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Pacific Bluefin Tuna Management Strategy Evaluation for Newly Agreed Management Procedures

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Submitted by ISC[1] Pacific Bluefin Tuna Working Group
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Subject to change and approval by the ISC27 Plenary.

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Abstract

In June 2025, the Pacific Bluefin Tuna Working Group (PBFWG) completed the first round of management strategy evaluation (MSE) for PBF. The MSE assessed 16 candidate management procedures (MPs) put forward by the Joint IATTC-WCPFC NC Working Group Meeting on PBF Management (JWG) relative to a set of management objectives. In August 2026, the JWG adopted an Interim MP that included a harvest control rule (HCR) parameterized with $F_{27.5\%SPR}$ as F_{TARGET}, 20%$SSB_{F=0}$ as the 1st control point, and 7.7%$SSB_{F=0}$ as the 2nd control point, and requested the PBFWG test this HCR with two distinct allocations of fishing impact, resulting in: HCR 17 (status quo, 80:20 for WCPO:EPO impact ratio), and HCR 18 (70:30 impact ratio). In addition, the interim MP is to be implemented every two years for 6 years instead of every three years as assumed the first round of MSE. The objective of this working paper is to evaluate HCRs 17 and 18, via closed-loop MSE simulations and to detail the associated specific modifications made to the PBF MSE framework previously established.

Simulation testing of the reference set scenarios confirmed that the HCRs 17 and 18 fully satisfied the management objectives for the newly agreed Interim MP. Both HCRs 17 and 18 successfully maintains F at or below F_{TARGET} with a probability of at least 50 percent (Status), maintains SSB above the 2nd control point with a probability of at least 90% (Safety), gradually achieves the equitable balance in proportional fishery impact between WCPO and EPO (Yield), increases average annual catch across the WCPO and EPO (Yield), and effectively limits the changes in overall catch limits between management periods (Stability).

Under the doubling discards scenario, both HCRs 17 and 18 performed comparably well across the Safety, Status, and Stability metrics, successfully satisfying all benchmark criteria. In contrast, under the catchability changes scenario, neither HCR met the Safety or Status criteria, but rebuilt SSB above target levels in the later years of the simulation. Similar to the 1st round of MSE, results from the "recruitment drop" robustness test revealed that neither HCR 17 nor 18 was fully resilient to a chronic drop in recruitment, likely due to the absence of a recruitment index within the MP. Therefore, the ISC has recommended monitoring of both longline CPUE and recruitment indices - reviewed alongside routine CPUE updates - as part of the exceptional circumstances protocol. The results of the evaluations for the reference set are available online at: https://connect.fisheries.noaa.gov/ISCPBF-adopted-MSE-tool/.

Introduction

Following the successful rebuilding of the Pacific bluefin tuna (PBF) spawning stock biomass (SSB) above the second rebuilding target of 20%$SSB_{F=0}$ in 2021, the two Regional Fisheries Management Organizations (RFMOs) responsible for PBF management - the Western and Central Pacific Fisheries Commission Northern Committee (WCPFC NC) and the Inter American Tropical Tuna Commission (IATTC) - requested through the Joint IATTC-WCPFC NC Working Group Meeting on PBF Management (JWG) that the PBF working group (PBFWG) of the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC) develop a Management Strategy Evaluation (MSE). In June 2025, the ISC PBFWG completed the first round of MSE, which assessed performance of 16 candidate management procedures (MPs) put forward by the JWG relative to a set of management objectives defined by the JWG (ISC 2025). The candidate MPs largely differed in the control points defined by the harvest control rule (HCR) and the allocation of fishing impact between the Western Central Pacific Ocean (WCPO) and the Eastern Pacific Ocean (EPO). All the MPs set a Total Allowable Catch (TAC) for three fleet segments: the EPO fleet, the WCPO small fish fleet, and the WCPO large fish fleet. Later, the JWG reviewed the performance of all 16 candidates, setting the stage for the development of more tailored options. The results were also presented thoroughly at IATTC SAC and WCPFC SC in 2025.

Consequently, during the March 2026 intersessional JWG workshop, managers proposed a new HCR (Figure 1, Attachment C in JWG 2026a) as a promising compromise among the candidate MPs, and this MP was later adopted by the JWG in August 2026 as an interim MP (JWG 2026b). This MP used the same data and estimation model as those previously tested but had a different HCR (Table 1). This HCR (Figure 1) differed in its control points as compared to the candidate HCRs previously evaluated, where: 1) F is maintained at a target fishing rate ($F_{27.5\%SPR}$) when spawning biomass is at or above 20% of unfished levels ($SSB_{F=0}$), 2) F is decreased proportionally if $SSB/SSB_{F=0}$ falls between 20% and 7.7%, and 3) F is reduced to a minimum rate ($F_{70\%SPR}$) if $SSB/SSB_{F=0}$ drops to or below 7.7% (Table 1). Additionally, the JWG requested testing this HCR with two distinct allocations of fishing pressure, resulting in: **HCR 17**, which reflects the status quo with a 80:20 (WCPO:EPO) impact ratio, and **HCR 18**, which is tuned to a 70:30 ratio. The interim MP is to be implemented every two years for 6 years instead of the 3-year cycle assumed in the first round MSE (JWG 2026b). As requested by the JWG, ISC provided the TACs for the new HCRs (ISC 2026).

The objective of this paper is to evaluate HCRs 17 and 18, via a closed-loop MSE simulation and to detail the associated specific modifications made to the PBF MSE framework previously established by ISC (ISC 2025). Specifically, this work documents the adaptation of the MSE framework to incorporate a 2-year assessment and management cycle and test the performance of the new HCR and associated control points that the JWG had agreed upon, and fishing impact allocation ratios of 80:20 and 70:30 (WCPO:EPO).

Table 1. The new HCR was put forward by the JWG in March 2026 and adopted in August 2026. The target reference point (F_{TARGET}) is an indicator of fishing mortality based on SPR. SPR is the spawning potential ratio. An F_{TARGET} of $F_{SPR27.5\%}$ is associated with a fishing mortality that would leave 27.5% of the SSB per recruit compared to the unfished state. The control points are SSB-based and refer to the specified percentage of equilibrium unfished SSB ($SSB_{F=0}$). The minimum F (F_{min}) refers to the level fishing mortality is set to when SSB is below the 2nd control point.

F_{TARGET}	Control Point 1 (ThRP)	Control Point 2	Fmin	MP update cycle	Review
$F_{27.5\%SPR}$	20%$SSB_{F=0}$	7.7%$SSB_{F=0}$	$F_{70\%SPR}$	2 year	MP will be reviewed after 6 years (3 x 2- year cycles)

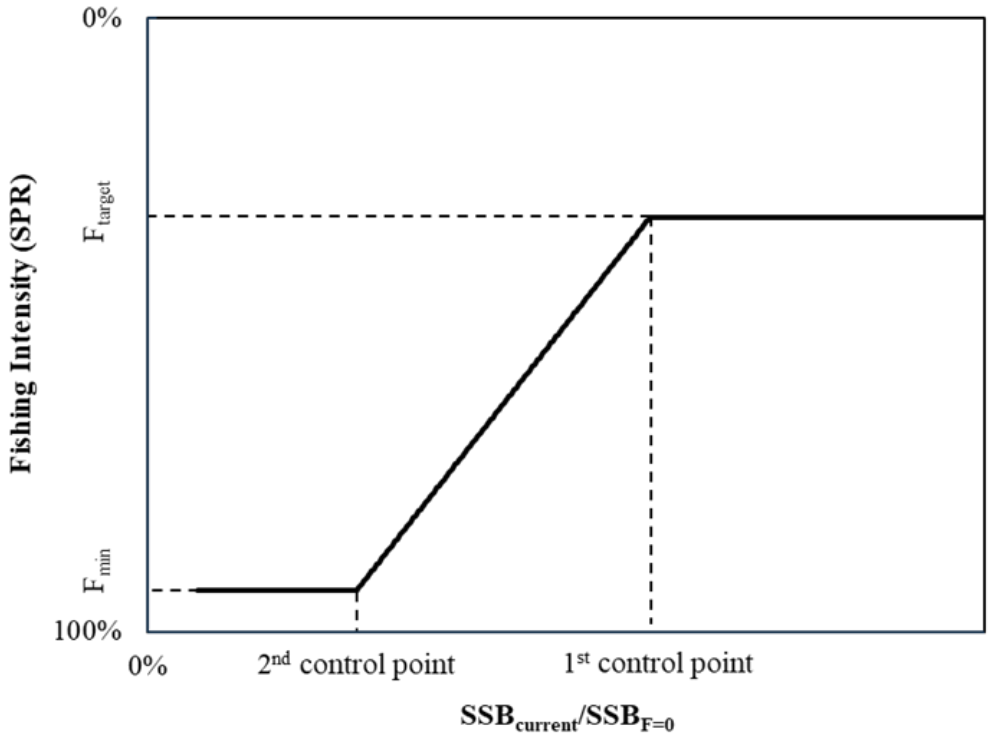


Figure 1. Illustration of the newly agreed harvest control rule (HCR) with target reference point (F_{target}), 1st control point, and 2nd control point, and the minimum allowed fishing intensity (F_{min}). by the JWG in August 2026. Fishing intensity is an indicator of fishing mortality based on SPR. SPR is the spawning potential ratio that would result from the current year's pattern and intensity of fishing mortality relative to the unfished stock. $SSB/SSB_{F=0}$ is SSB relative to the equilibrium unfished SSB ($SSB_{F=0}$).

Methods

We used the same MSE Framework described in the 2025 PBF MSE report (ISC 2025), which is described briefly below. Please see the 2025 PBF MSE report (ISC 2025) for details. Performance was evaluated across the same 20 operating models (OMs) and 3 robustness tests, using the same data generation routine, estimation model (EM), implementation error, and process error. The TAC calculation algorithm was also the same as the other candidate HCRs. The code was updated to be able to test HCRs with a 2 year management cycle instead of the 3 year management cycle. In the following sections, we summarized the key elements and changes made to mimic the newly adopted HCR with two fishing impact allocation ratios (80:20 and 70:30; WCPO:EPO; HCRs 17 and 18).

1. Conditioning Process & Base Case OM (OM1)

- Conditioning Data: OMs were conditioned on historical fishery data from 1983 through 2023, including catch statistics, abundance indices, and size compositions from the 2024 stock assessment (ISC 2024).
- Base Case Structure (OM1): OM1 adopts the settings and assumptions of the 2024 base-case assessment model:
    - Stock Structure: Assumes a single, well-mixed North Pacific stock.
    - Demographics: Assumes an equal 1:1 sex ratio (no sexual dimorphism) and a fixed, time-invariant weight-at-length relationship.
    - Growth: Used a time-invariant sex-combined length-at-age relationship as in the 2024 base-case model.
    - Natural Mortality (M): Uses fixed, age-specific natural mortality rates.
    - Selectivity & Catchability: Selectivity in forward simulations is fixed at 2015–2022 fleet averages, and catchability is assumed constant over time.
    - Observation Error: Observed catch data assumes a lognormal error distribution. Fishery CPUE and recruitment deviations were fit assuming a lognormal error structure. Size composition data assumed a multinomial error structure.
    - Data Weighting: Assumes high precision for catches at S.E. = 0.1 (log space) for most fleets but S.E. = 0.3 for unaccounted mortality fleets. Baseline CV = 0.2 (or the model-estimated CV if higher) for CPUE Abundance indices. As for length compositions, generally < 15 effective sample sizes; longline sizes were scaled based on total fish sampled relative to other fleets.

2. Reference Set of Alternative OMs (20 OMs)

To capture fundamental uncertainties in stock productivity, an uncertainty grid was constructed around three highly influential parameters:

- Key Parameters: Natural mortality for age 2 and older (M_{2+}), length at age 3 (L_2), and stock-recruitment steepness (h).
- Diagnostic Screening: Candidate models were evaluated across five quantitative diagnostic tests to screen out poorly conditioned or unrepresentative models:

1. Convergence & Stability: 25 jitter runs per model to verify convergence to a global minimum.
2. Goodness-of-Fit: Comparison of total negative log-likelihoods (NLLs) against the base model for abundance indices and size compositions.
3. R_0 Likelihood Profile: Evaluation of consistency among data sources regarding overall population scale.
4. Retrospective Analysis: Consistency check across historical data cutbacks using Mohn's rho (models with $|\rho| > 0.1$ were eliminated).
5. Age-Structured Production Model with Recruitment (ASPM-R): Verification of production relationship estimation.

- Ensemble Selection: Candidate models passing 3 or more diagnostics were chosen for the reference set, resulting in 20 equally weighted OMs representing plausible variations in stock productivity ranging from 10% to 25% $SSB_{F=0}$ in 2022 (terminal year for the 2024 assessment model).

3. Robustness Set of Operating Models

Three additional robustness scenarios were constructed from OM1 to test HCR performance under extreme or detrimental conditions:

- Recruitment Drop: Models a 10-year, ~40% drop in recruitment (2042–2051) by resampling historical low-recruitment deviations. The simulation had a later end year (2066).
- Effort Creep (Catchability Change): Simulates an unobserved 2% annual increase in CPUE catchability for the Chinese Taipei longline fleet since 2002.
- Increase in Discards: Models a doubling of unobserved post-release/discard mortality relative to assessment assumptions.

4. "Future" Process

Once all the selected OMs were "conditioned", they were projected forward in time in a closed loop simulation with feedback between the PBF population and the management actions. The simulation recreates the full real-world feedback loop over a **22-year simulation period (2023–2044)** across all 20 reference OMs and 100 iterations of recruitment process variability

(standard deviation for recruitment in log space, σ_R = 0.6) for each HCR. The first simulated assessment in the MSE ran in the fishing year 2023 (July 2023 to June 2024 in calendar year) and set the MP-derived TAC for calendar year 2025. Catches in 2023 reflected actual catches provided by member countries while 2024 catches were based on the agreed upon catch limits set by IATTC and WCPFC plus EPO recreational catches in the last year of the 2024 stock assessment and discards. At each time step of the 22-year simulation, each OM simulated the "true" population dynamics of PBF stock and the fisheries operating on it, given the TAC set by each HCR. Catch, CPUE, and size composition data with error were sampled from the OM every two years and input with error into a stock assessment model (i.e., the EM below).

The estimation model (EM) is constructed as a quasi age-structured production model with estimated recruitment deviates (ASPM-R+) in Stock Synthesis (SS3). This streamlined structure achieves more than 50% reduction in computation time compared to the full SS3 model while maintaining estimation performance. In the ASPM-R+, all fleet selectivities are fixed at the baseline values estimated in OM1, except for the Japanese longline (Fleet 1) and Chinese Taipei southern longline (Fleet 3), which estimate selectivities using size composition data. Operating as a real-world assessment, the EM processes data sampled with error from the operating models to estimate terminal-year spawning stock biomass (SSB), numbers-at-age, unfished biomass ($SSB_{F=0}$), and the fishing mortality multiplier (F_{mult}) required to achieve the target fishing mortality (F_{TARGET}).

