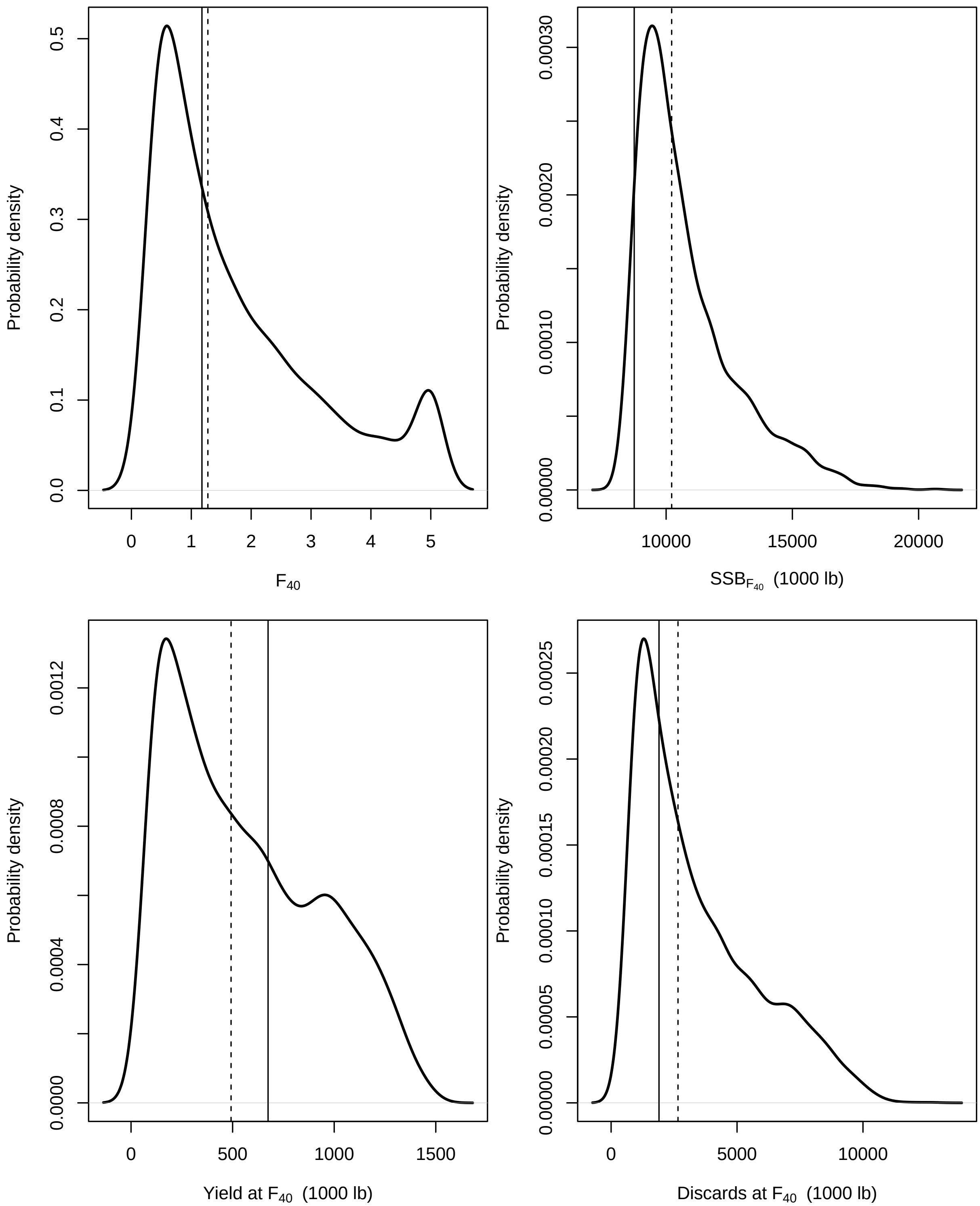


*Figure 5. Estimated time series relative to benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model and dashed vertical lines represent medians from the MCBE; gray error bands indicate 5^{th} and 95^{th} percentiles of the MCBE. Top panel: spawning biomass relative to the minimum stock size threshold (*MSST*). Middle panel: spawning biomass relative to* $\mathrm{SSB_{F40\%}}$. *Bottom panel: F relative to* $F/F_{40\%}$.

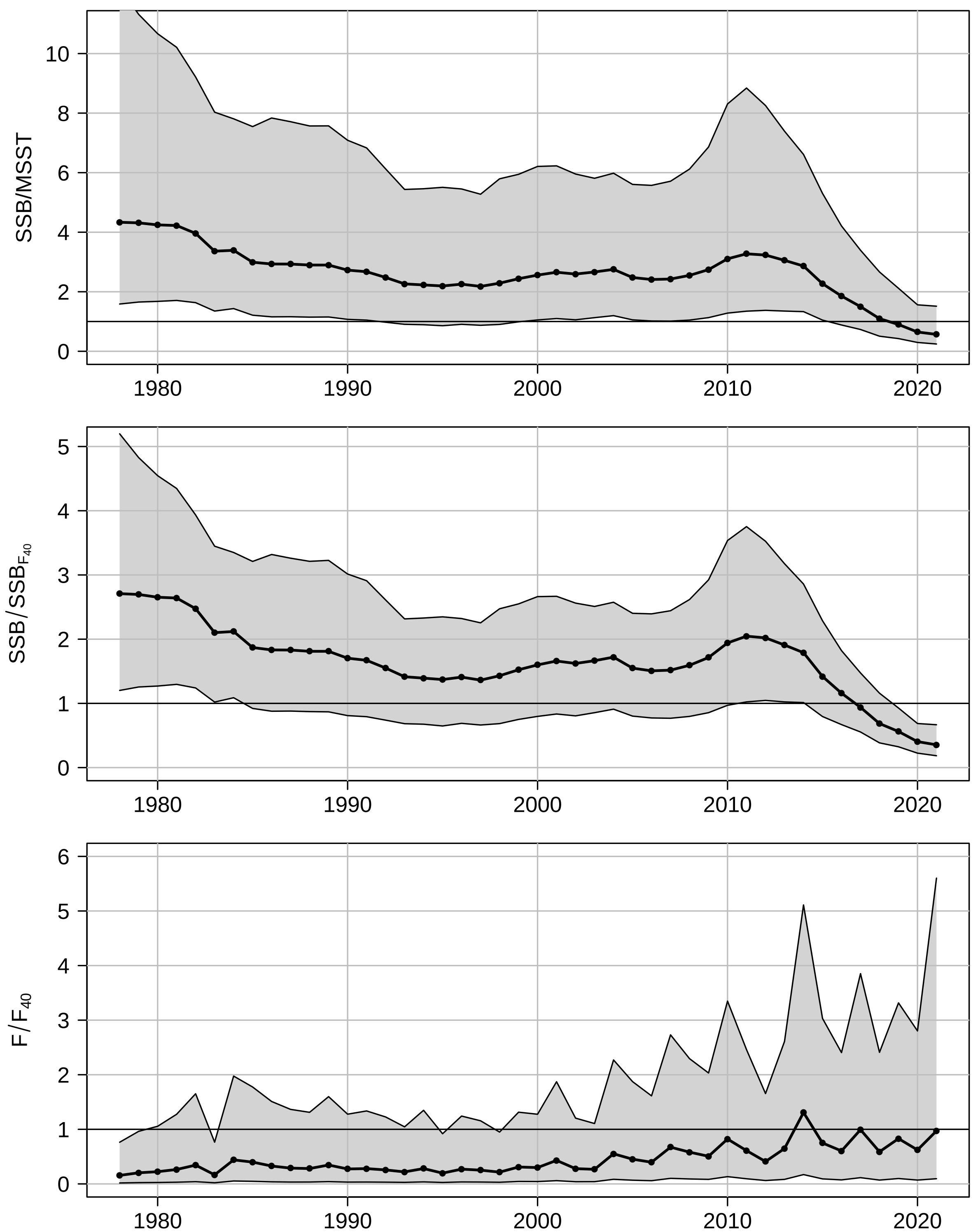


Figure 6. Probability densities of terminal status estimates from the MCBE of the Beaufort Assessment Model. Solid vertical lines represent point estimates from the base run and dashed vertical lines represent medians from the MCBE.

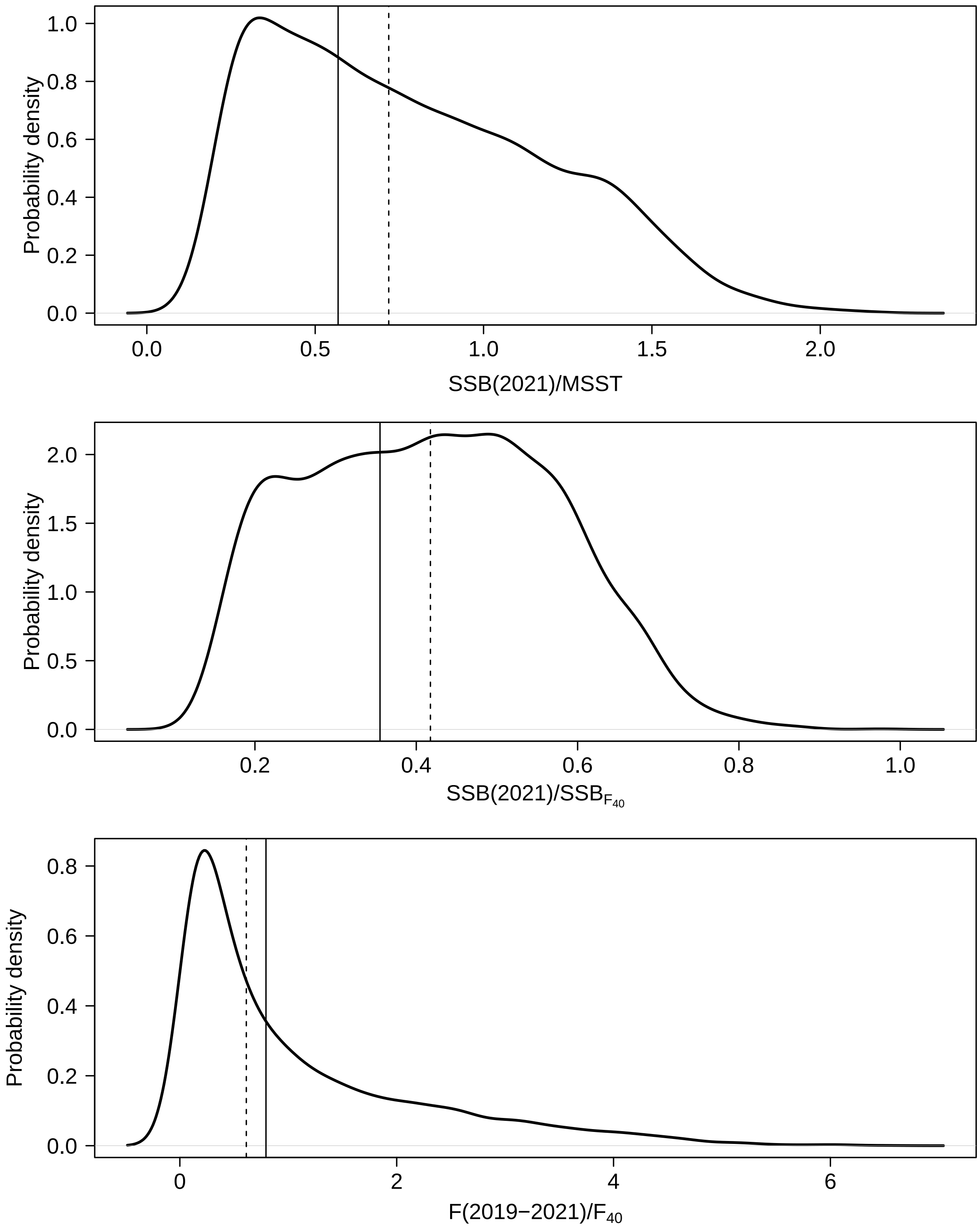


Figure 7. Phase plots of terminal status estimates from the MCBE of the Beaufort Assessment Model. Top panel is status relative to MSST*, and the bottom panel is status relative to* $F_{40\%}$*. The filled black dot indicates the estimate from the base run; the grey points indicate estimates from the MCBE runs and the shaded region is the* 90^{th} *percentile of the two parameters.*

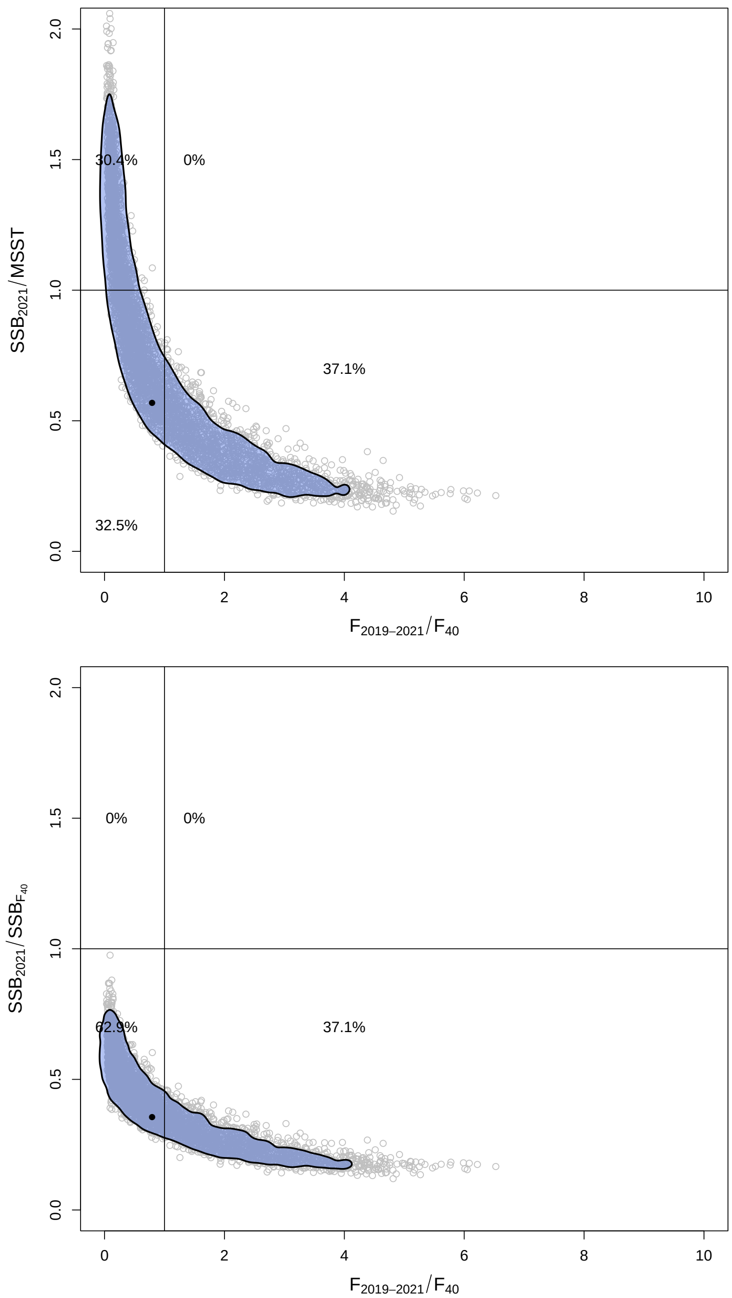


Figure 8. Projected time series under scenario fishing mortality rate at F = 0, discards proportional to landings (i.e., 0), and long-term average recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$*-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.*

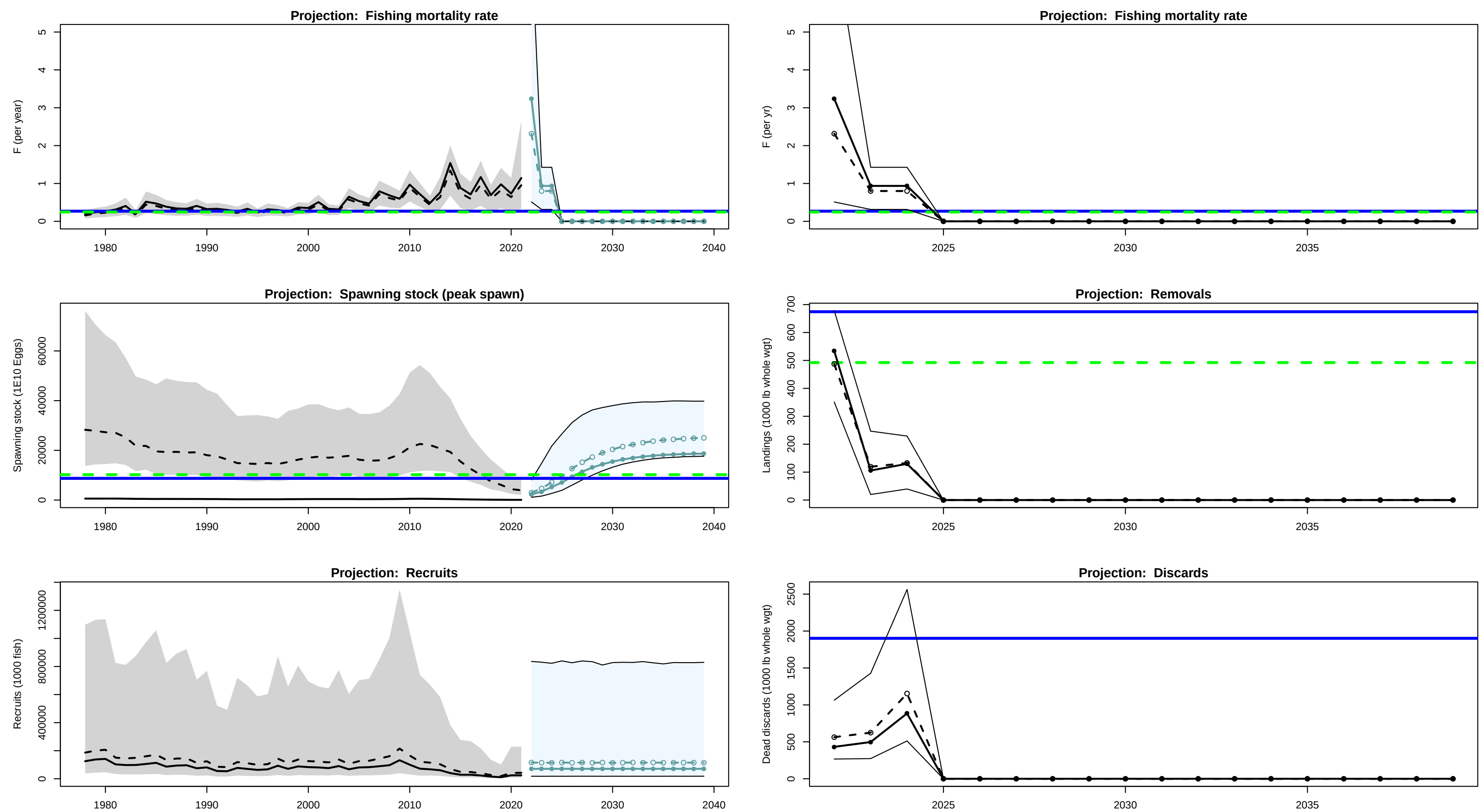
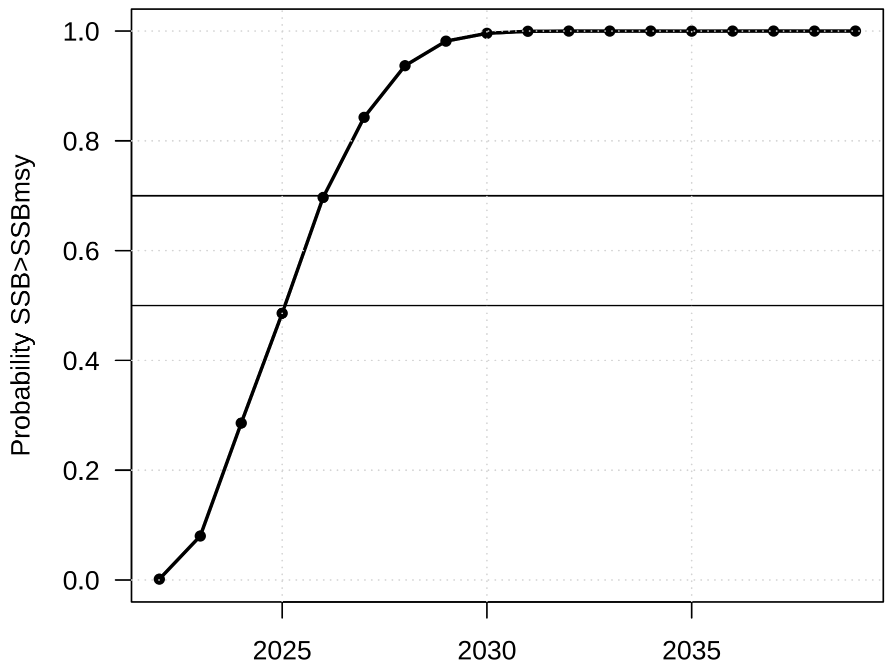


Figure 9. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at F = 0, discards proportional to landings (i.e., 0), and long-term average recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*



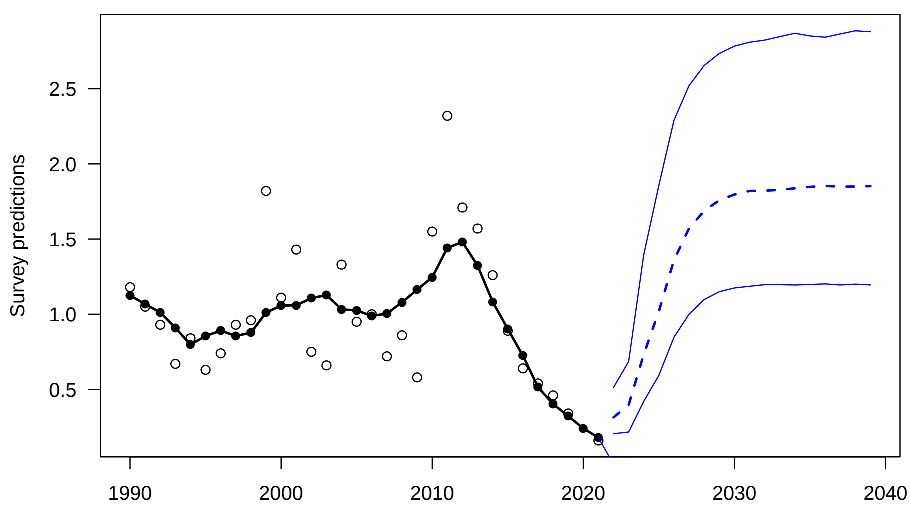


Figure 10. Projected time series under scenario fishing mortality rate at F = 0, discards proportional to landings (i.e., 0), and recent mean recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