The management module uses outputs from the EM and a candidate HCR to derive a TAC by fleet segment (EPO, WCPO small fish, WCPO large fish). First, the EM uses the SS3 forecast algorithm to determine the F_{mult} needed to achieve F_{TARGET}, assuming biological parameters, fleet selectivities, and relative fishing mortality across fleets averaged over 2015–2022. If terminal relative SSB falls below control points, the module adjusts F_{mult} downward according to the HCR. The adjusted fishing mortality is then converted into seasonal catch-at-age using terminal numbers-at-age, natural mortality, and weight-at-age, which are summed across seasons and fleets into three primary TAC segments: WCPO large fish, WCPO small fish, and EPO. Finally, unless relative SSB drops below the second control point (7.7% of $SSB_{F=0}$), the module enforces a stability constraint that limits TAC changes between management periods to a maximum of ±25%.

The implementation error accounts for errors in reporting, problems with compliance, operational implementation of the management measure, unforeseen changes in fisher behavior, or discards that lead to the actual catch being different from the TAC. Driven by stringent catch

quotas and a growing population, implementation error is modeled as unobserved discard mortality using three dedicated discard fleets. Unaccounted mortality for general WCPO fisheries (Fleet 24) is modeled as an additional 5% above total WCPO catches (excluding Fleet 14), while Japanese troll for penning (Fleet 25) discards are included as 100% of Fleet 14 catch to account for high release rates. Unaccounted mortality for the EPO recreational fleet (Fleet 26) is set to 1.2% of total EPO recreational catch. These additional discard removals are added to the HCR-derived TACs before updating the population dynamics in the OMs.

Proportional fishery impact measures the specific reduction in SSB caused by a fleet group relative to all fisheries combined, determined by both fleet-specific age selectivities and the relative fishing mortality (relative F) across fleets. For HCR 17, applying the 2015–2022 historical baseline relative F and selectivity in OM1 naturally produced an impact ratio close to 80:20 without requiring additional adjustment. To achieve the 70:30 fishery impact ratio for HCR 18, a tuning protocol ran simulations across varying relative F levels in the EM forecast file and fitted a polynomial regression to map relative F against proportional impact.

Results

The simulation resulted in a total of 4,000 (20 OMs x 2 HCRs x 100 iterations) runs for the reference set. Each run had 11 rounds of simulated stock assessments (i.e., EMs) for a total of 44,000 EMs. We used the same criteria as in the previous PBF MSE to screen problematic EMs. For example, EMs that produced unrealistically low (<1e-60) terminal SSB estimates not seen in the OM or had absolute relative errors in SSB, calculated as $100*|(SSB_{OM}-SSB_{EM})|/SSB_{OM}$, greater than 1000% were flagged. Only a very small proportion (0.01%) of all the EMs were flagged and required further investigation. These EMs had estimation issues and extremely large gradients (> than 100), indicating non convergence. As with the previous MSE, iterations associated with the problematic EMs were removed for all OMs and HCRs. This was done to ensure performance metrics were computed for HCRs exposed to the same recruitment trends. All results are therefore presented only for the 91 out of 100 iterations without any associations with the problematic EMs.

Performance metrics for the reference set are calculated across 20 OMs and 91 iterations and **20 evaluation years from 2025 to 2044** as the first simulated TAC was applied in 2025. The same iterations were also used to evaluate results from the robustness scenarios. The performance metrics presented are the same ones used for previous HCRs. All performance metrics in the

reference set are in Table 2 and also showcased in the figures and text below. Table 2 also includes the first MP TAC calculated externally from the MSE in ISC 2026. The results of the evaluations for the reference set are available online at: https://connect.fisheries.noaa.gov/ISCPBF-adopted-MSE-tool/.

Table 2. Performance indicators for harvest control rules (HCRs) 17 and 18 across all iterations, evaluation years, and reference set operating models. SSB refers to spawning stock biomass, $SSB_{F=0}$ refers to unfished spawning stock biomass, F refers to fishing mortality measured as 1-SPR where SPR is spawning potential ratio, TAC refers to total allowable catch, WCPO refers to Western Central Pacific Ocean, and EPO refers to Eastern Pacific Ocean. Note that to ensure that for all indicators a higher value is better, here we reversed the performance metrics showed in Figures 2, 3, and 6 to be the probability of SSB≥2nd control point, $SSB \geq 20\% SSB_{F=0}$, and of $SSB \geq SSB_{TARGET}$. The % change upwards in TAC (% change TAC +) was set to negative so that high values (smaller -) are better. The % change downwards does not include years when SSB is below 2nd control point as provided by the management objective. The 2026 TAC is the total TAC and the TAC for each fleet segment that could be applied in 2026 if each of the HCR would be adopted as reported in ISC (2026). It is calculated based on biomass status estimated by EM outside the MSE simulation.

Performance Indicators - Reference Set																	
HCR	**Prob SSB >= 2nd control point**	**Prob SSB >= 20%$SSB_{F=o}$**	**Prob F <= Ftarget**	**Prob SSB >= SSBtarget**	**% change TAC +**	**% change TAC -**	**EPO Impact**	**Median annual catch**	**Median 5-10 years annual catch**	**Median 11-22 years annual catch**	**Median WCPO large fish annual TAC**	**Median WCPO small fish annual TAC**	**Median EPO annual TAC**	**2026 TAC**	**2026 TAC WCPO large fish**	**2026 TAC WCPO small fish**	**2026 TAC EPO**
17	100	85	82	66	-14	-10	23	29841	25882	33499	16861	4379	7162	26642	14836	4823	6983
18	100	84	81	63	-13	-8	33	30932	30238	31584	13718	3914	10552	28388	14836	4076	9476

Safety

Performance of both HCRs with respect to the safety management objective, *there should be a less than 10% probability of the stock falling below the 2nd control point*, was measured by :two performance indicators (Annex G in JWG 2023). The first computed the probability that SSB < 2nd control point (7.7%$SSB_{F=0}$) in any given year of the evaluation period. The second, although not explicitly specified, evaluated whether the probability of SSB falling below the 1st control point (20%$SSB_{F=0}$) was less than 20% in any given year of the evaluation period.

Both HCRs were able to maintain a very low probability (0.001 for both HCRs) of the stock breaching the 2nd control point of 7.7%$SSB_{F=0}$ and a low probability (15% and 16% for HCR 17 and 18, respectively) of the stock breaching the 1st control point of 20%$SSB_{F=0}$ (Table 2, Figures 2 and 3). Under both HCRs, median SSB increased from initial conditions to levels above their respective targets (Figure 4). **In general, both HCRs demonstrate comparable performance for the Safety management objective, with both rules meeting the required criteria.**

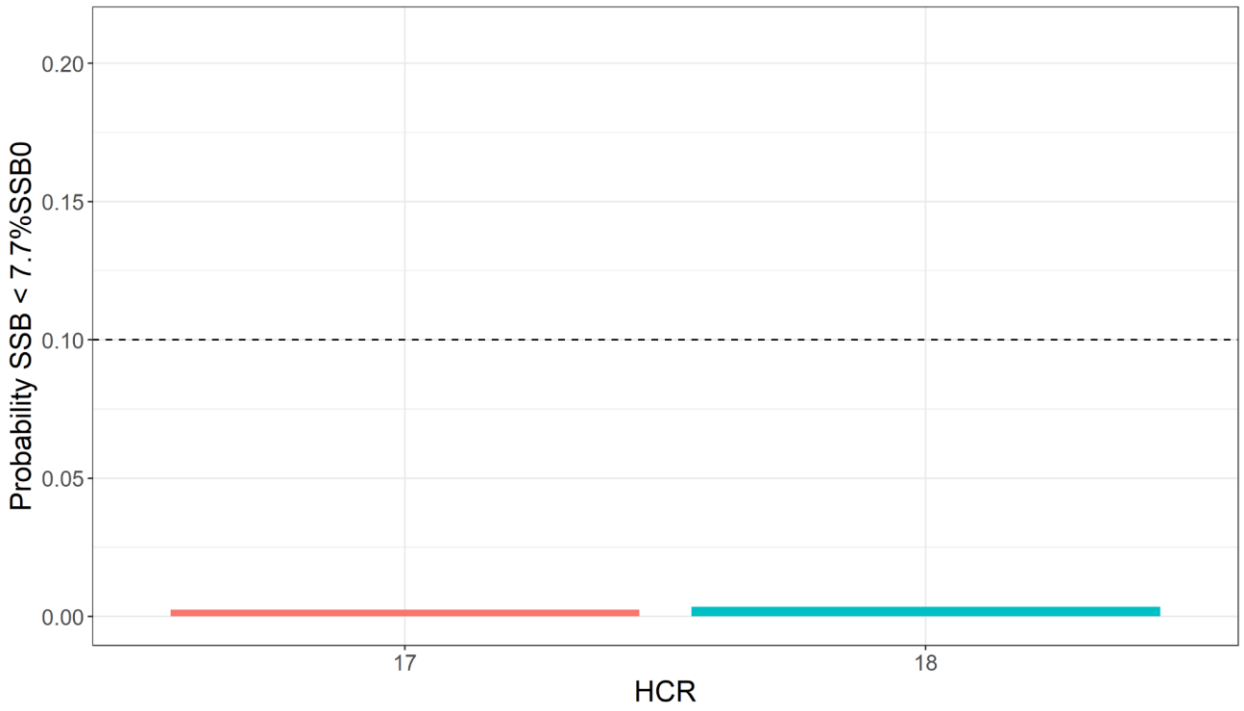


Figure 2. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 2nd control point of 7.7%$SSB_{F=0}$ across all reference scenarios, iterations, and simulation years.

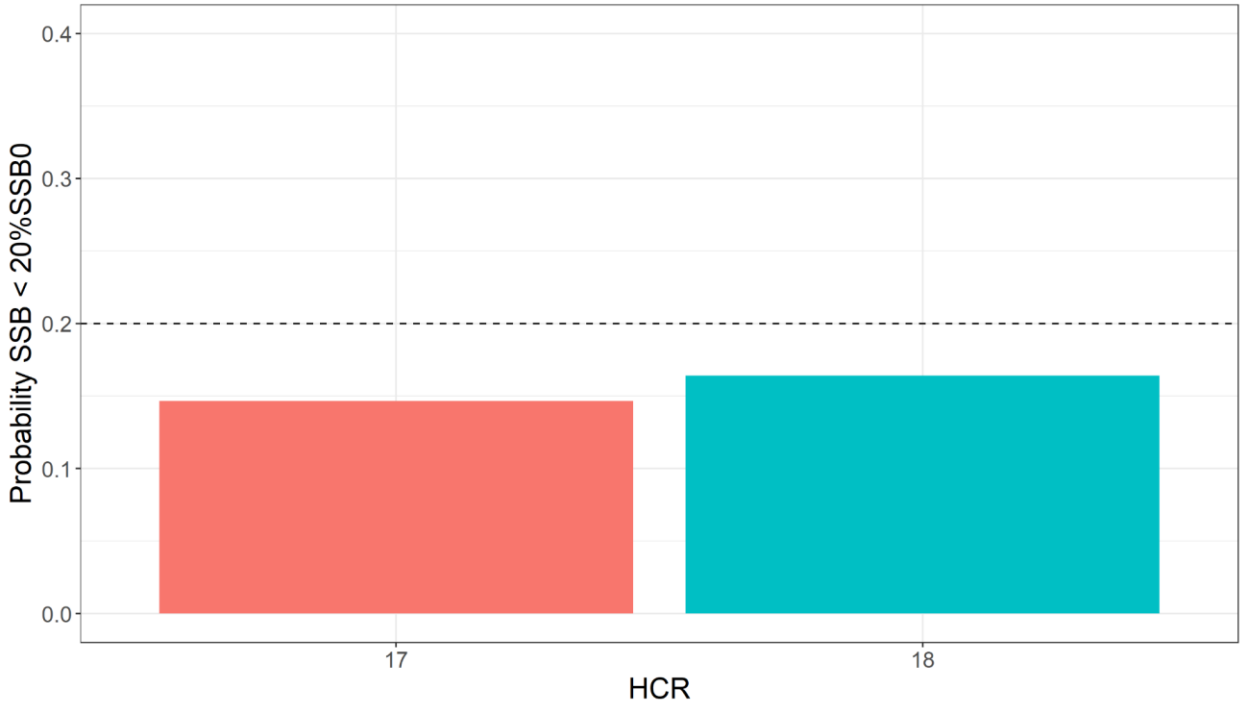


Figure 3. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 1st control point of 20%$SSB_{F=0}$ across all reference scenarios, iterations, and simulation years.

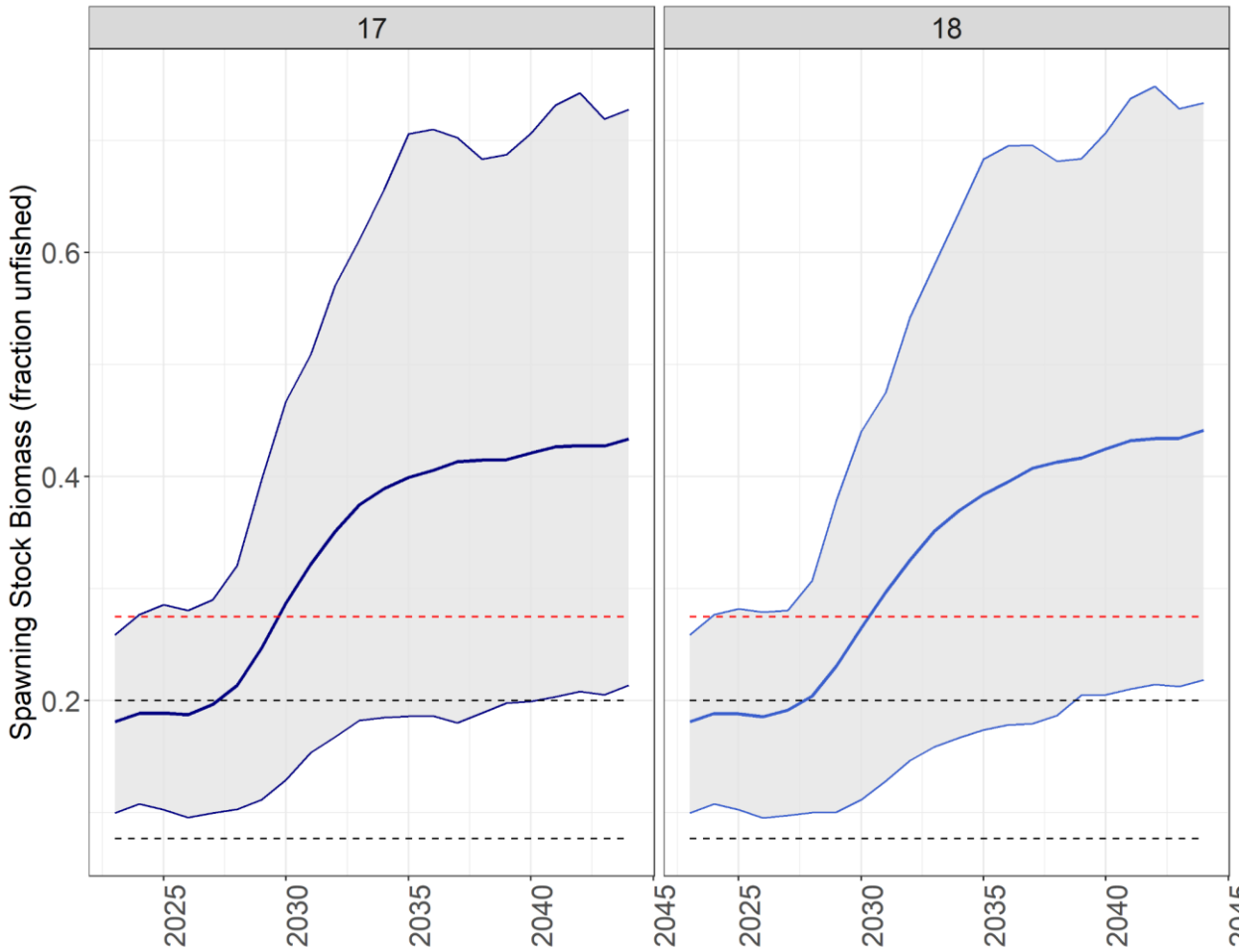


Figure 4. Trends in median relative spawning stock biomass (SSB/unfished SSB, thick solid color lines) across all the reference set operating models and iterations by harvest control rule (HCR). The grey shading represents trends in the 5th to 95th quantile range. The lowest black dotted line represents the lowest control point for each HCR (7.7%$SSB_{F=0}$), and the highest black dotted line represents the highest control point (20%$SSB_{F=0}$). The dashed red line represents the SSB associated with the respective F_{TARGET} ($F_{27.5\%SPR}$).