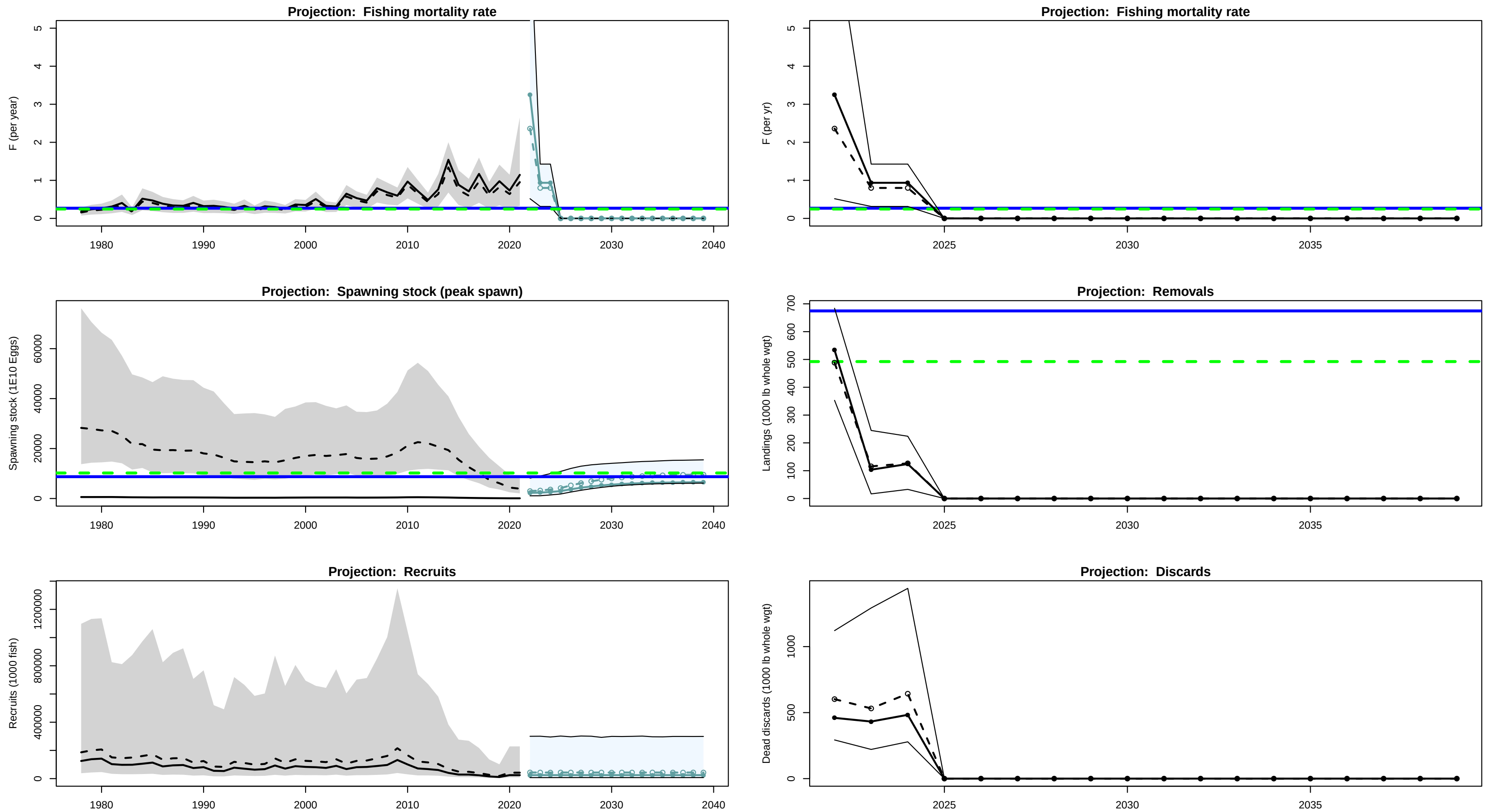
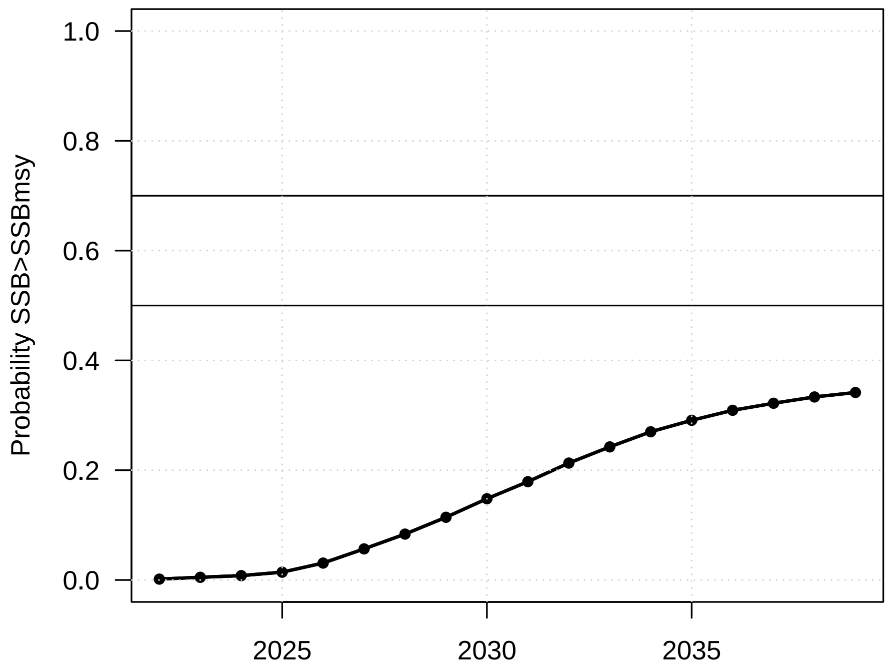


Figure 11. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at F = 0, discards proportional to landings (i.e., 0), and recent mean recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*



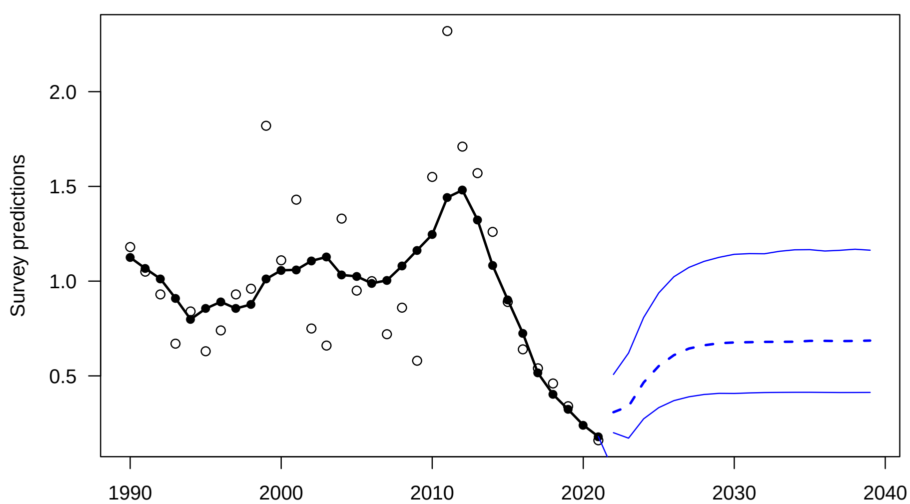


Figure 12. Projected time series under scenario fishing mortality rate at F = 0, discards proportional to landings (i.e., 0), and autocorrelated recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

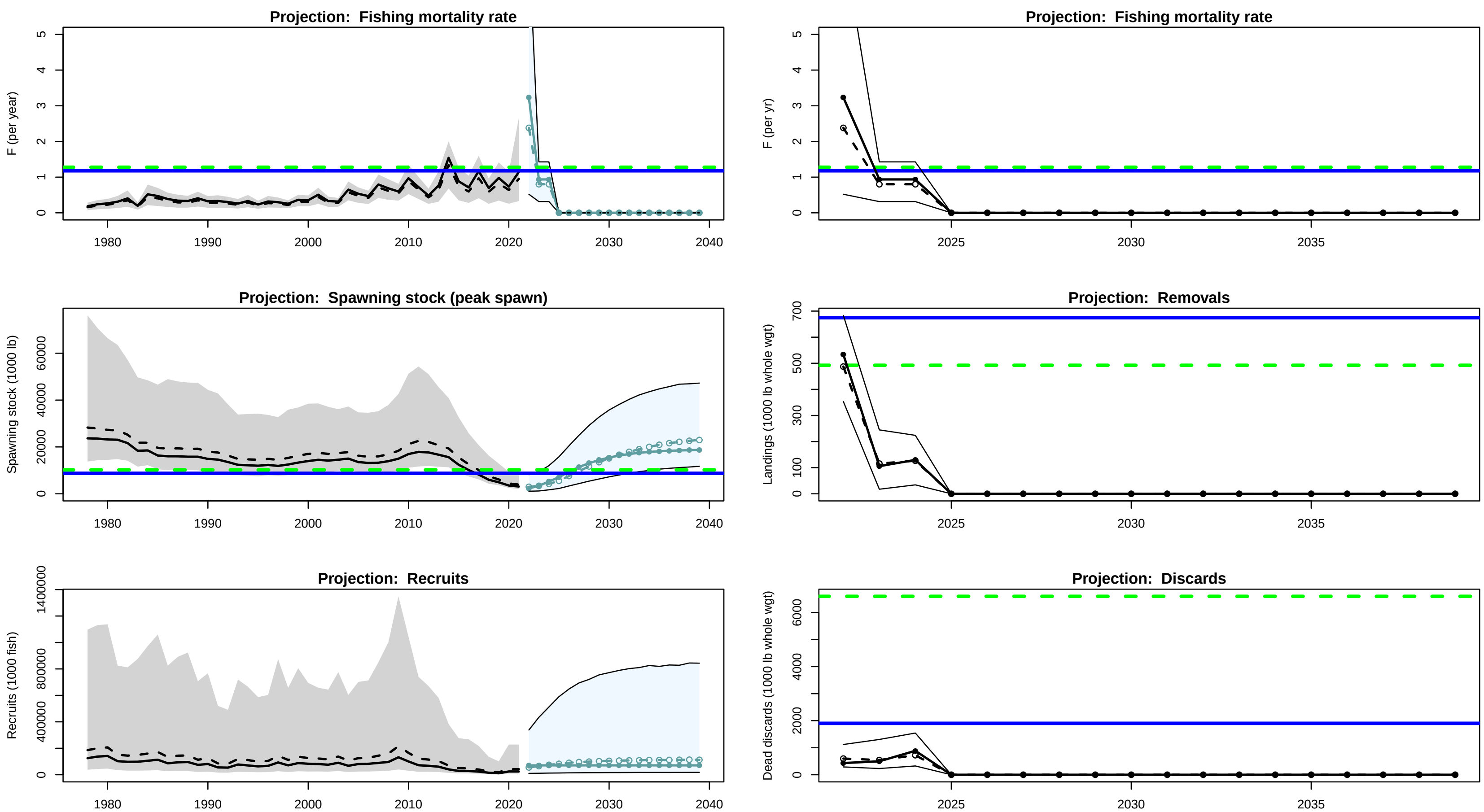
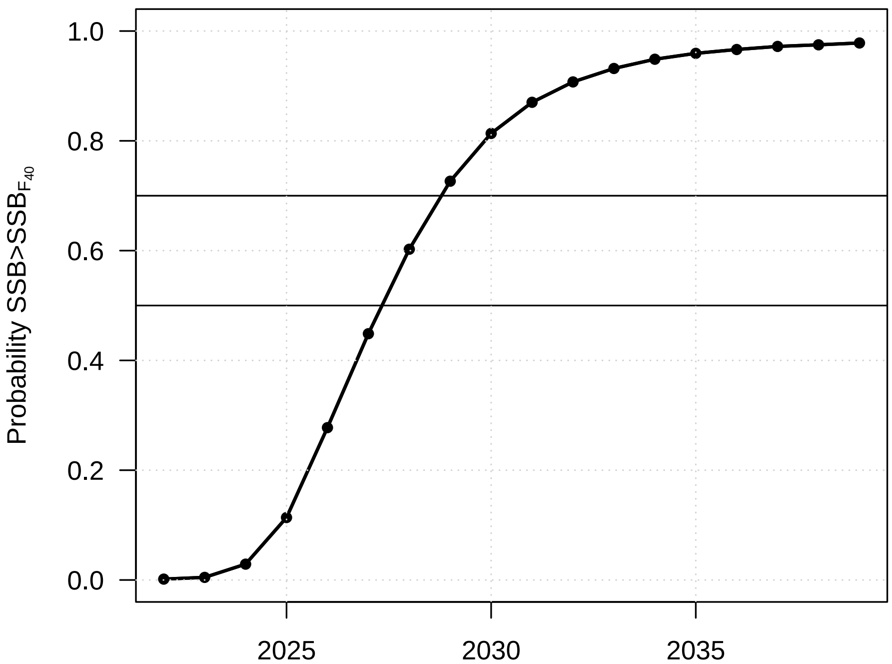


Figure 13. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at F = 0, discards proportional to landings (i.e., 0), and autocorrelated recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*