Status

Performance of both HCRs with respect to the status management objective, *to maintain fishing mortality at or below* F_{TARGET} *with at least 50% probability*, was measured by two performance indicators (Annex G in JWG 2023). The first computed the probability that F≤F_{TARGET} in any given year of the evaluation period. The second calculated the probability that SSB is below the equivalent biomass depletion levels associated with the F_{TARGET}.

Both HCRs met the status objective of maintaining fishing mortality at or below the F_{TARGET} with at least 50% probability (82% and 81% for HCR 17 and 18, respectively; Table 2, Figure 5). Furthermore, under both HCRs the probability that SSB is below the equivalent biomass depletion levels associated with the F_{TARGET} was less than 50% (34% and 37% for HCR 17 and 18, respectively; Table 2, Figure 6). Under both HCRs, median F decreased from initial conditions to levels below their respective targets (Figure 7). **In general, both HCRs demonstrate comparable performance for the Status management objective, with both rules meeting the required criteria.**

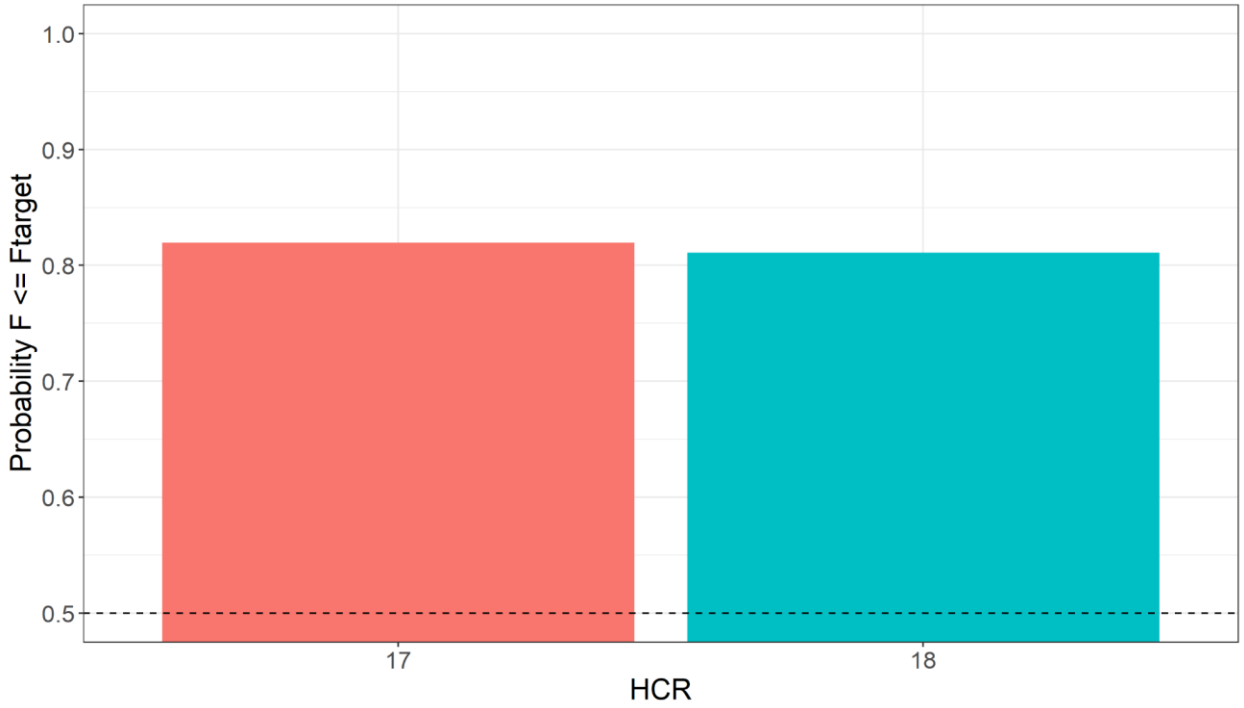


Figure 5. Probability, for each harvest control rule (HCR), of fishing mortality (F, 1-SPR) being less or equal to the F_{TARGET} across all reference scenarios, iterations, and simulation years. The horizontal dotted line represents a 50% probability.

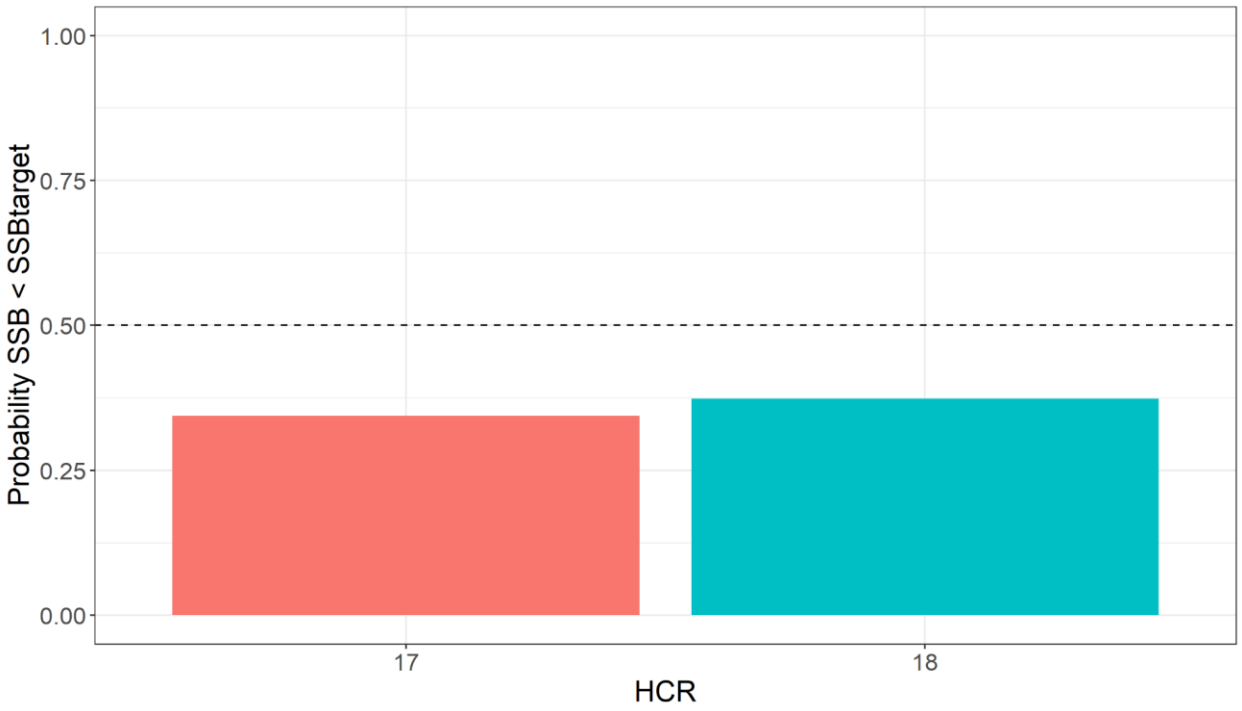


Figure 6. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being less or equal to the equivalent biomass depletion levels associated with the F_{TARGET} across all reference scenarios, iterations, and simulation years. The horizontal dotted line represents a 50% probability.

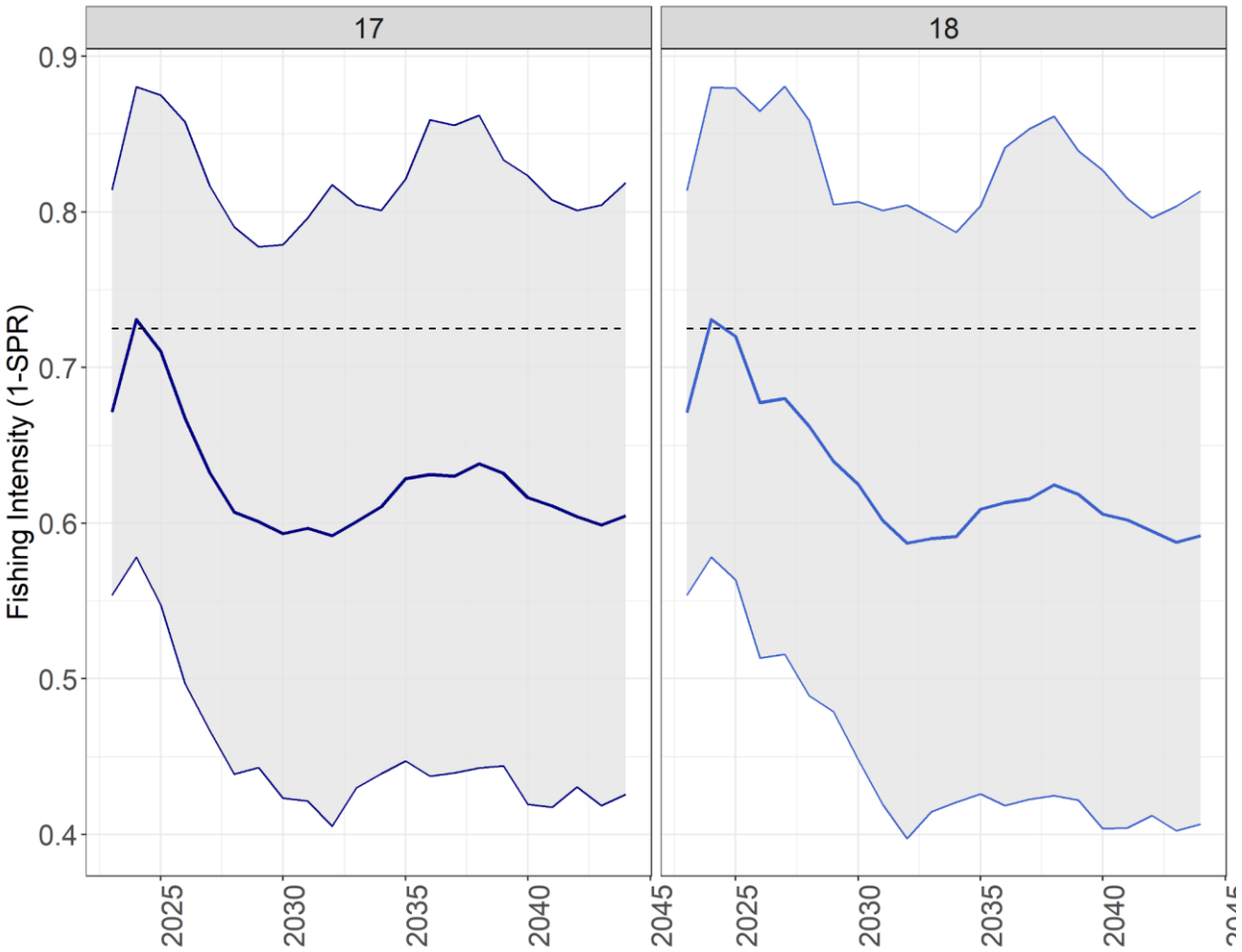


Figure 7. Trends in median fishing mortality (F, 1-SPR, thick solid color lines) across all the reference set operating models and iterations by harvest control rule (HCR). The grey shading represents trends in the 5th to 95th quantile range. The dashed red line represents the F_{TARGET} ($F_{27.5\%SPR}$).

Stability

Performance of both HCRs with respect to the stability management objective, *to limit changes in overall catch limits between management periods to no more than 25%, unless the ISC has assessed that the stock is below the 2nd control point*, was measured by the percent change upwards or downwards in catches between management periods excluding periods when SSB < 2nd control point (Annex G in JWG 2023).

By design, changes in TAC, either downwards (Figure 8) or upwards (Figure 9), for both HCRs were capped at 25%. Changes in median TAC between management periods were slightly

less for HCR 18 compared to 17, regardless of whether adjustments were downward or upward (Table 2, Figures 8 and 9). A violin plot of the whole distribution of changes in TAC demonstrates that median change in TAC is positive (Figure 10), highlighting that both HCRs have more increases than decreases in TAC. **In general, both HCRs demonstrate comparable performance for the Stability management objective, with both rules meeting the required criteria.**

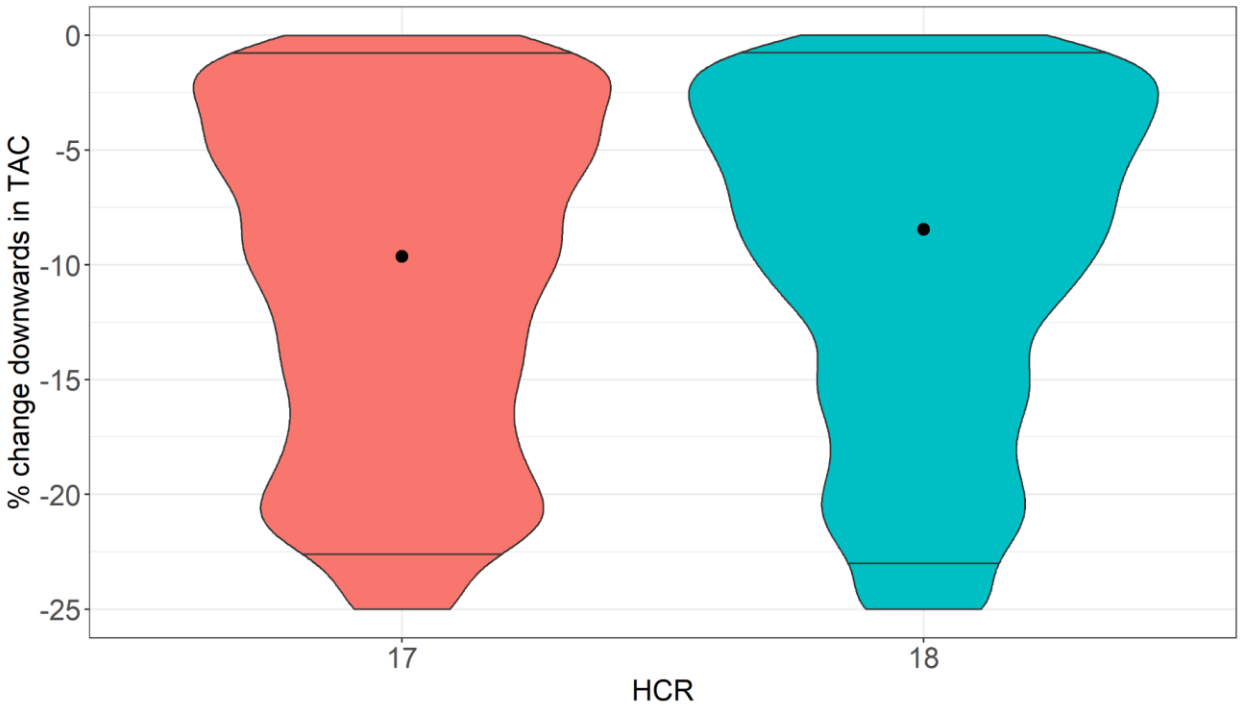


Figure 8. Violin plots showing the probability density of downward changes in TAC between management periods when SSB≥2nd control point for each harvest control rule (HCR) across all iterations, reference scenarios, and simulation years. The marker inside each violin plot is the median downward change in TAC, and horizontal solid lines within each violin represent the 5th to 95th quantile range.

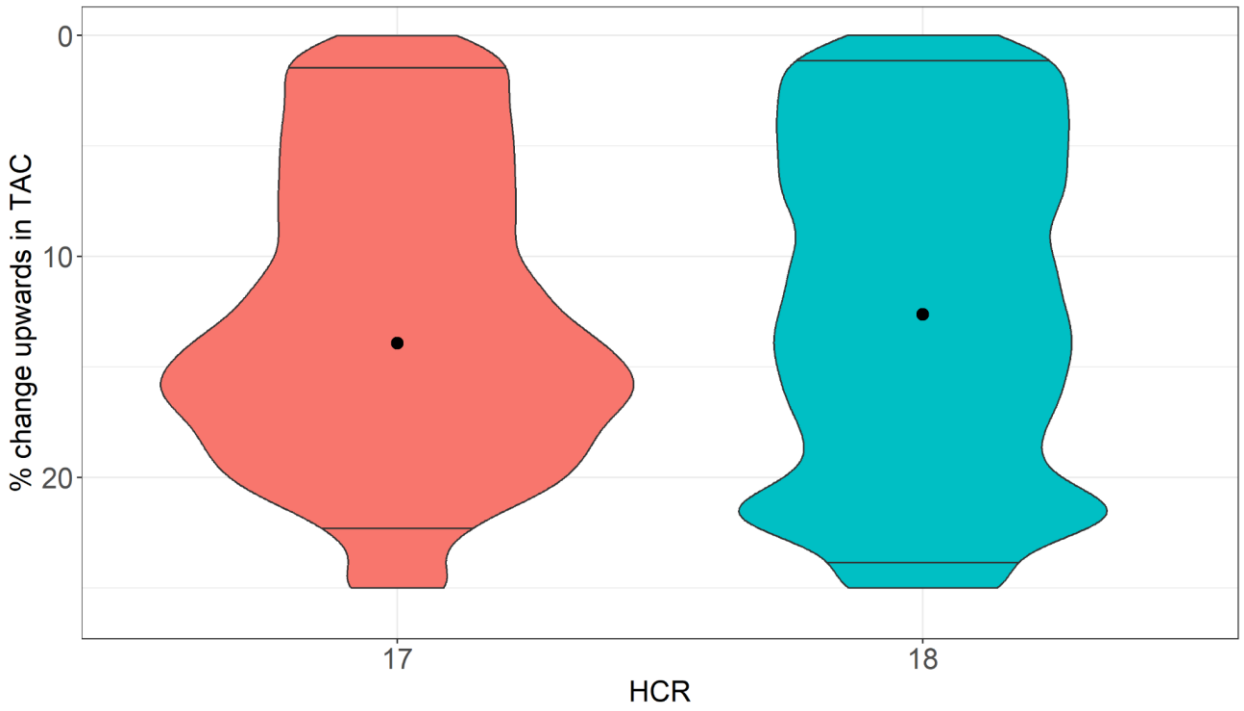


Figure 9. Violin plots showing the probability density of upward changes in TAC between management periods when SSB≥2nd control point for each harvest control rule (HCR) across all iterations, reference scenarios, and simulation years. The marker inside each violin plot is the median upward change in TAC, and horizontal solid lines within each violin represent the 5th to 95th quantile range.

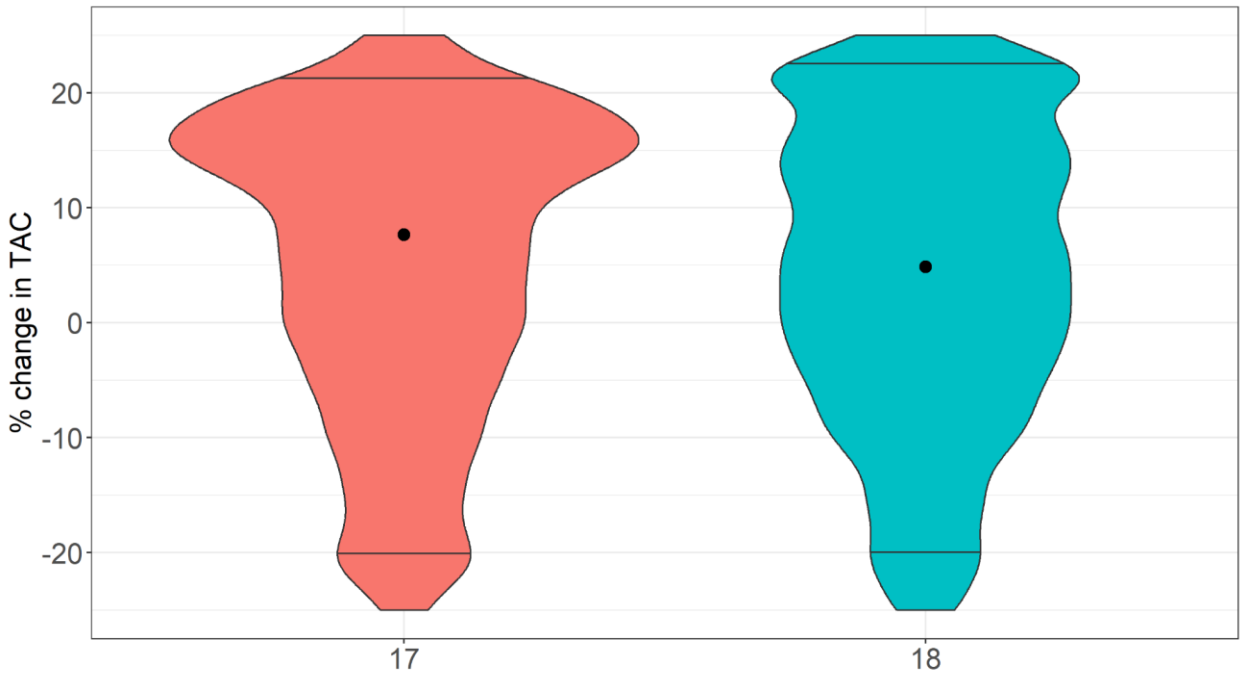


Figure 10. Violin plots showing the probability density of changes in TAC between management periods when SSB≥2nd control point for each harvest control rule (HCR) across all iterations, reference scenarios, and simulation years. The marker inside each violin plot is the median % change in TAC, and horizontal solid lines within each violin represent the 5th to 95th quantile range.

Yield

Yield has multiple management objectives (Annex G in JWG 2023). The first yield management objective, *to maintain an equitable balance in proportional fishery impact between the WCPO and the EPO*, was measured by computing the median fishery impact on SSB (in %) in the terminal year of the evaluation period by WCPO and EPO fisheries. Both HCRs were able to maintain median fishery impact on SSB (in %) in the terminal year of the evaluation period around the level set by each HCR, with the EPO fishery impact being around 23% for HCR 17 and around 33% for HCR 18 (Table 2, Figure 11). The difference between the specified WCPO:EPO impact ratios (80:20 or 70:30) and the observed performance values arises because the MP was designed to control the impact ratio under OM1 that assumes the same biological assumptions with the EM. This was done as it was assumed that other versions of reality (i.e., OMs) would not be

known during operational application of the MP. As a result, the impact ratios observed across all OMs do not necessarily match the specified values, but the relative difference between the HCRs 17 and 18 is preserved as intended.

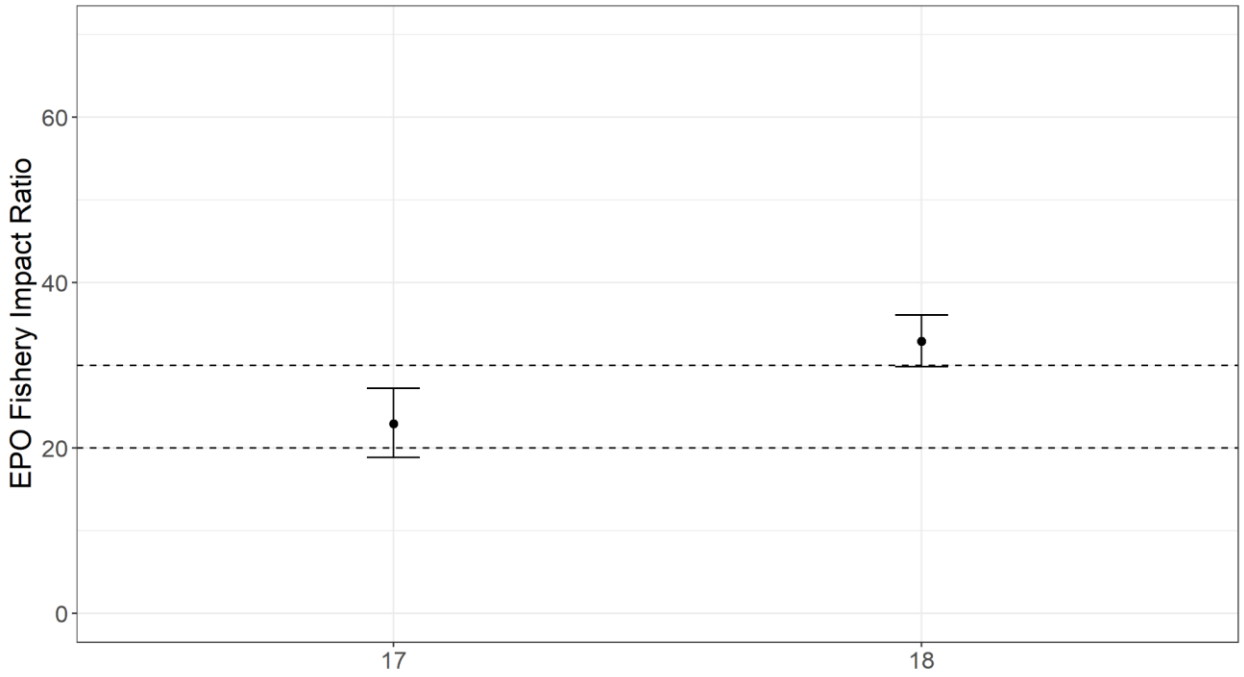


Figure 11. Median (dot) and 5th to 95th quantile range (error bars) of fishery impact on spawning stock biomass for the Eastern Pacific Ocean (EPO) fleet segment in the terminal year of the MSE simulation across all iterations and reference OMs for each HCR. The impact of the Western and Central Pacific Ocean fleet segment is 100 – the EPO impact.

The other yield management objectives, *to maximize yield over the medium (5-10 years) and long (10-30 years) terms, as well as average annual yield from the fishery* and *to increase average annual catch in all fisheries across WCPO and EPO*, were measured by looking at trends in overall catch and by WCPO fisheries and EPO fisheries TAC. Under both HCRs, median total annual catch increased over time and stabilized at around 35,000 mt and 33,000 mt for HCR 17 and HCR 18, respectively, towards the end of the simulation, although HCR 18 had higher catches at the start of the simulation (Figure 12). Indeed, while HCR 17 had the higher median long-term catch, medium-term catch was higher for HCR 18, which resulted in a slightly higher annual catch for HCR 18 (Table 2, Figure 12). The median annual catch in the medium and long terms, as well

as in all evaluation years for both HCRs were higher than the current catch limit (Figure 13). The higher long-term catch of HCR 17 is associated with higher catch of WCPO large fish (Figure 14), whose catch early in the simulation is limited by the 25% limit in sector-specific TAC changes, but which can increase faster under the 2-year management cycle than that of previous HCRs under the 3-year management cycle.