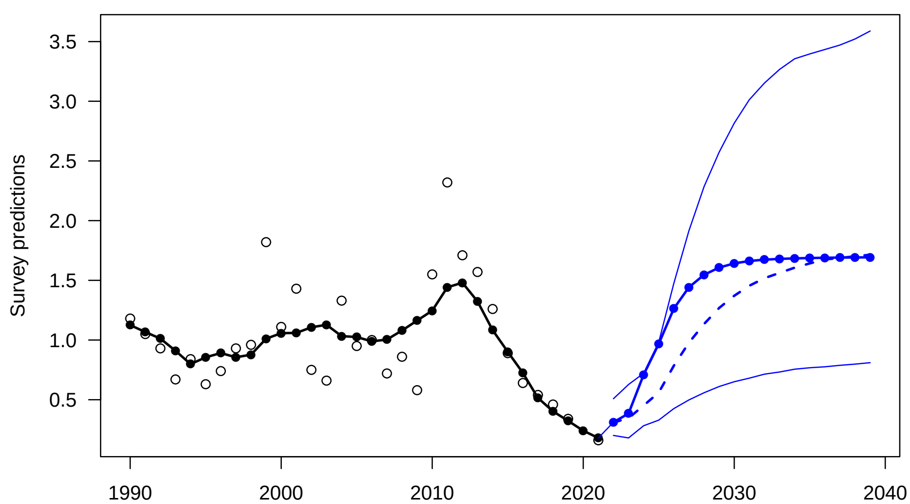


Figure 14. Projected time series under scenario fishing mortality rate at F = 0, discards at current fishing levels, and long-term average recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

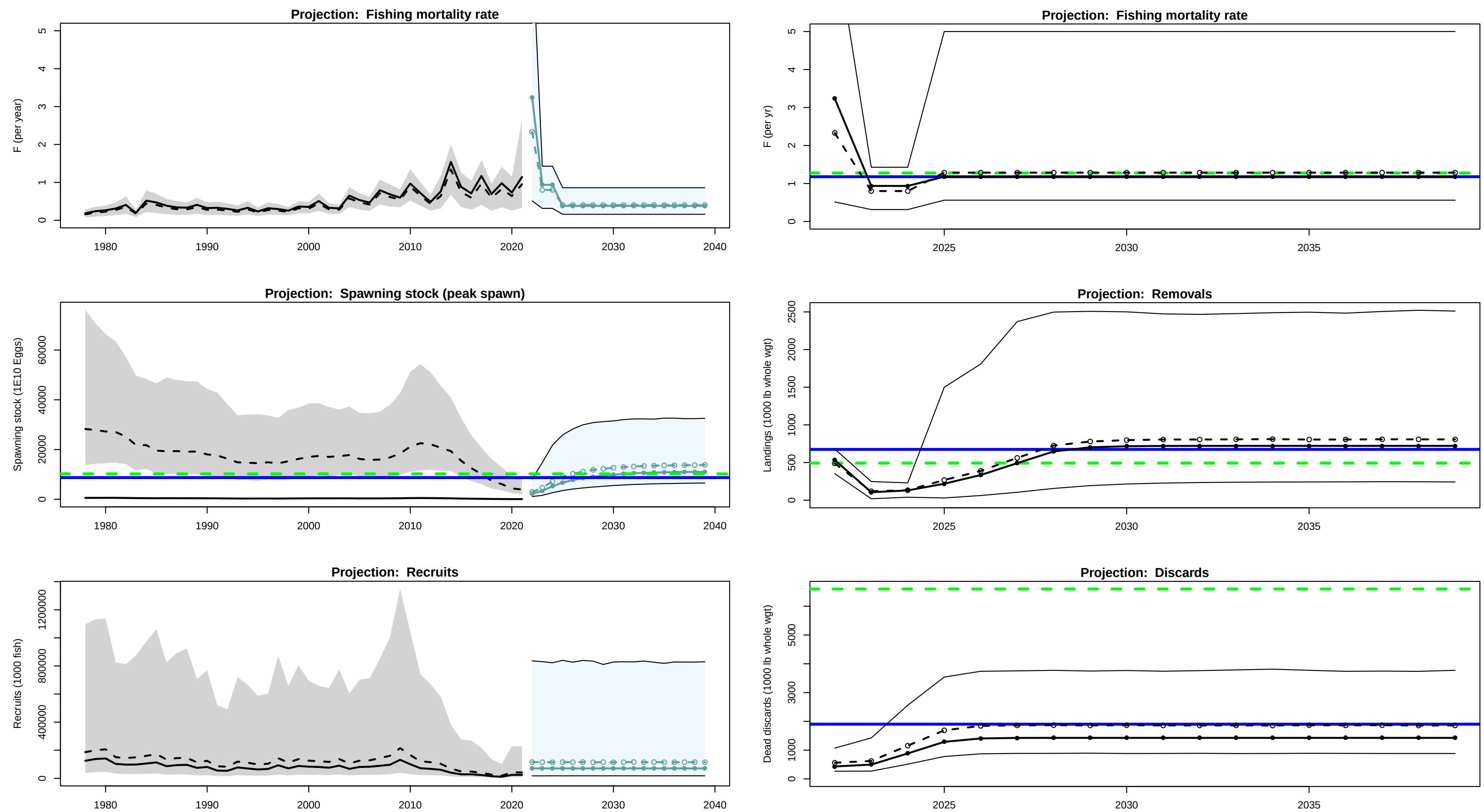
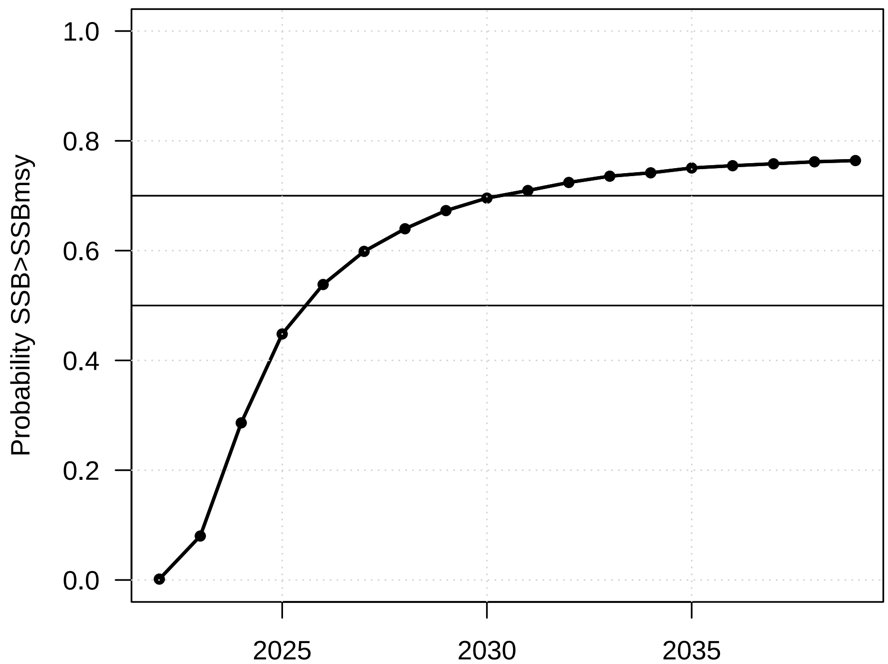


Figure 15. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at F = 0, discards at current fishing levels, and long-term average recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*



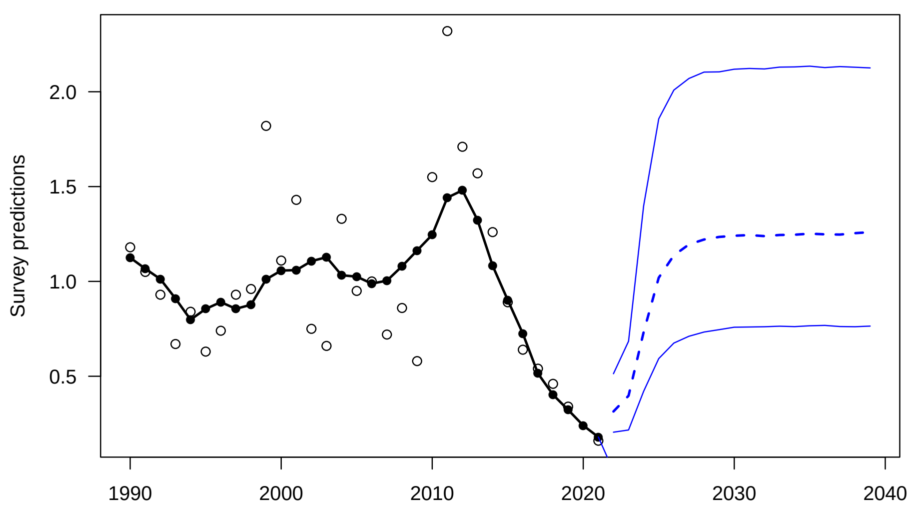


Figure 16. Projected time series under scenario fishing mortality rate at F = 0, discards at current fishing levels, and recent mean recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

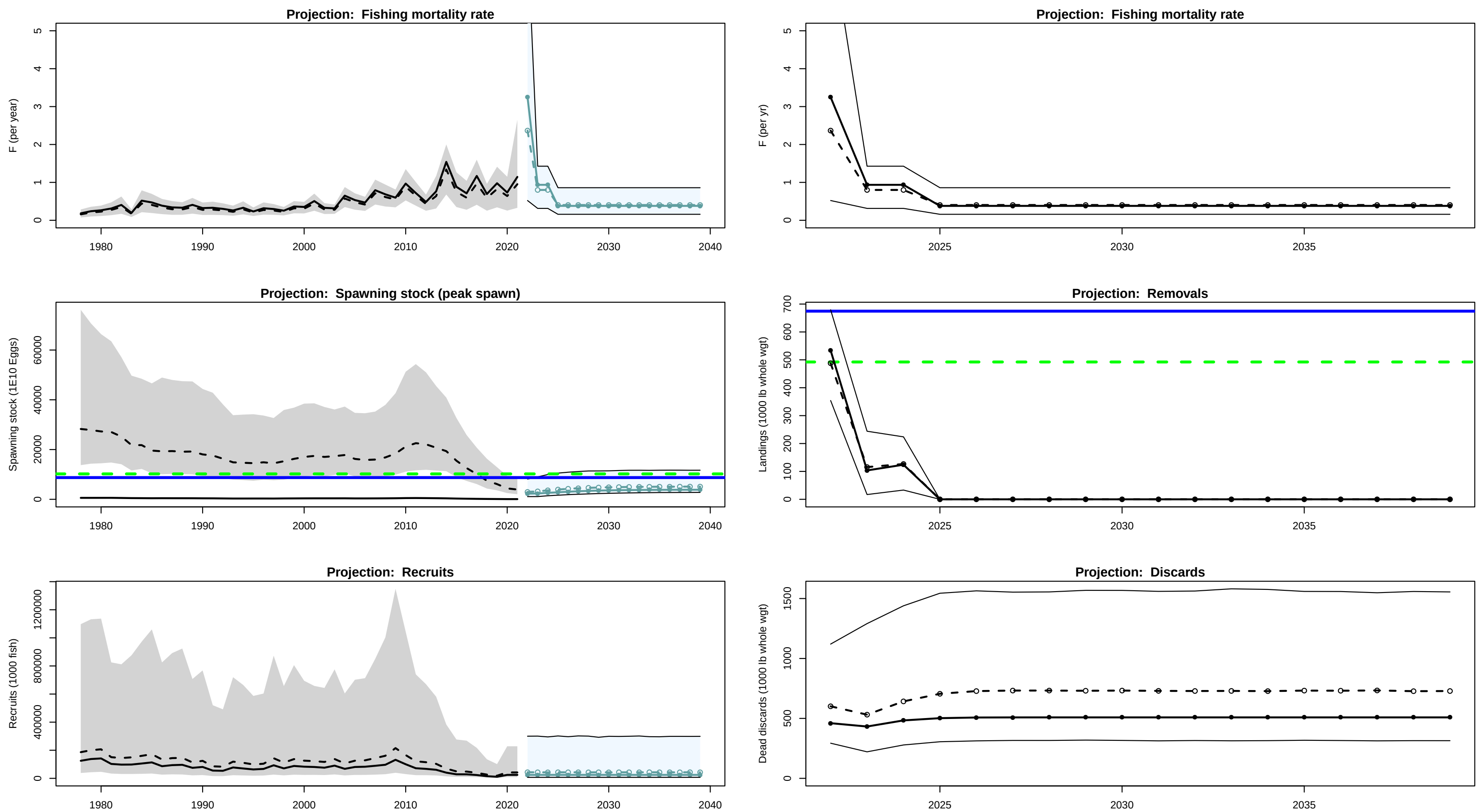


Figure 17. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at F = 0, discards at current fishing levels, and recent mean recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*

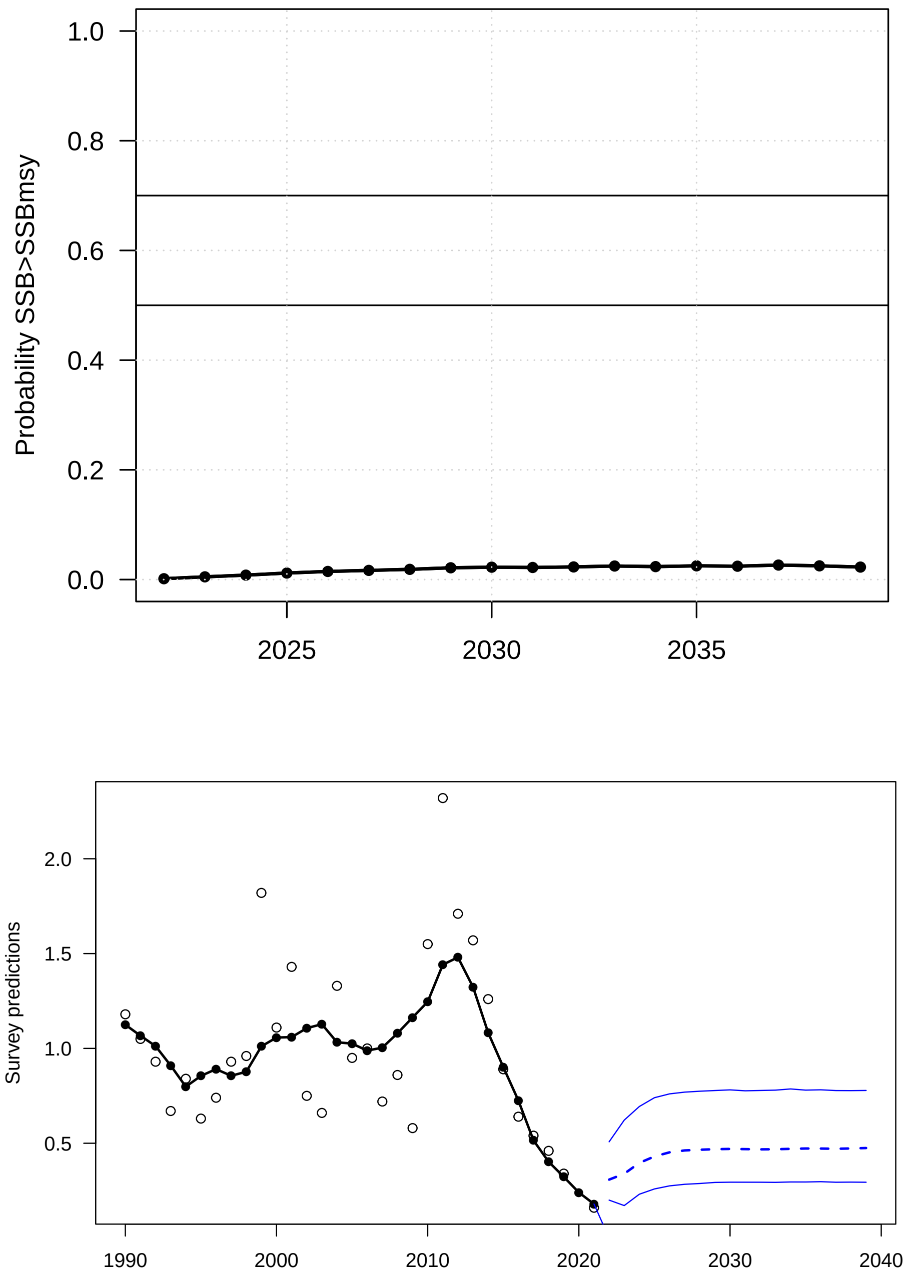


Figure 18. Projected time series under scenario fishing mortality rate at $F = 0$, discards at current fishing levels, and autocorrelated recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

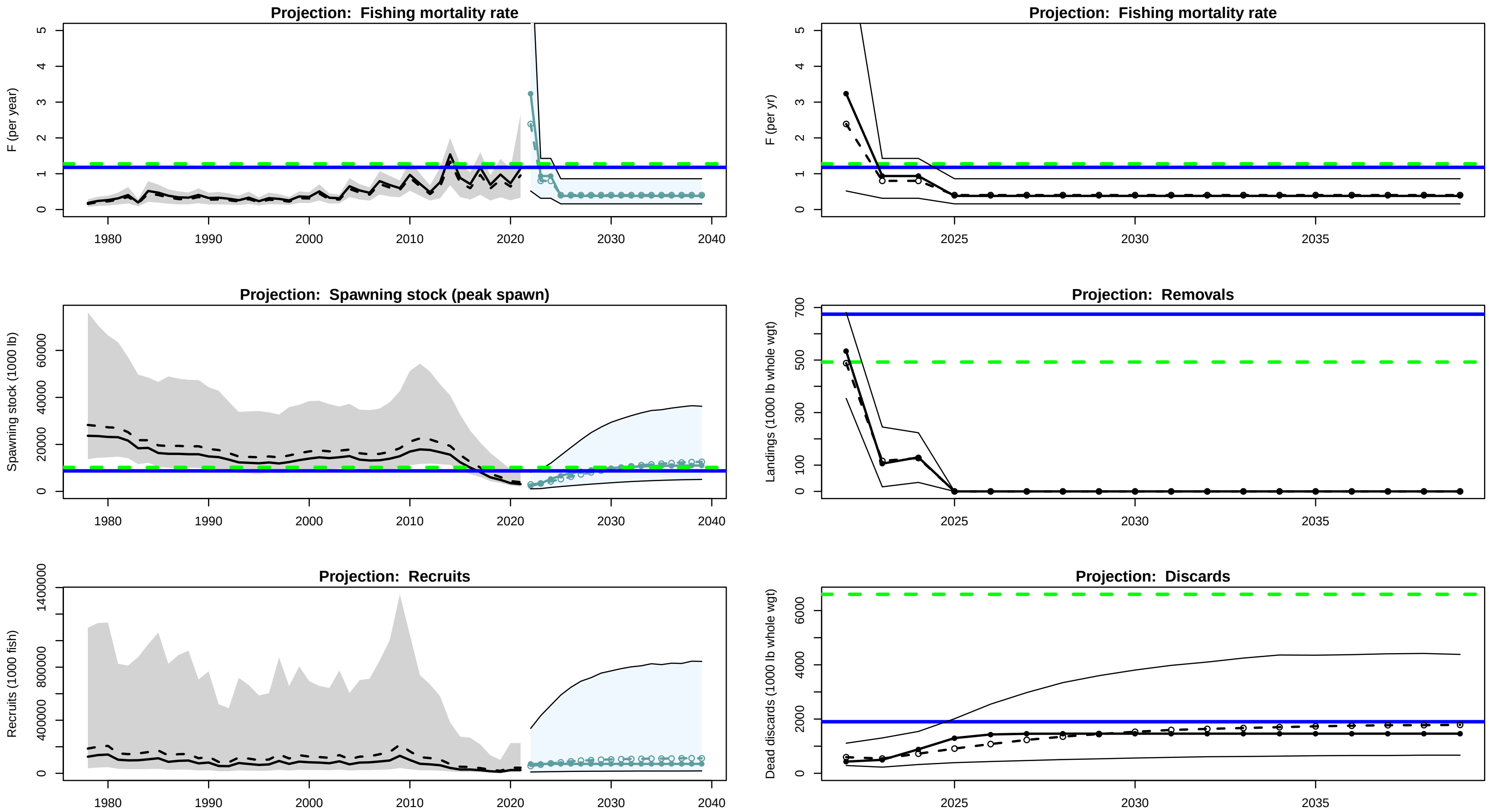


Figure 19. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at F = 0, discards at current fishing levels, and autocorrelated recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*

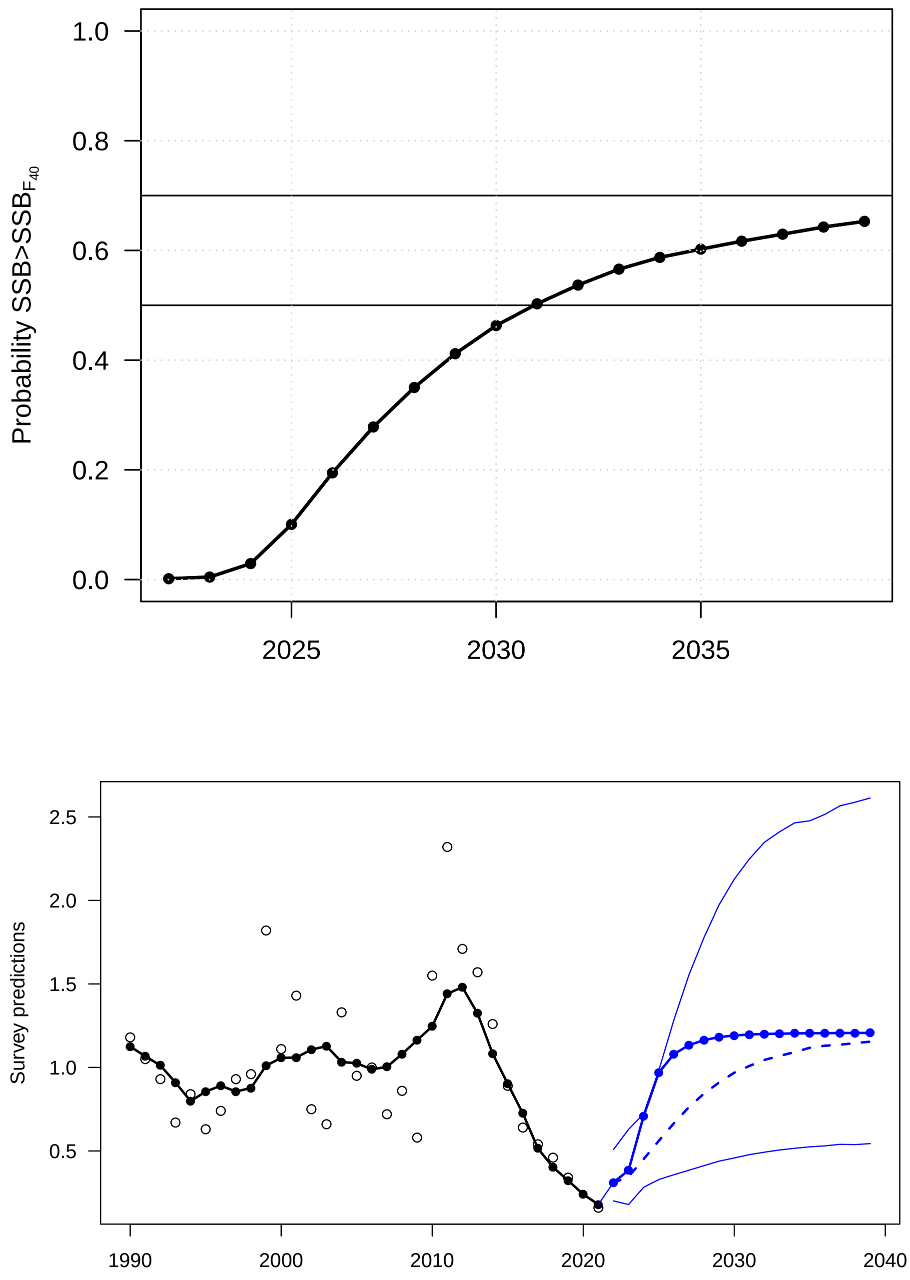


Figure 20. Projected time series under scenario fishing mortality rate that gives a 65% probability of rebuilding in 10 years, discards at current fishing levels, and long-term average recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