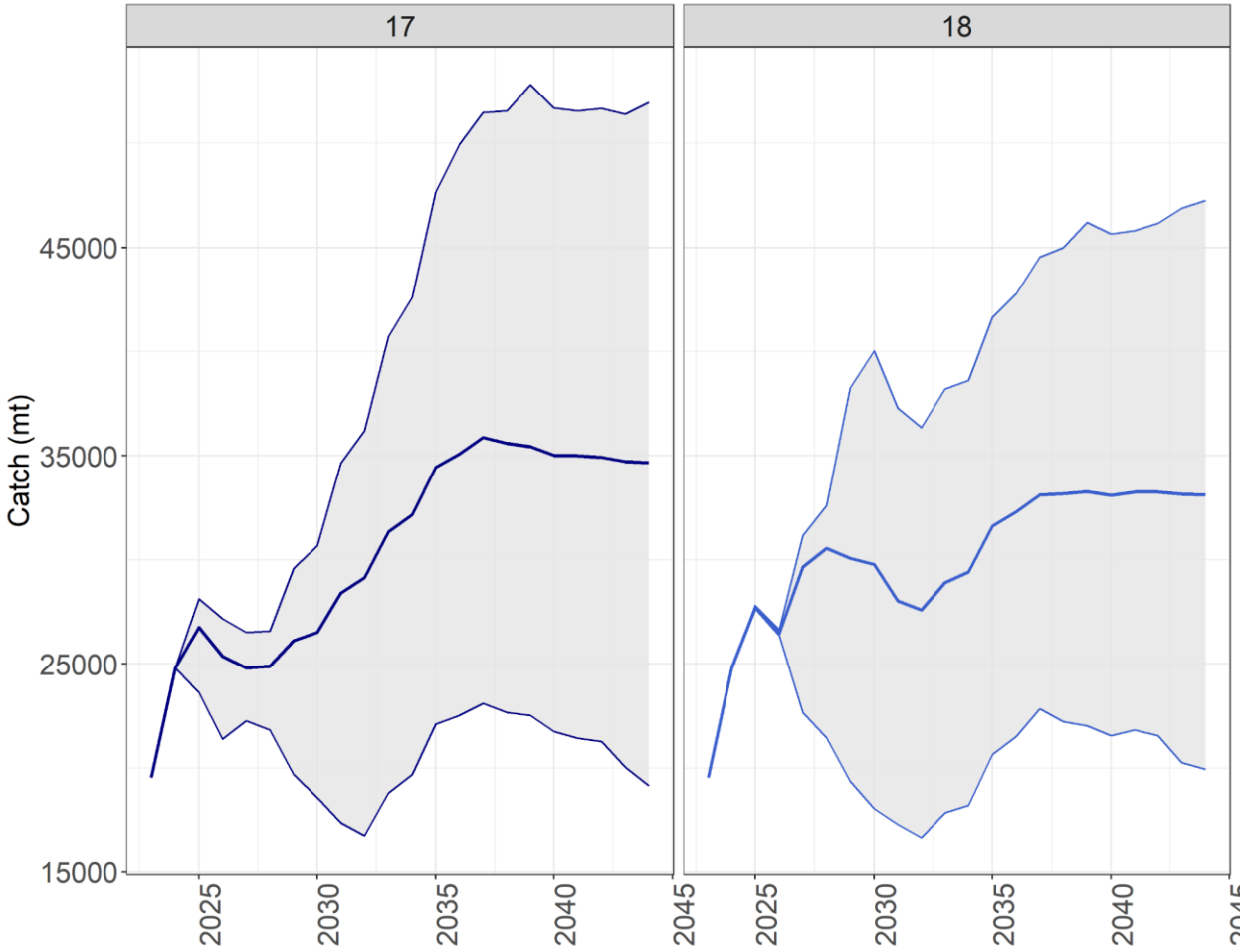


Figure 12. Trends in median total annual catch (including discards and the EPO recreational fleet) set by each harvest control rule (HCR) under all iterations and reference scenarios. The grey shading represents trends in the 5th to 95th quantiles of TAC.

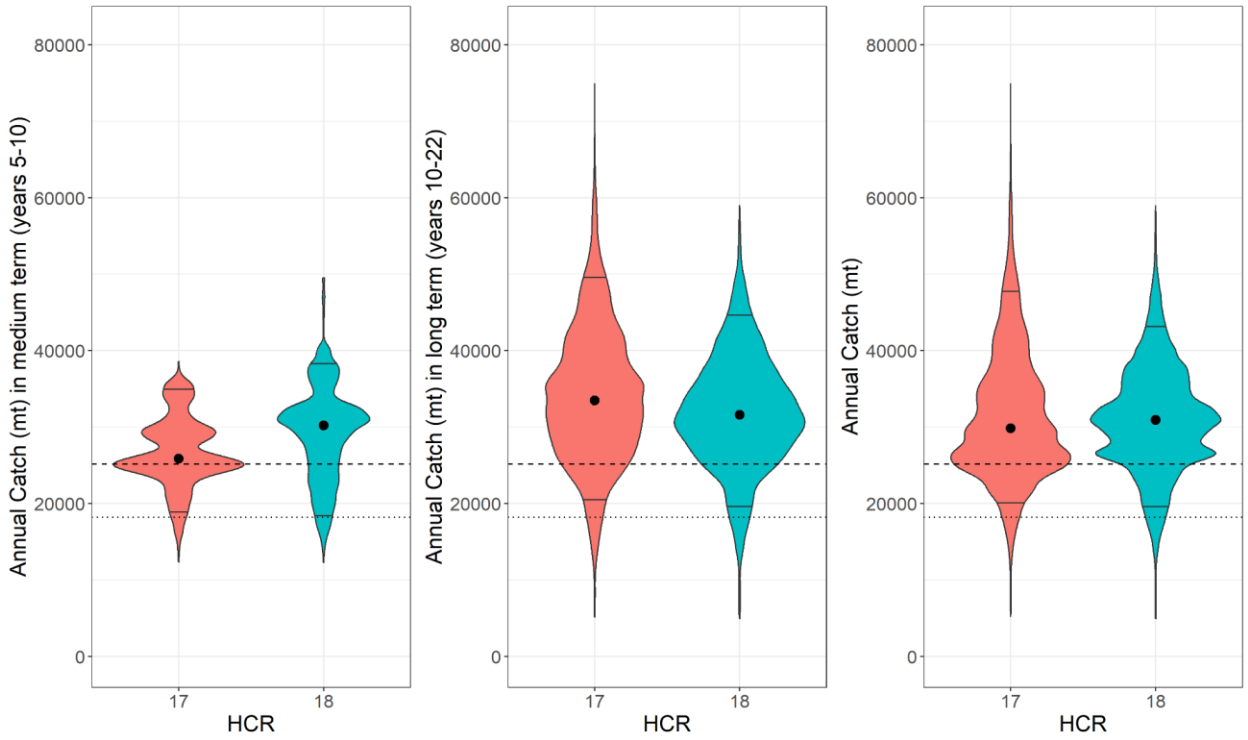


Figure 13. Violin plots showing the probability density of total annual catch (including discards and the EPO recreational fleet) for each harvest control rule (HCR) across all iterations, reference scenarios, and simulation years in the medium term (first panel), long term (second panel), and all years (third panel). The marker inside each violin plot is the median value and horizontal solid lines within each violin represent the 5th to 95th quantile range. The dotted line identifies the total catch limit set by the WCPFC's CMM 23-02 plus IATTC's Resolution C-21-05, effective in 2024, plus EPO recreational catches for the calendar year 2023. The dashed line identifies the total catch limit set by the WCPFC's CMM 24 01 plus IATTC's Resolution C-24-02, effective in 2025, plus EPO recreational catches for the calendar year 2023. For the IATTC's resolution, catch limits were based on half of the biennial TAC.

However, the expected median annual TAC trends differ among fleet segments. The median TAC for WCPO large-fish fleets was always higher than the 2025 catch limit across all evaluated time horizons (Figure 14). The median TAC for the EPO fleets was above the current catch limit only under HCR 18 (Figure 15), which has a higher EPO allocation resulting in an EPO fisheries impact of 30 rather than the 20 used in HCR 17. The median TAC for WCPO small-fish

fleets was lower than the current catch limit for both HCRs across all evaluated time horizons (Figure 16).

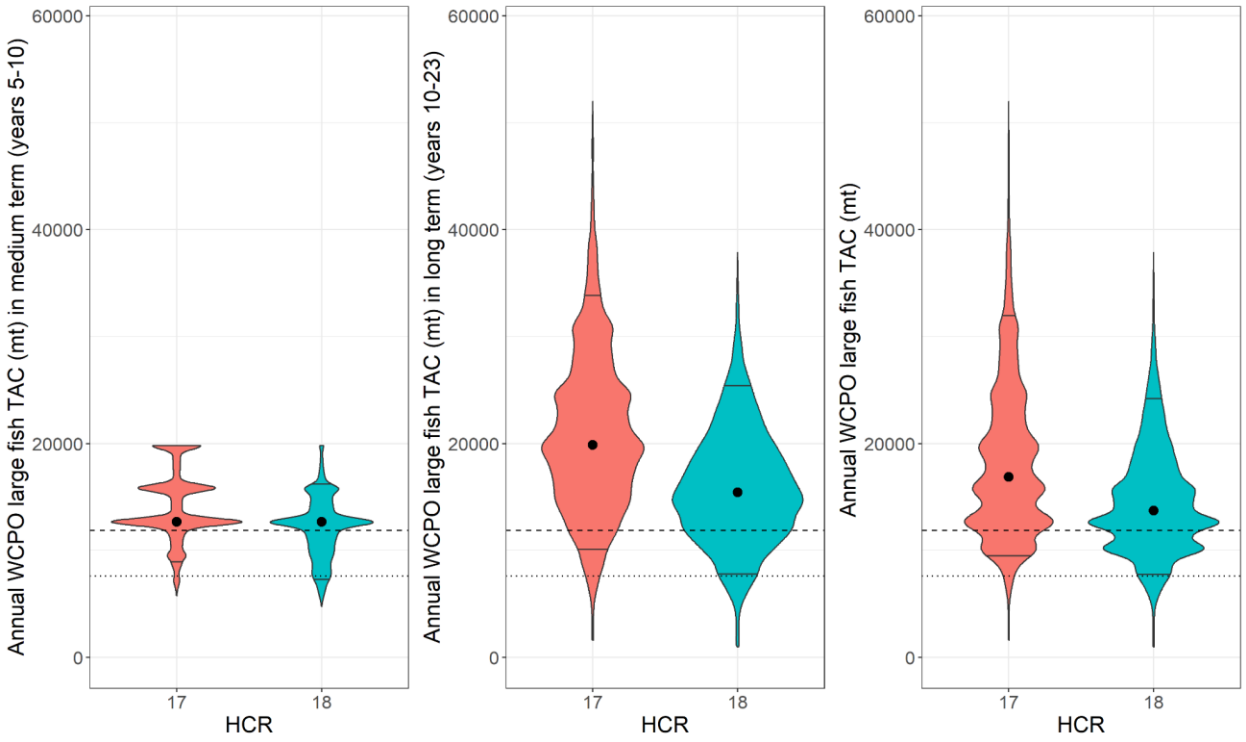


Figure 14. Violin plots showing the probability density of the TAC for the Western Central Pacific Ocean (WCPO) large fish fleets for each harvest control rule (HCR) across all iterations, reference scenarios, and simulation years in the medium term (first panel), long term (second panel), and annually (third panel). The marker inside each violin plot is the median value and horizontal solid lines within each violin represent the 5th to 95th quantile range. The dotted line identifies the catch limit for large fish set by the WCPFC's CMM 23-02, effective in 2024. The dashed line identifies the catch limit for large fish set by the WCPFC's CMM 24-01, effective in 2025.

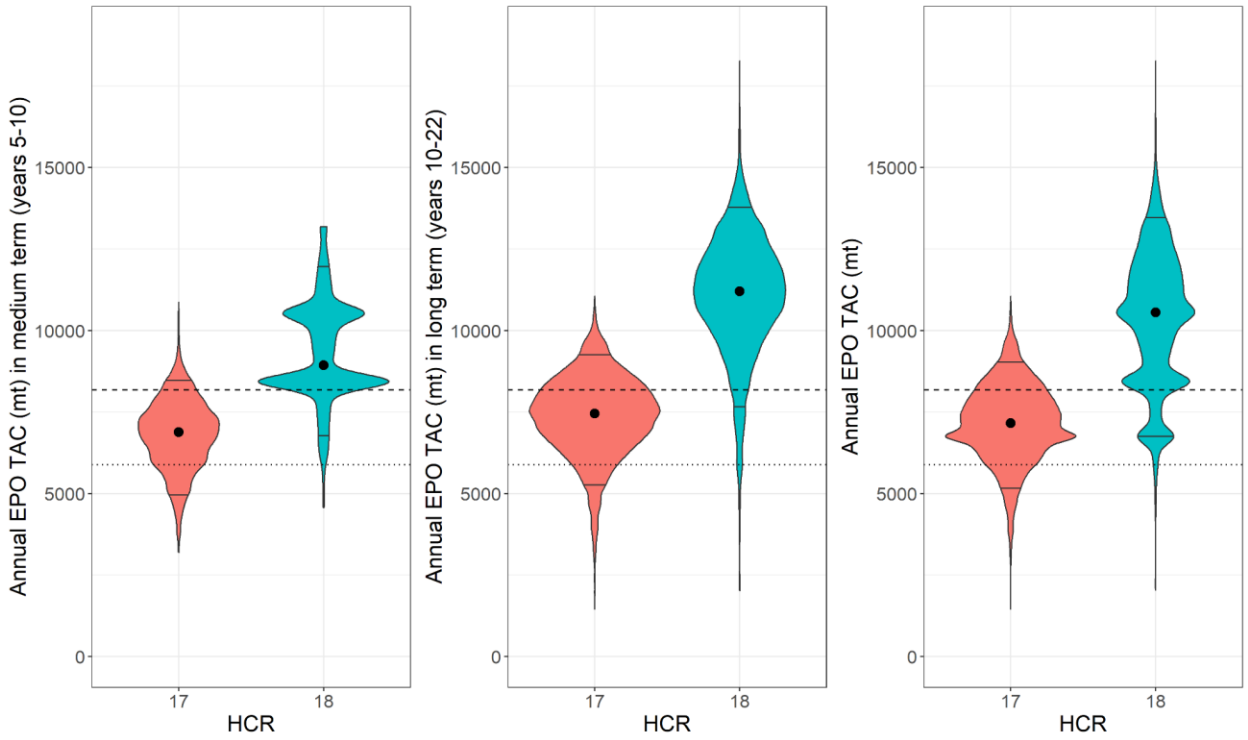


Figure 15. Violin plots showing the probability density of the TAC for the Eastern Pacific Ocean (EPO) fleets for each harvest control rule (HCR) across all iterations, reference scenarios, and simulation years in the medium term (first panel), long term (second panel), and annually (third panel). The marker inside each violin plot is the median value and horizontal solid lines within each violin represent the 5th to 95th quantile range. The dotted line identifies the catch limit for the EPO set by IATTC's Resolution C-21-05, effective in 2024, plus EPO recreational catches for the calendar year 2023. The dashed line identifies the catch limit set by IATTC's Resolution C-24-02, effective in 2025, plus EPO recreational catches for the calendar year 2023. Catch limits were based on the half of the biennial TAC. Note that in the MSE, the EPO TAC includes recreational fleets.