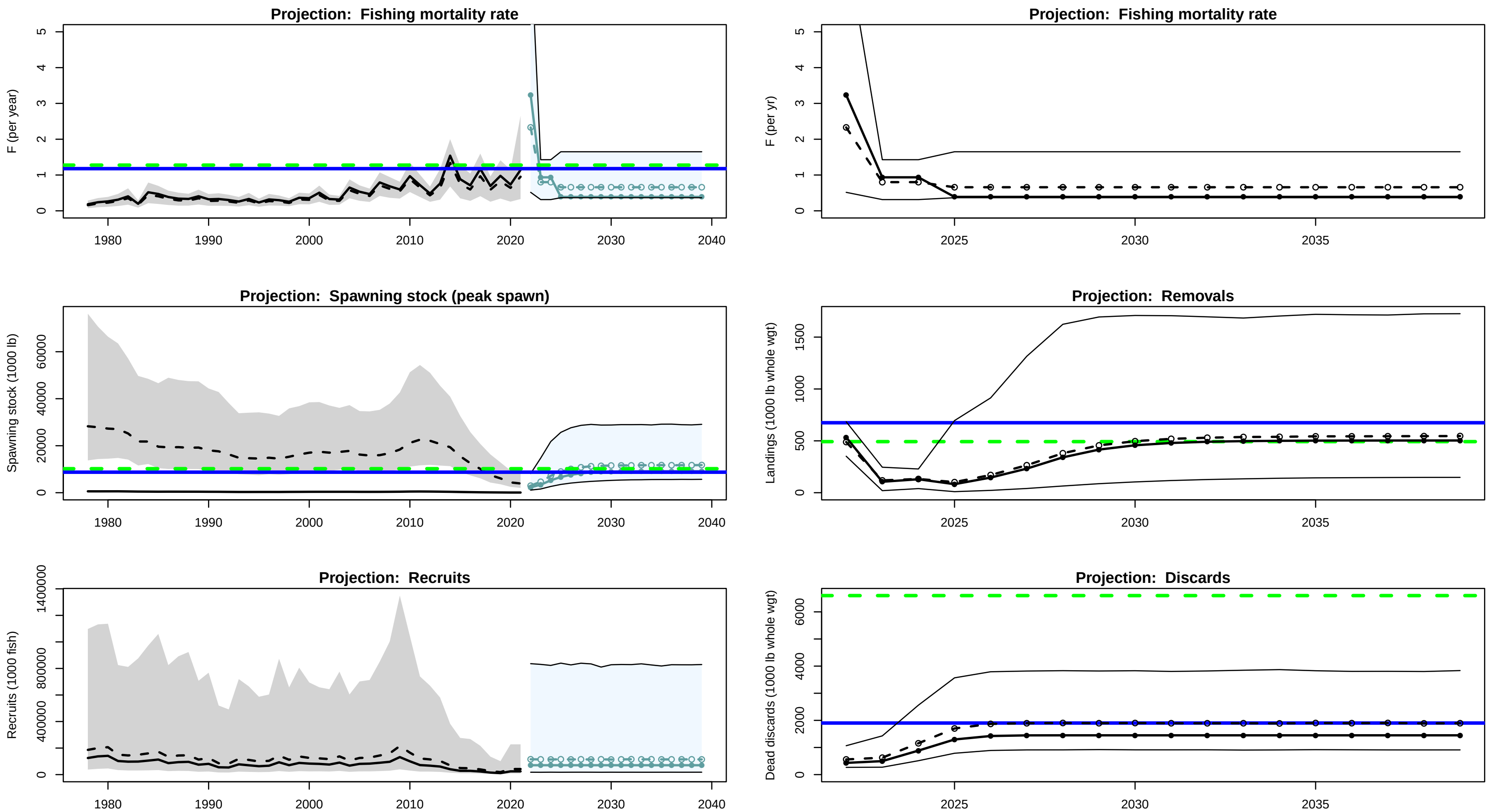


Figure 21. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate that gives a 65% probability of rebuilding in 10 years, discards at current fishing levels, and long-term average recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*

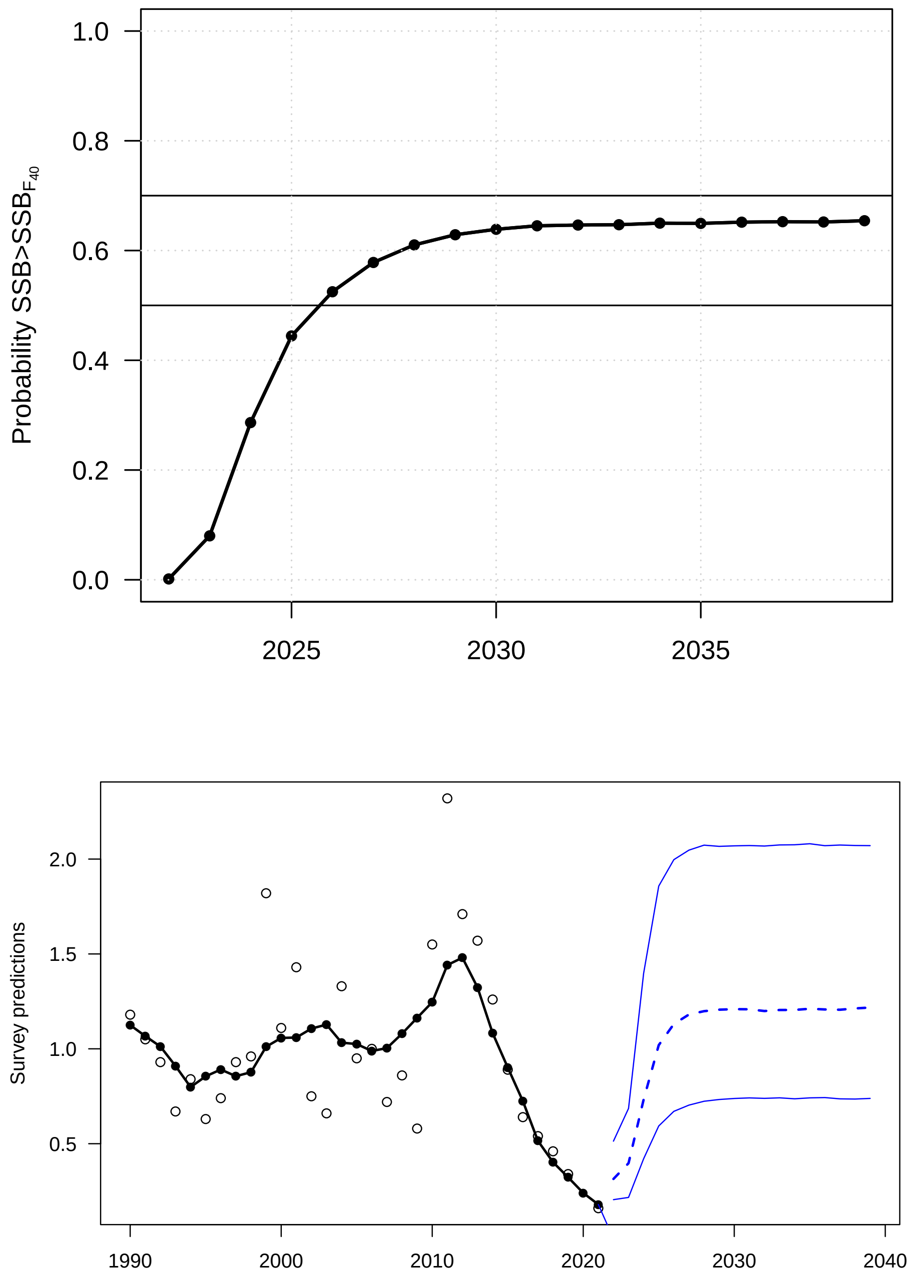


Figure 22. Projected time series under scenario fishing mortality rate that gives a 70% probability of rebuilding in 10 years, discards at current fishing levels, and long-term average recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

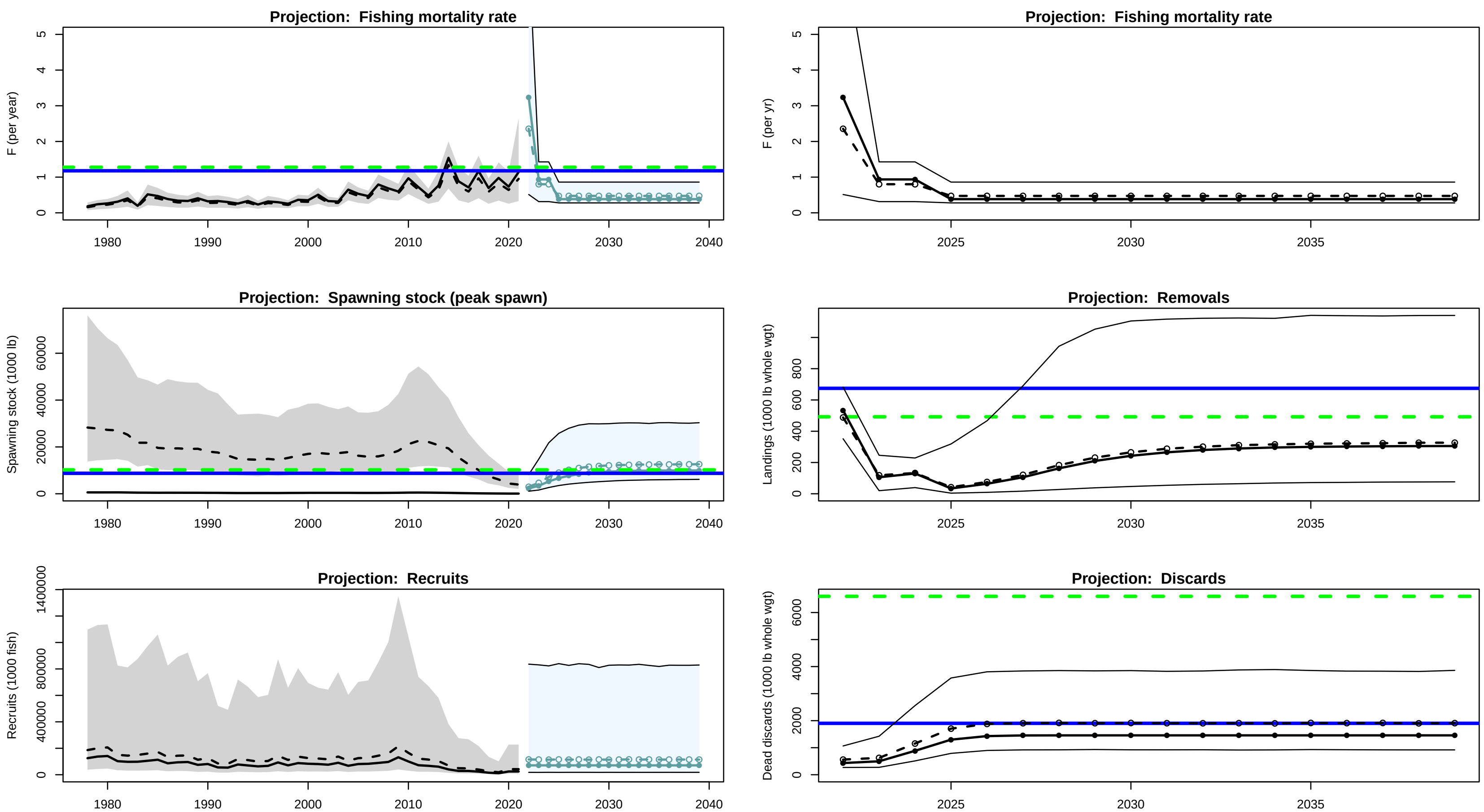


Figure 23. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate that gives a 70% probability of rebuilding in 10 years, discards at current fishing levels, and long-term average recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*