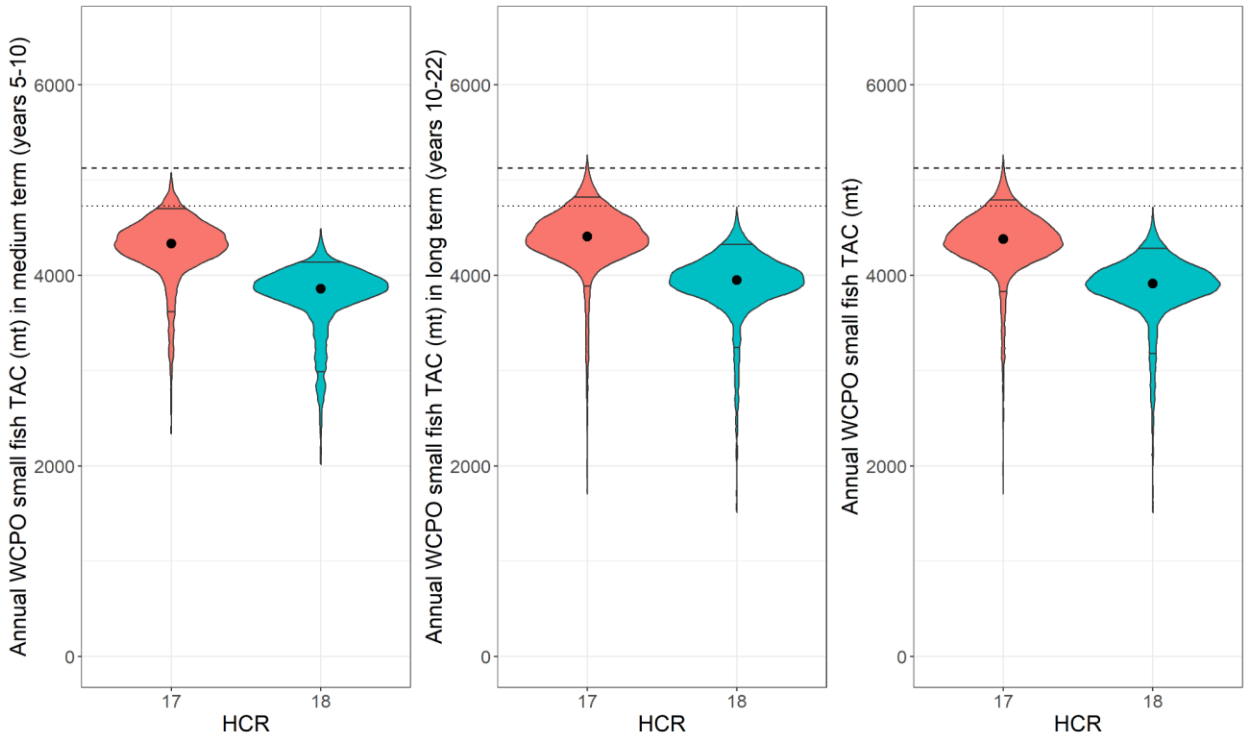


Figure 16. Violin plots showing the probability density of the TAC for the Western Central Pacific Ocean (WCPO) small fish fleets for each harvest control rule (HCR) across all iterations, reference scenarios, and simulation years in the medium term (first panel), long term (second panel), and annually (third panel). The marker inside each violin plot is the median value and horizontal solid lines within each violin represent the 5th to 95th quantile range. The dotted line identifies the catch limit for large fish set by the WCPFC's CMM 23-02, effective in 2024. The dashed line identifies the catch limit for large fish set by the WCPFC's CMM 24-01, effective in 2025.

Trade-offs between Performance Metrics

Both HCRs 17 and 18 performed comparably well across the Safety, Status, Stability, and Yield (i.e., median annual catch) metrics, successfully satisfying all benchmark criteria (Figure 17). When compared to all other HCRs previously tested, there was a trade-off between yield and safety (probability of SSB being below the 1st control point) (top left panel in Figure 17), with results for HCRs 17 and 18 being between those of HCRs with $F_{25\%SPR}$ and $F_{30\%SPR}$. HCRs 17 and 18 also had higher stability (i.e., lower decreases in catch) than all other HCRs except HCRs with an F_{TARGET} of $F_{40\%SPR}$ (top middle panel in Figure 17). This may be because the 2-year management cycle allows the TAC to more closely follow biomass trends than a 3-year cycle, leading to the

TAC not changing as drastically between management periods. Like the other HCRs, status performance for HCRs 17 and HCR 18 was well above 50% (top right panel in Figure 17) as the 25% catch limit and estimation error maintained F below the F_{TARGET}.

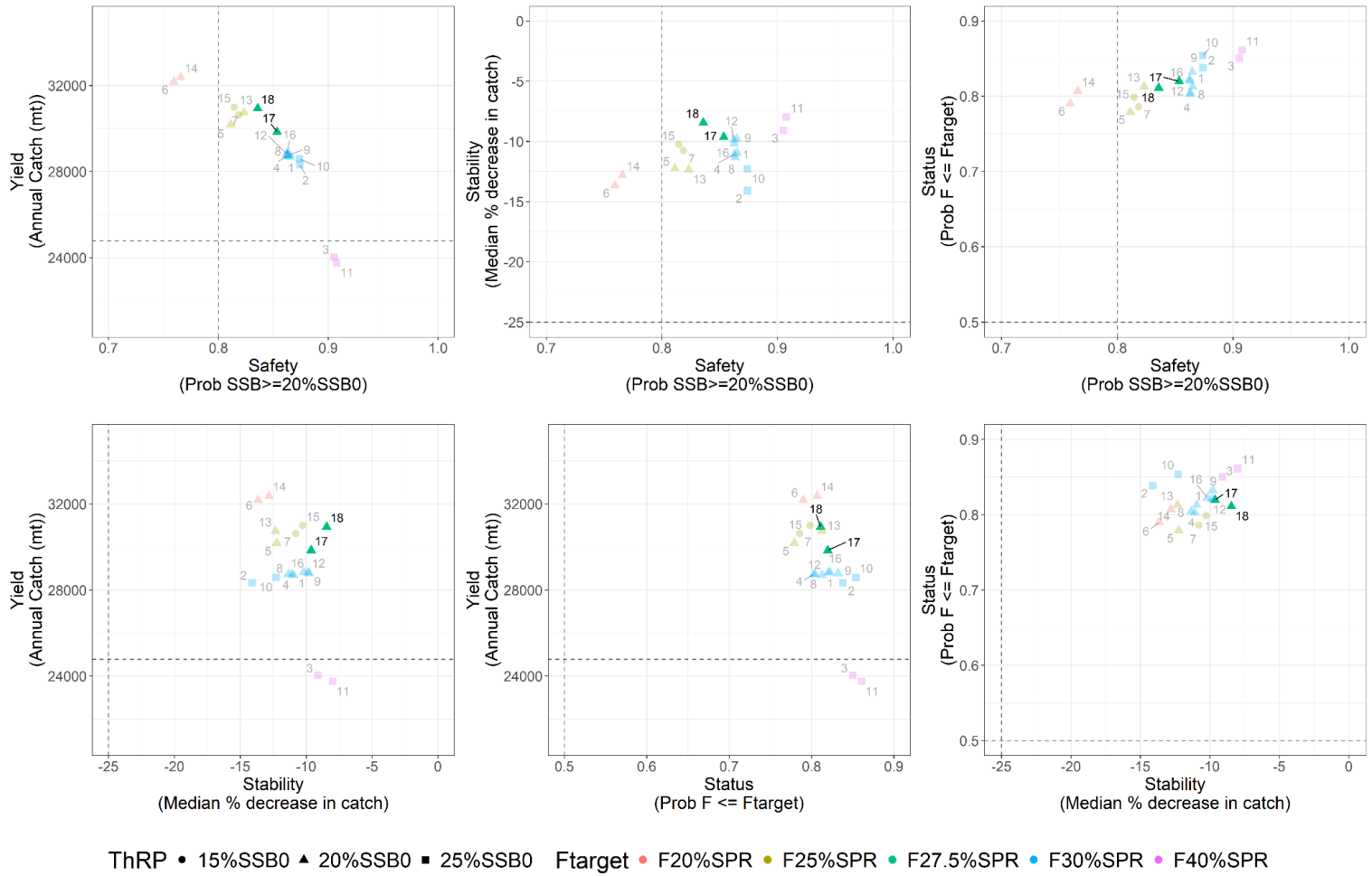


Figure 17. Trade-off between different performance metrics. Previous results for other candidate HCRs presented in ISC 2025 are included here in addition to the new results for HCRs 17 and 18. Each HCR is labeled and colored according to its F_{TARGET}. Each symbol represents a different Threshold reference point, which is the first control point for each HCR and stands for Threshold Reference Point. The dashed line indicates the acceptable levels of probability in each operational management objective.

Robustness Tests

- Increase in Discards

Both HCRs were robust to a doubling of discards not detected in the EM, with median SSB relative to unfished SSB remaining at or above SSB control points throughout the simulation (Figure 18). Both HCRs maintained a less than 10% probability of being below the 2nd control point of 7.7%$SSB_{F=0}$ and 20% probability of being below the 1st control point of 20%$SSB_{F=0}$ (Safety; Figures 19 and 20). Both HCRs also maintained a probability of F being at or below F_{TARGET} higher than 50% (Status; Figure 21) and had a less than 50% probability of SSB being below SSB levels associated with the F_{TARGET} (Status; Figure 22).

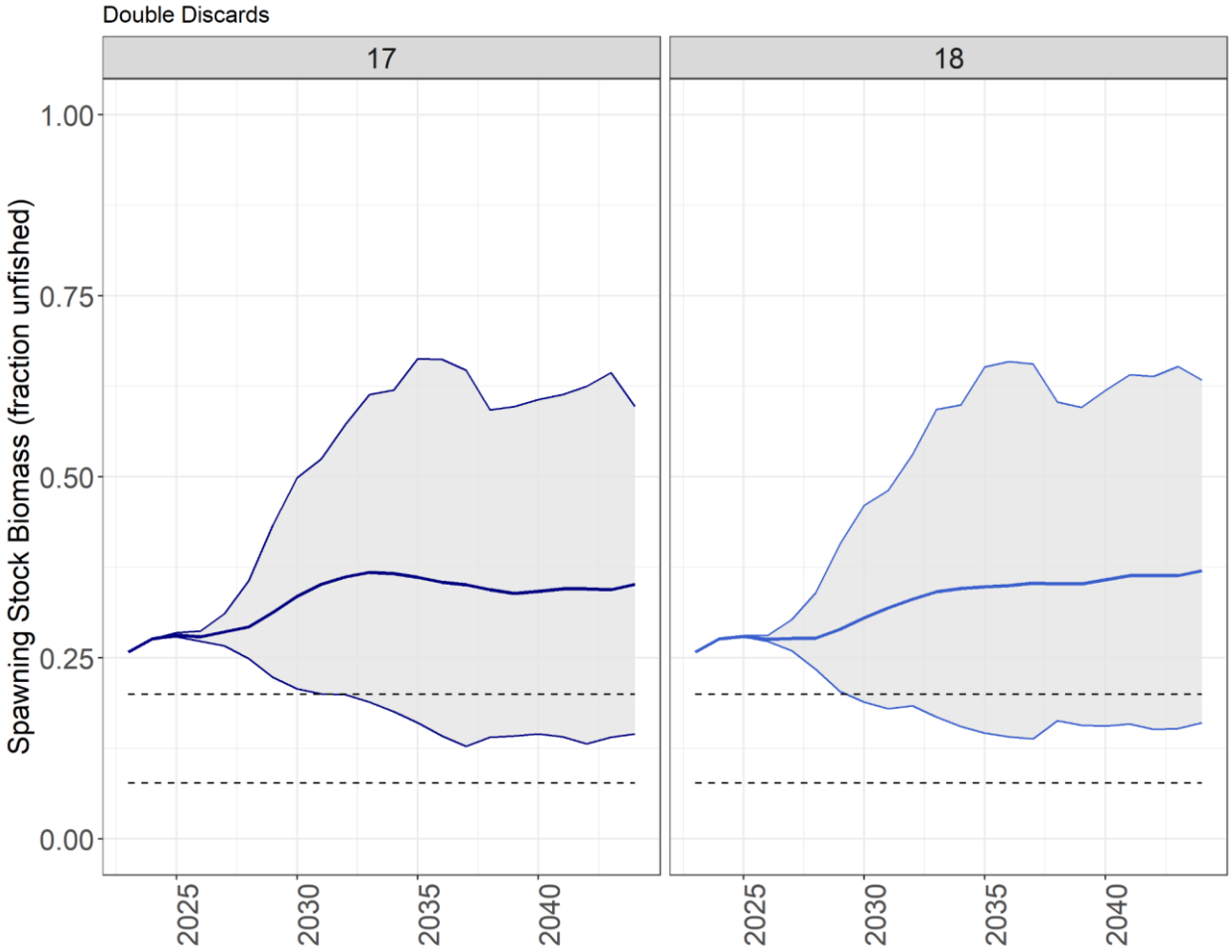


Figure 18. Trends in median relative spawning stock biomass (SSB/unfished SSB, thick solid color lines) operating model 1 across all iterations for the doubling of discards robustness test for each HCR. The grey shading represents trends in the 5th to 95th quantile range. The lowest black

dotted line represents the lowest control point of (7.7%$SSB_{F=0}$), and the highest black dotted line represents the highest control point (20%$SSB_{F=0}$).

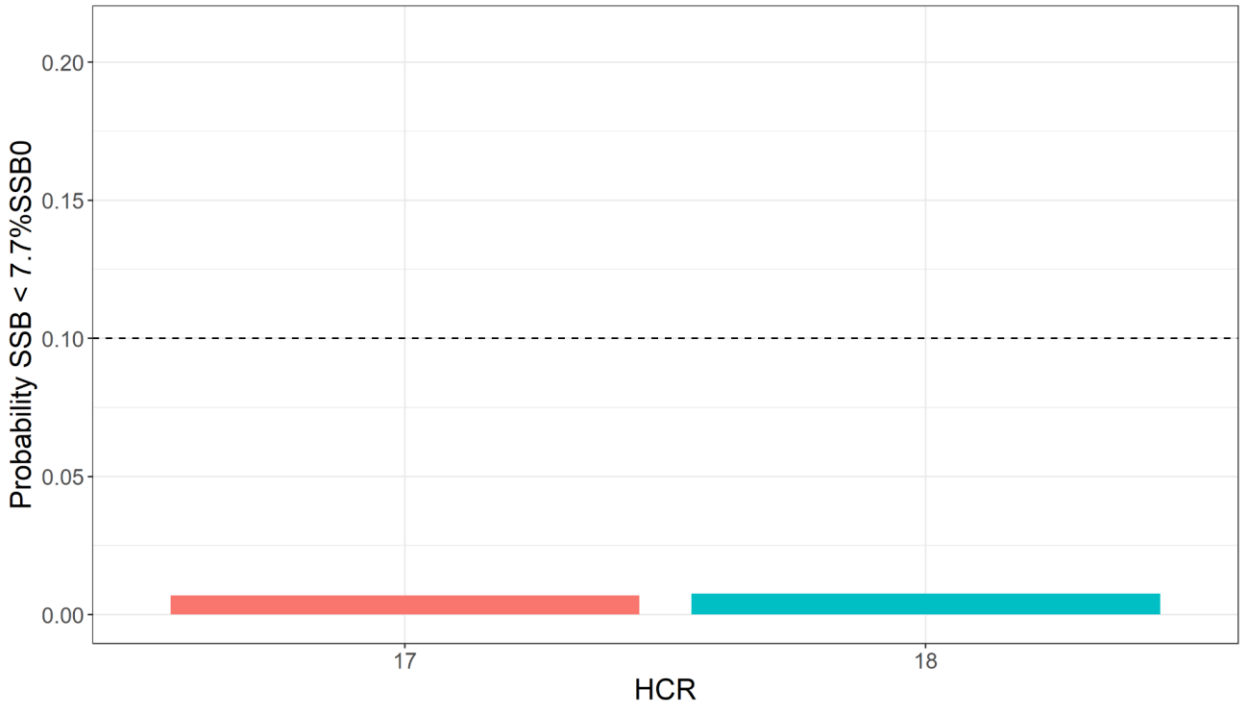


Figure 19. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 2nd control point of 7.7%$SSB_{F=0}$ for operating model 1 across all iterations and simulation years for the doubling of discards robustness test.