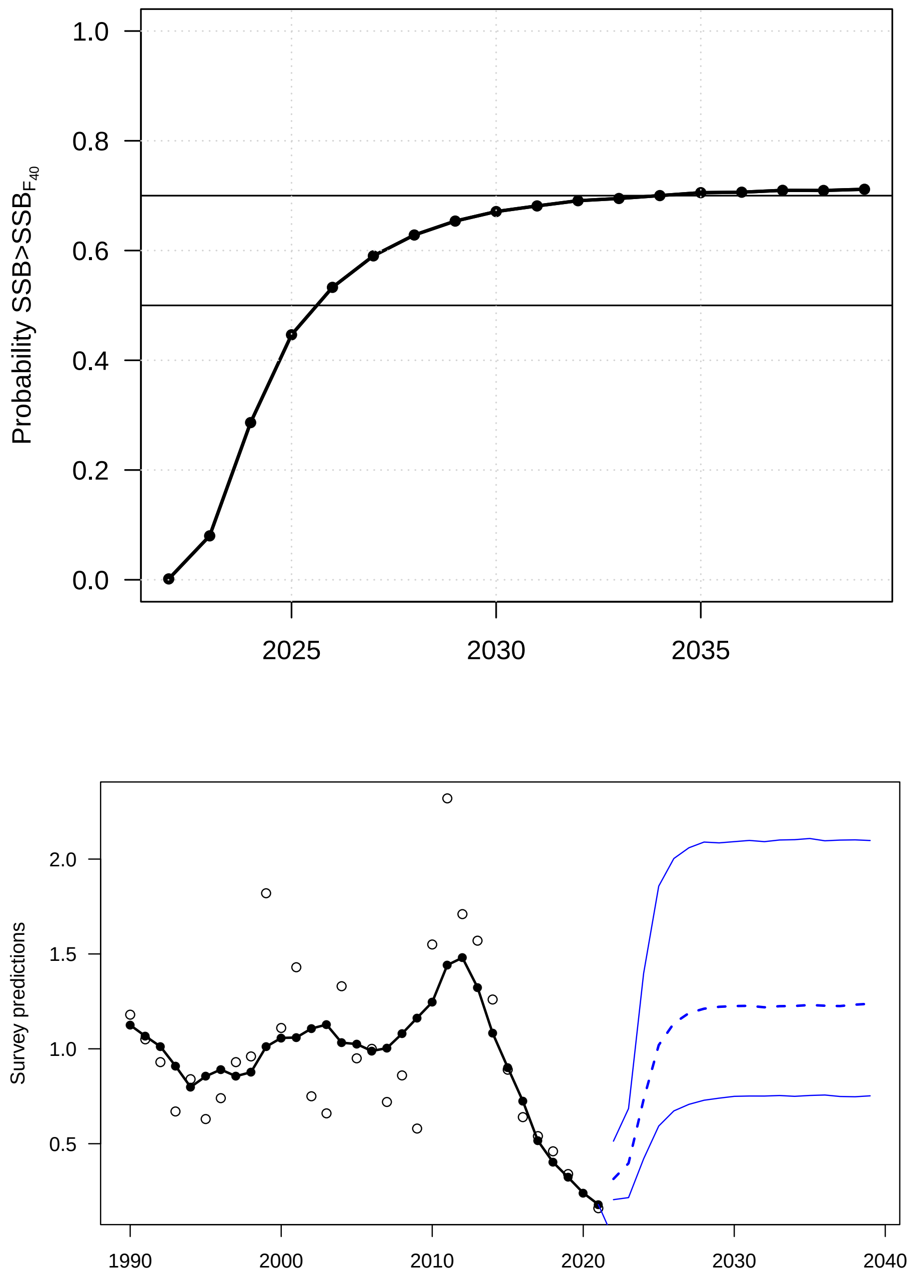


Figure 24. Projected time series under scenario fishing mortality rate at PStar 30, discards at current fishing levels, and recent mean recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

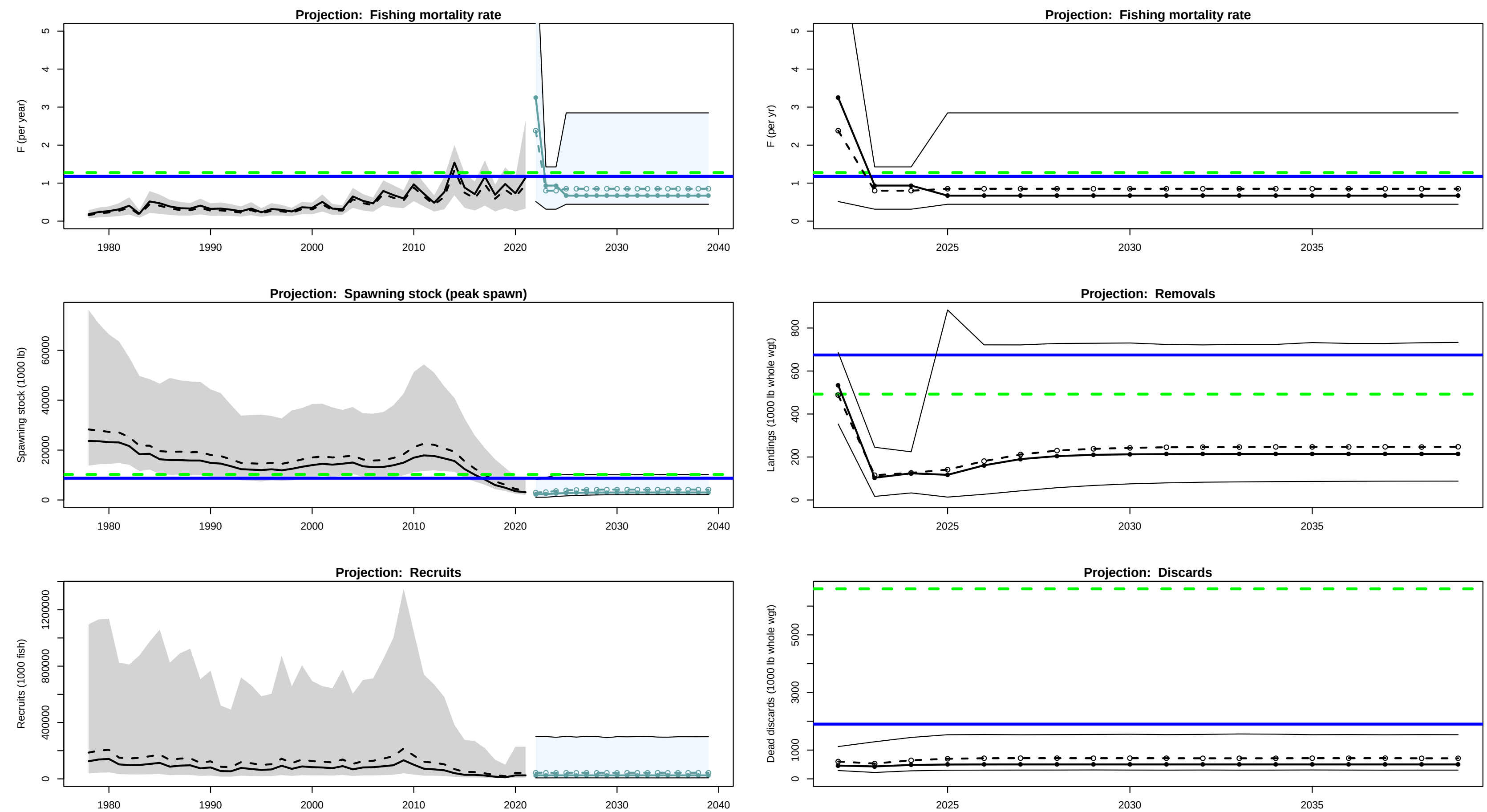


Figure 25. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at PStar 30, discards at current fishing levels, and recent mean recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB_{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*

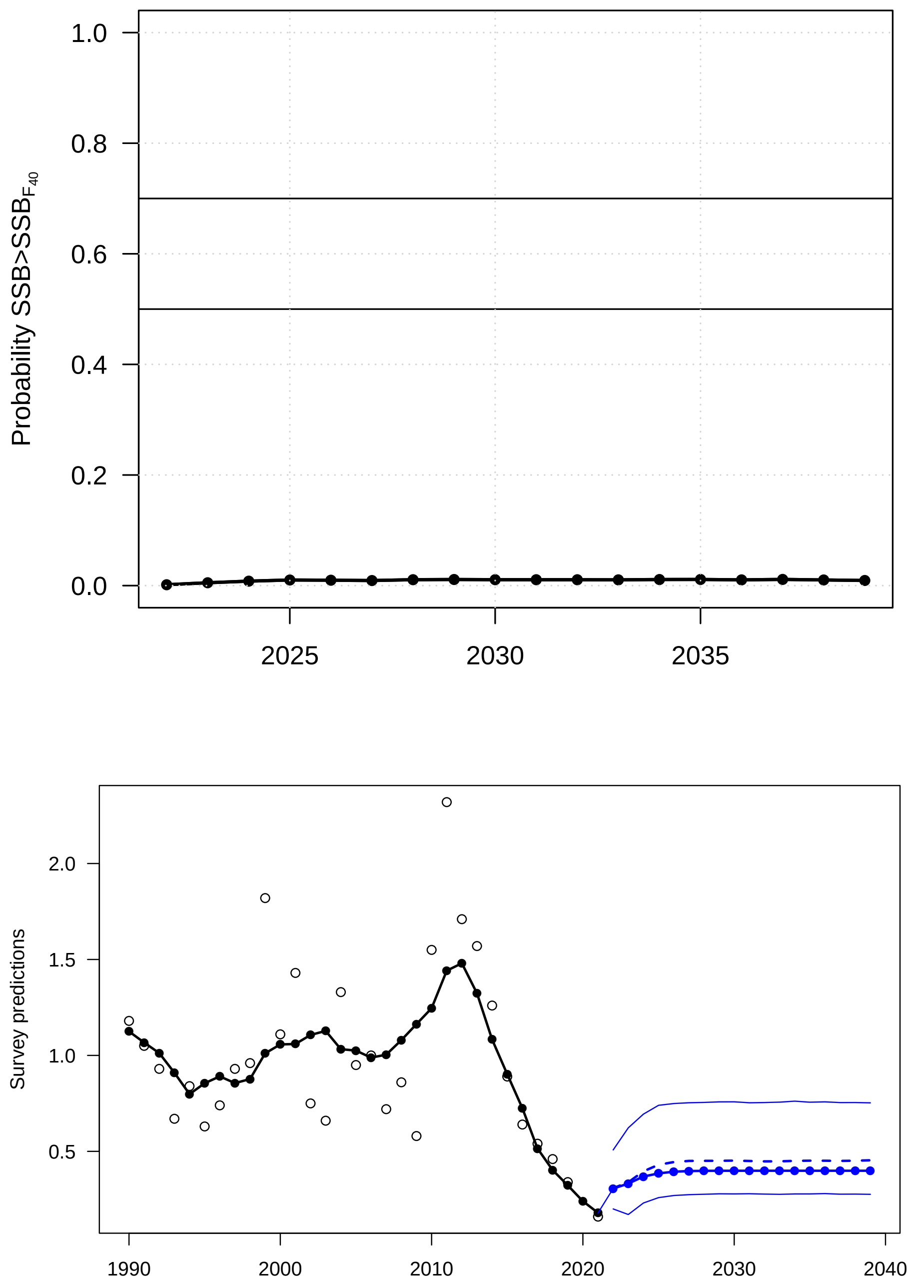


Figure 26. Projected time series under scenario fishing mortality rate at PStar 35, discards at current fishing levels, and recent mean recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