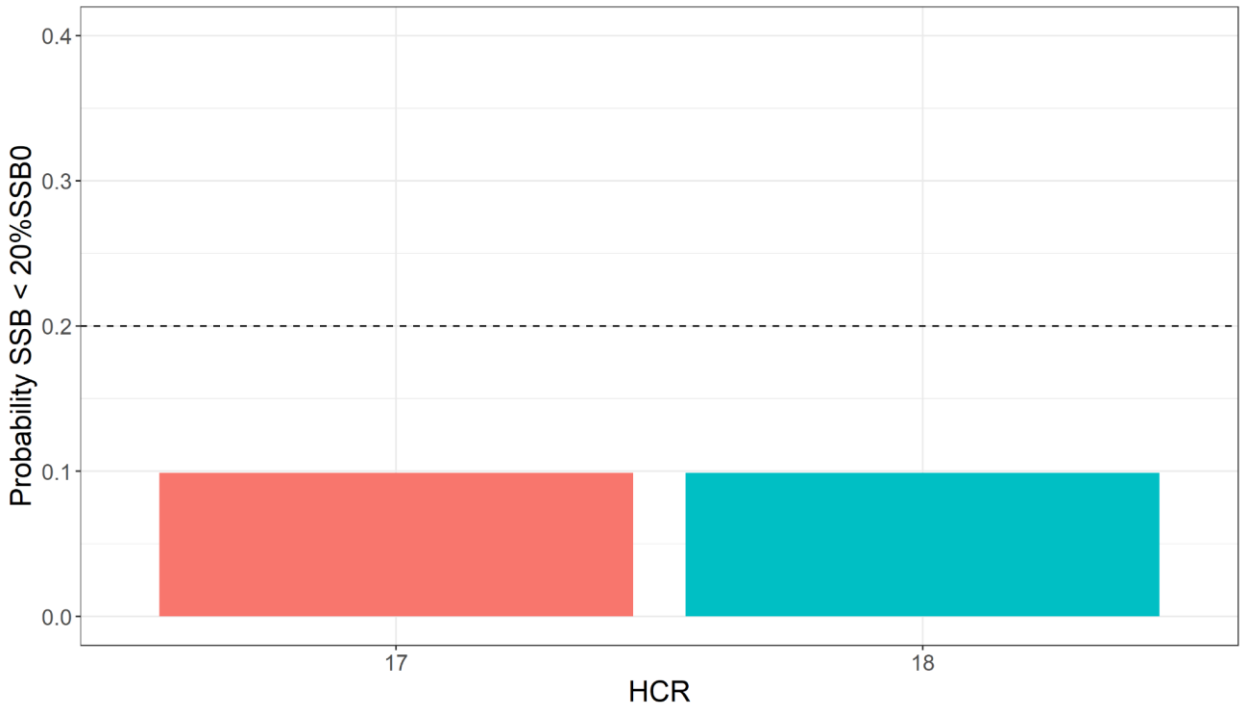


Figure 20. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 1st control point of 20%$SSB_{F=0}$ for operating model 1 across all iterations and simulation years for the doubling of discards robustness test.

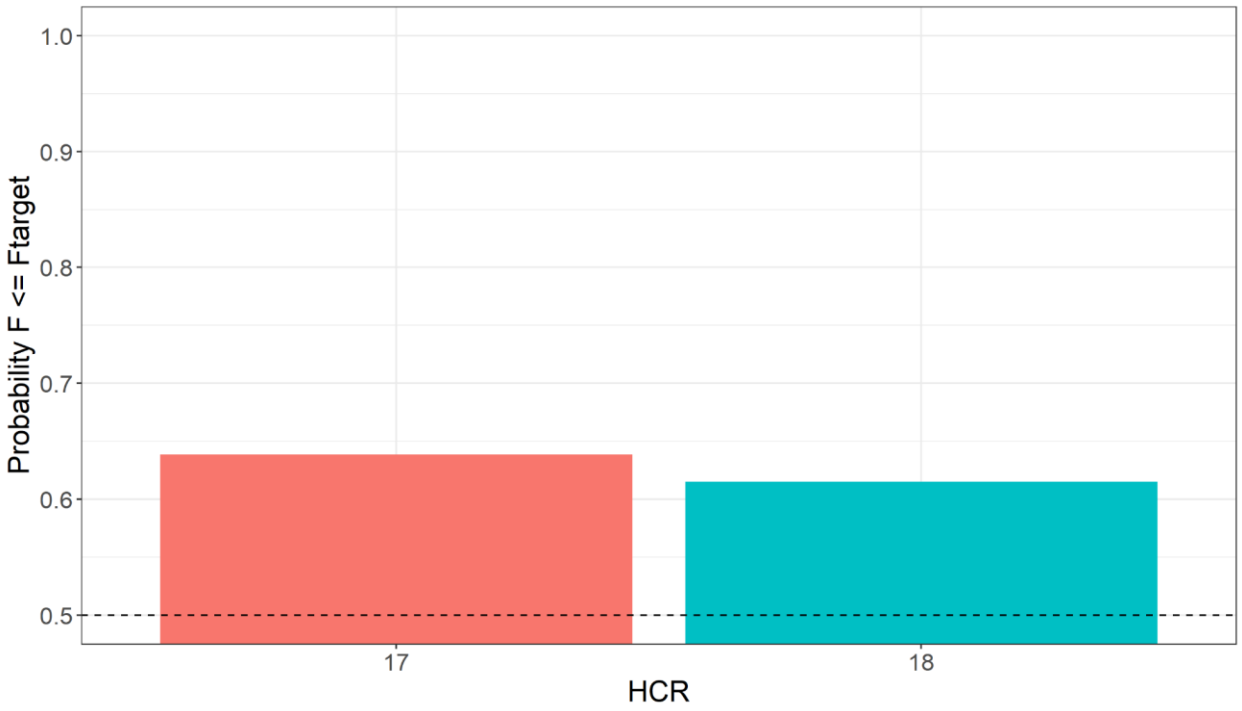


Figure 21. Probability, for each harvest control rule (HCR), of fishing mortality (F, 1-SPR) being less or equal to the F_{TARGET} for operating model 1 across all iterations and simulation years for the doubling of discards robustness test. The horizontal dotted line represents a 50% probability.

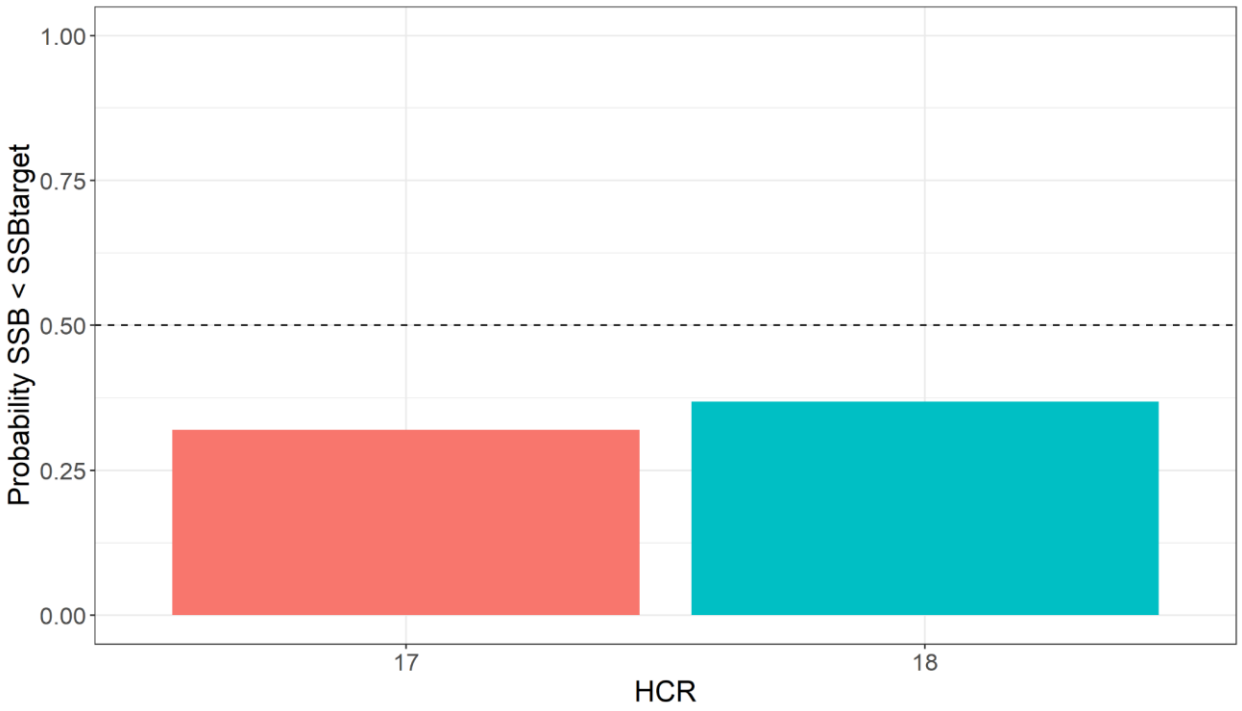


Figure 22. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being less or equal to the equivalent biomass depletion levels associated with the F_{TARGET} for operating model 1 across all iterations and simulation years for the doubling of discards robustness test. The horizontal dotted line represents a 50% probability.

- Effort Creep (Catchability Change)

In the effort creep for the Chinese Taipei longline fleet robustness scenario, where the effort creep starts in 2002 and is undetected in the EM, as expected, the OM1 median SSB was lower than target and F higher than F_{TARGET} at the start of the simulation for both HCRs (Figures 23 and 24). After the HCRs started being implemented in 2025, management intervention was able to increase median SSB, which stabilizes above target levels at the end of the simulation (Figure 23). Median F decreased rapidly after the initial management intervention and then fluctuated around the F_{TARGET} in the long term (Figure 24). The overall probability of SSB breaching the 2nd control point of 7.7%$SSB_{F=0}$ remained below 10% for both HCRs (Safety; Figure 25). The probability of breaching the second rebuilding target of 20%$SSB_{F=0}$ was higher than 20% for both HCRs (Safety; Figure 26). With regards to status under the effort creep scenario, the probability of F being at or

below the F_{TARGET} was below 50% (Status; Figure 27), due to the high initial Fs and the wide oscillations around F_{TARGET} (Figure 24).

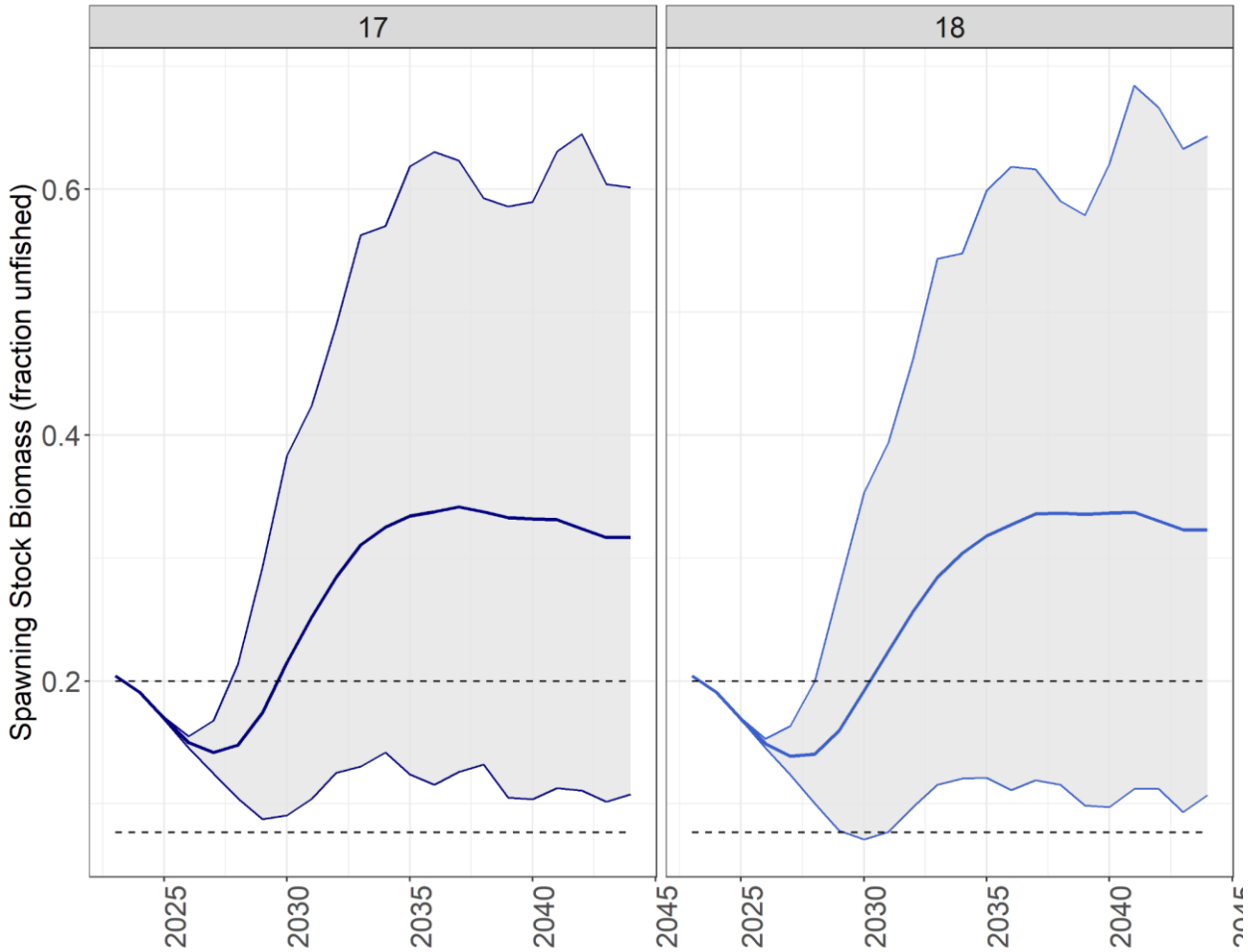


Figure 23. Trends in median relative spawning stock biomass (SSB/unfished SSB, thick solid color lines) for operating model 1 across all iterations for the effort creep robustness test for each HCR. The grey shading represents trends in the 5th to 95th quantile range. The lowest black dotted line represents the lowest control point of (7.7%$SSB_{F=0}$), the highest black dotted line represents the highest control point (20%$SSB_{F=0}$), and the dashed red line represents the SSB associated with the respective F_{TARGET} ($F_{27.5\%SPR}$).