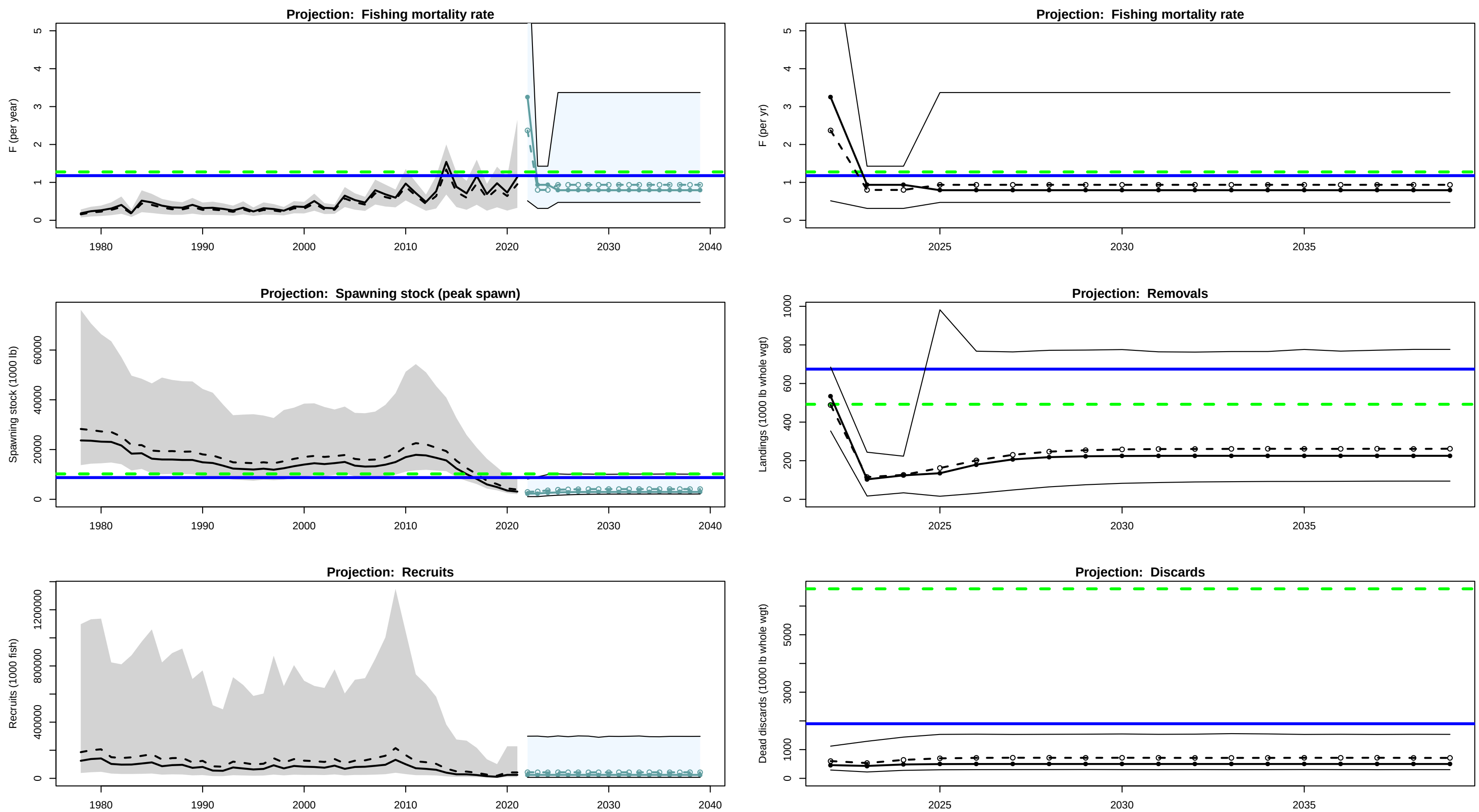


Figure 27. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at PStar 35, discards at current fishing levels, and recent mean recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{\mathrm{F40\%}}$*, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.*

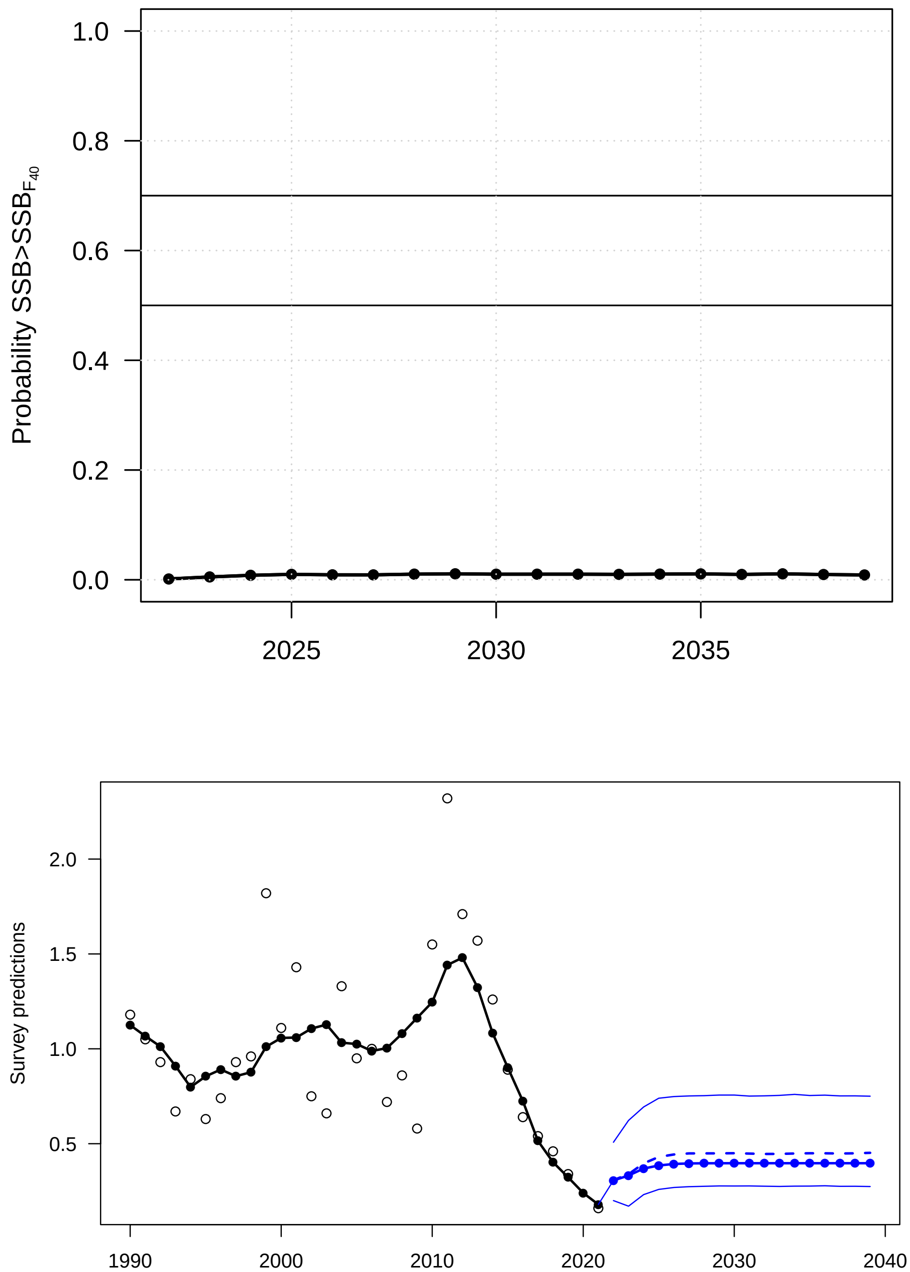


Figure 28. Projected time series under scenario fishing mortality rate at $F = F_{40\%}$, discards at current fishing levels, and long-term average recruitment. Expected values (base run) represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections. Solid horizontal lines mark $F_{40\%}$-related benchmarks from the base model; dashed horizontal lines represent corresponding medians from the MCBE. Spawning stock (SSB) is at time of peak spawning.

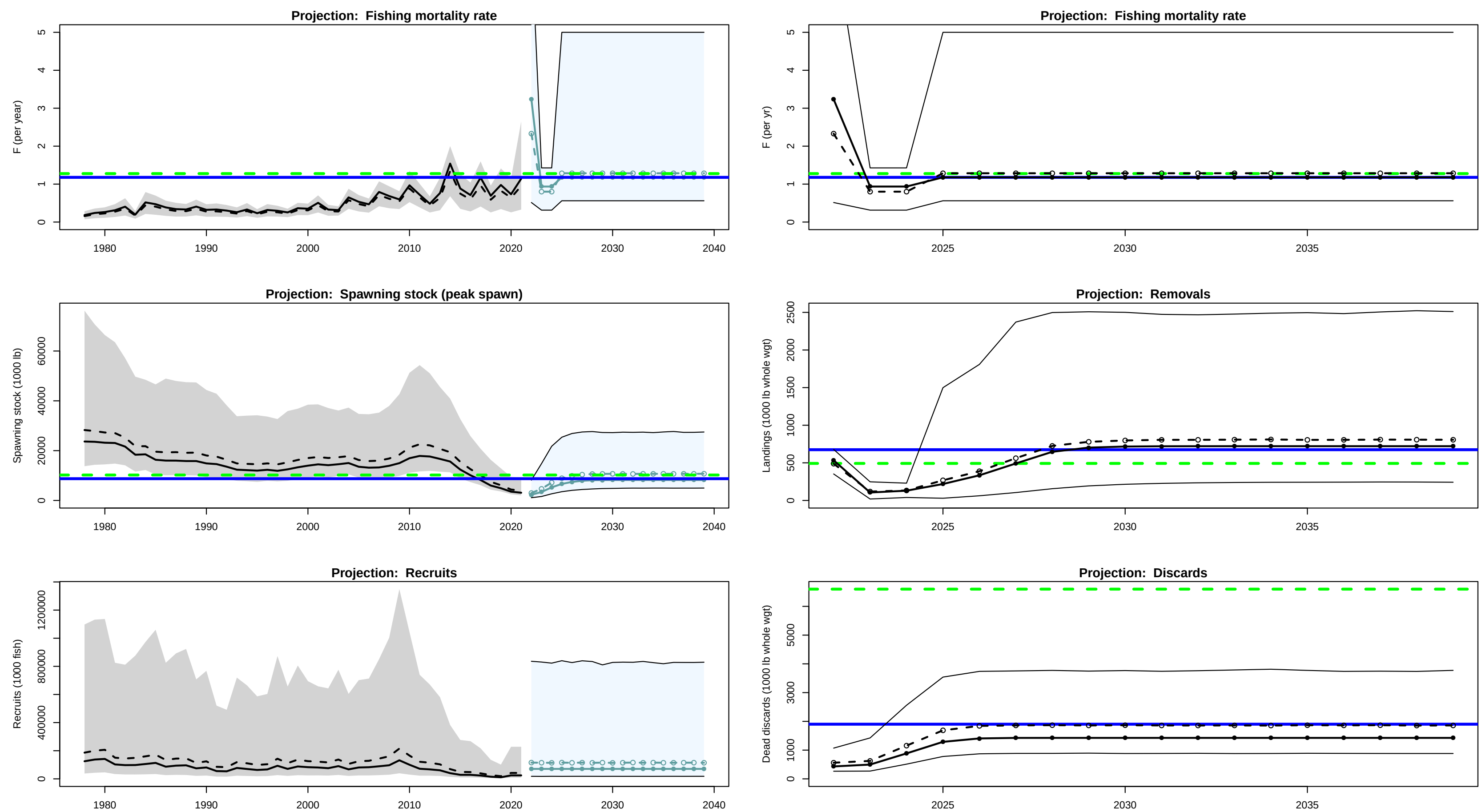


Figure 29. Top Panel: Projected probability of rebuilding under scenario fishing mortality rate at $F = F_{40\%}$, discards at current fishing levels, and long-term average recruitment. The curve represents the proportion of projection replicates for which SSB has reached the replicate-specific $\mathrm{SSB}_{F40\%}$, with reference lines at 0.5 and 0.7. Bottom panel: Projected SERFS index where the expected values (base run) are represented by solid lines with solid circles, medians represented by dashed lines with open circles, and uncertainty represented by thin lines corresponding to 5th and 95th percentiles of replicate projections.