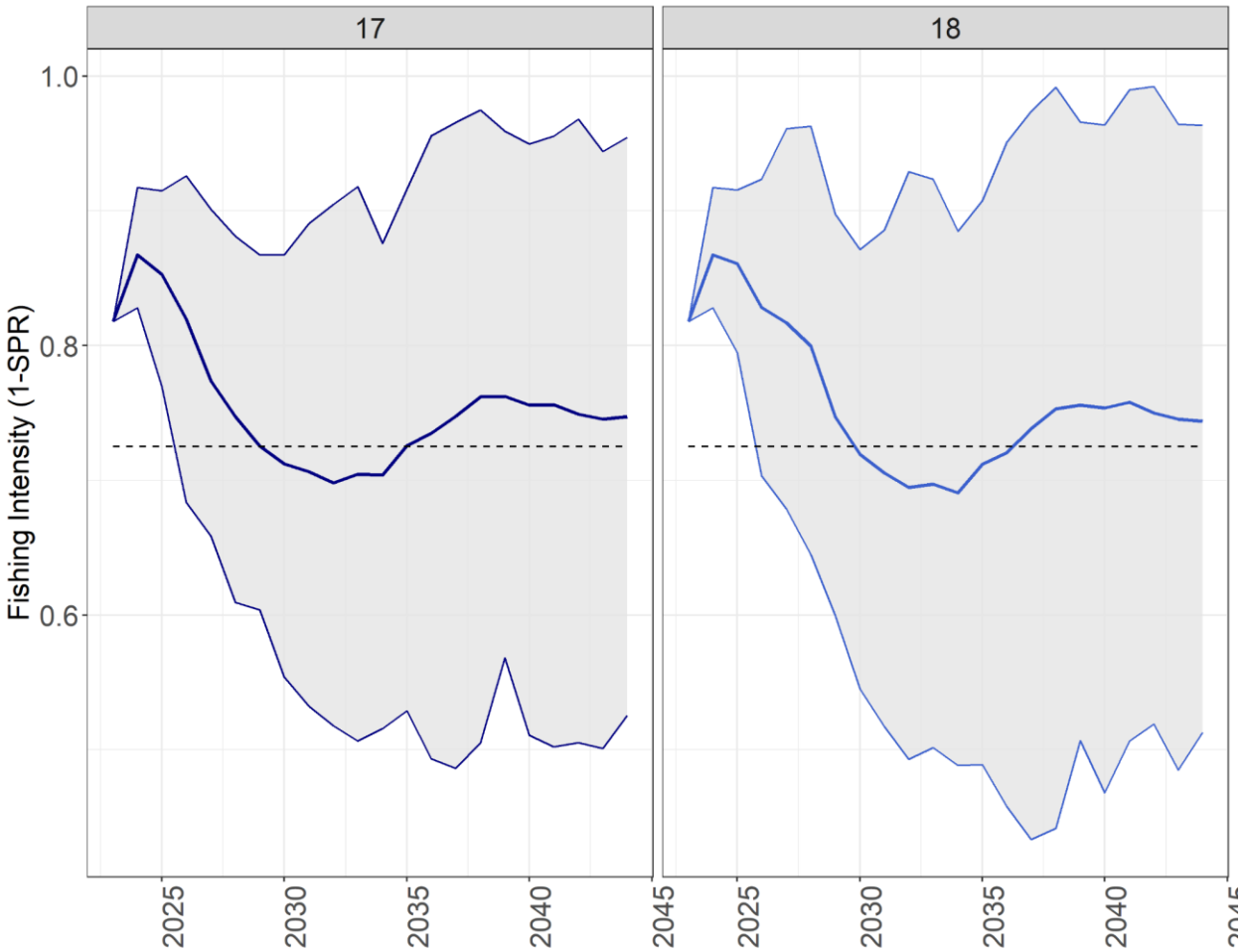


Figure 24. Trends in median fishing mortality (F, 1-SPR, thick solid color lines) for operating model 1 across all iterations for the effort creep robustness test for each HCR. The grey shading represents trends in the 5th to 95th quantile range. The dashed red line represents the F_{TARGET} ($F_{27.5\%SPR}$).

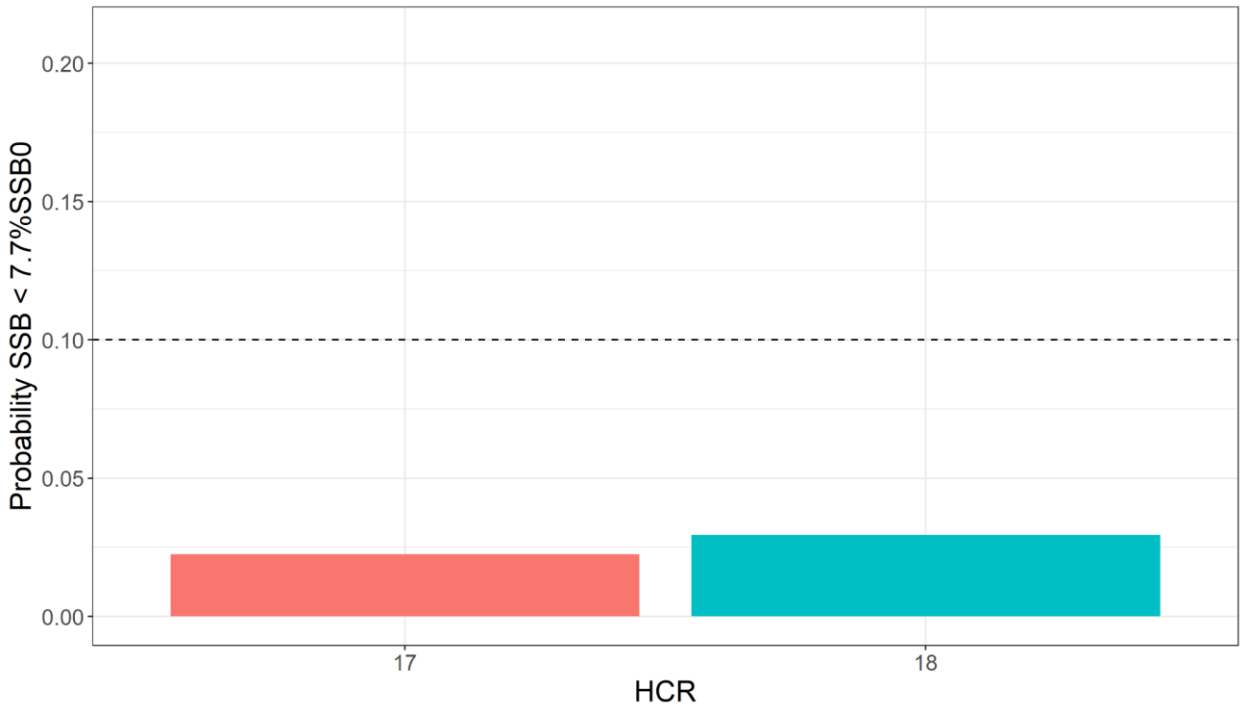


Figure 25. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 2nd control point of 7.7%$SSB_{F=0}$ for operating model 1 across all iterations and simulation years for the effort creep robustness test.

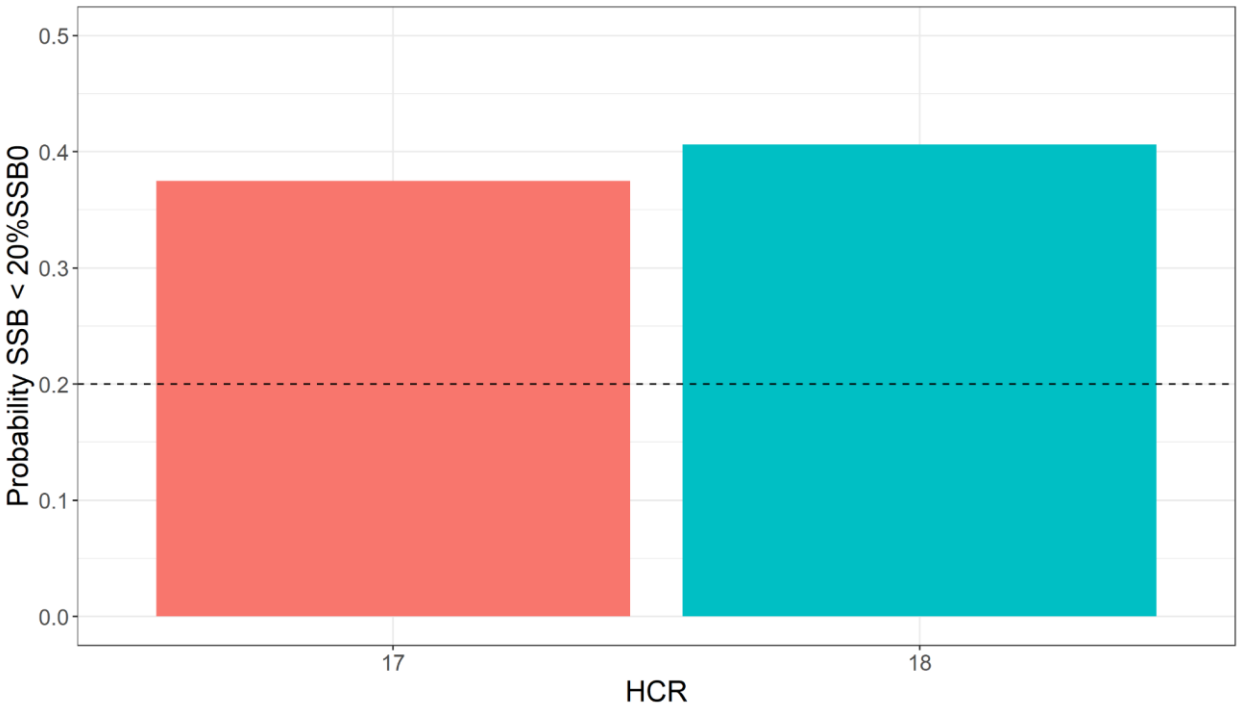


Figure 26. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 1st control point of 20%$SSB_{F=0}$ for operating model 1 across all iterations and simulation years for the effort creep robustness test.

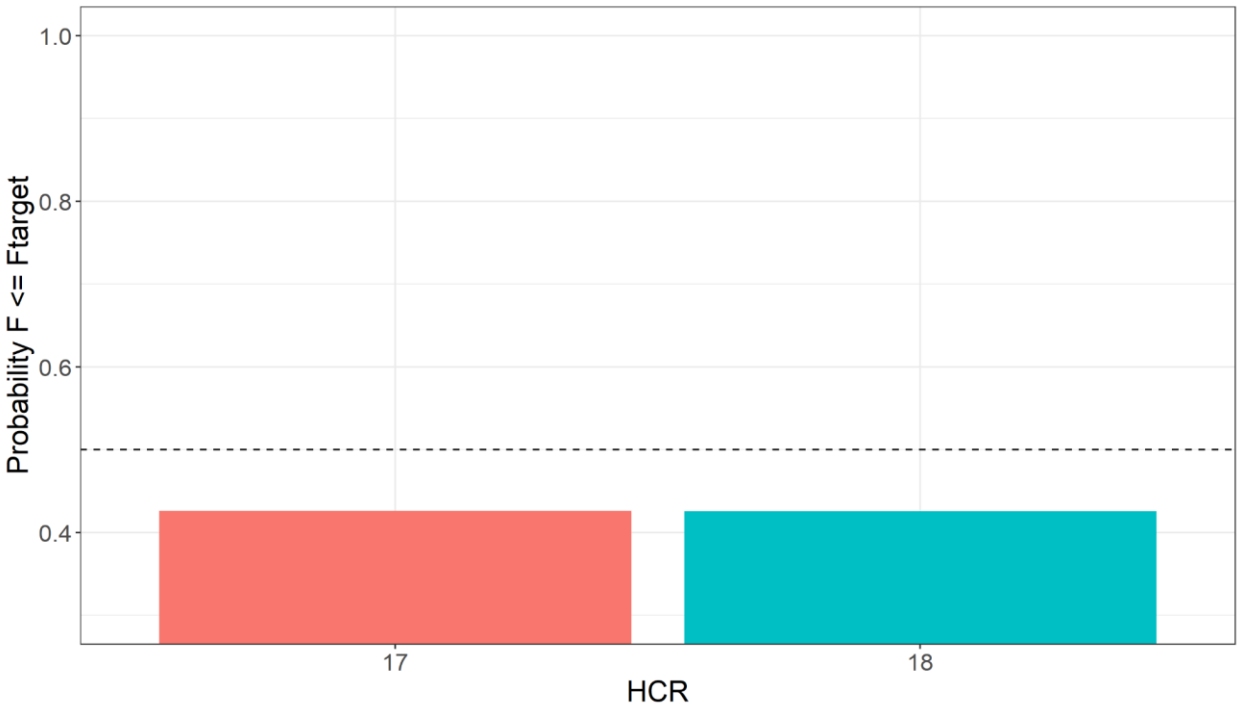


Figure 27. Probability, for each harvest control rule (HCR), of fishing mortality (F, 1-SPR) being less or equal to the F_{TARGET} for operating model 1 across all iterations and simulation years for the effort creep robustness test. The horizontal dotted line represents a 50% probability.

- Recruitment Drop

The drop in recruitment started in 2042 when the median SSB had increased to target levels and stabilized (Figure 28). In the reference set, performance metrics were calculated over the 20-year period from 2025 to 2044. In this scenario, however, the 20-year time period was instead from 2047 to 2066 to cover the period of low SSB resulting from the drop in recruitment (Figure 28).

Both HCRs had difficulty in dealing with the 10-year recruitment drop scenario. As the recruitment drop was not timely detected, median SSB declined to levels close to the second control point of 7.7%$SSB_{F=0}$ for both HCRs (Figure 28), and, when calculated across the entire 20-yr evaluation period, the probability of SSB breaching this SSB levels remained above 10% (Safety; Figure 29). Both HCRs had a higher than 20% probability of breaching the 1st control point of 20%$SSB_{F=0}$ (Safety; Figure 30). Median F started increasing soon after the start of the low recruitment period and breached target levels for both HCRs (Figure 31). Since management

actions for both HCRs were based on SSB levels, it was only when SSB had been estimated by the EM to have breached the SSB-based control points that management actions began to reduce F. In the meantime, as there are fisheries catching young fish, F increased and median F breached target levels. After the EM detected that control points were breached, F quickly fell below target levels, and at the end of this robustness simulation, it was well below target levels for all HCRs (Status; Figure 31) due to the 25% limit on TAC changes between management periods.

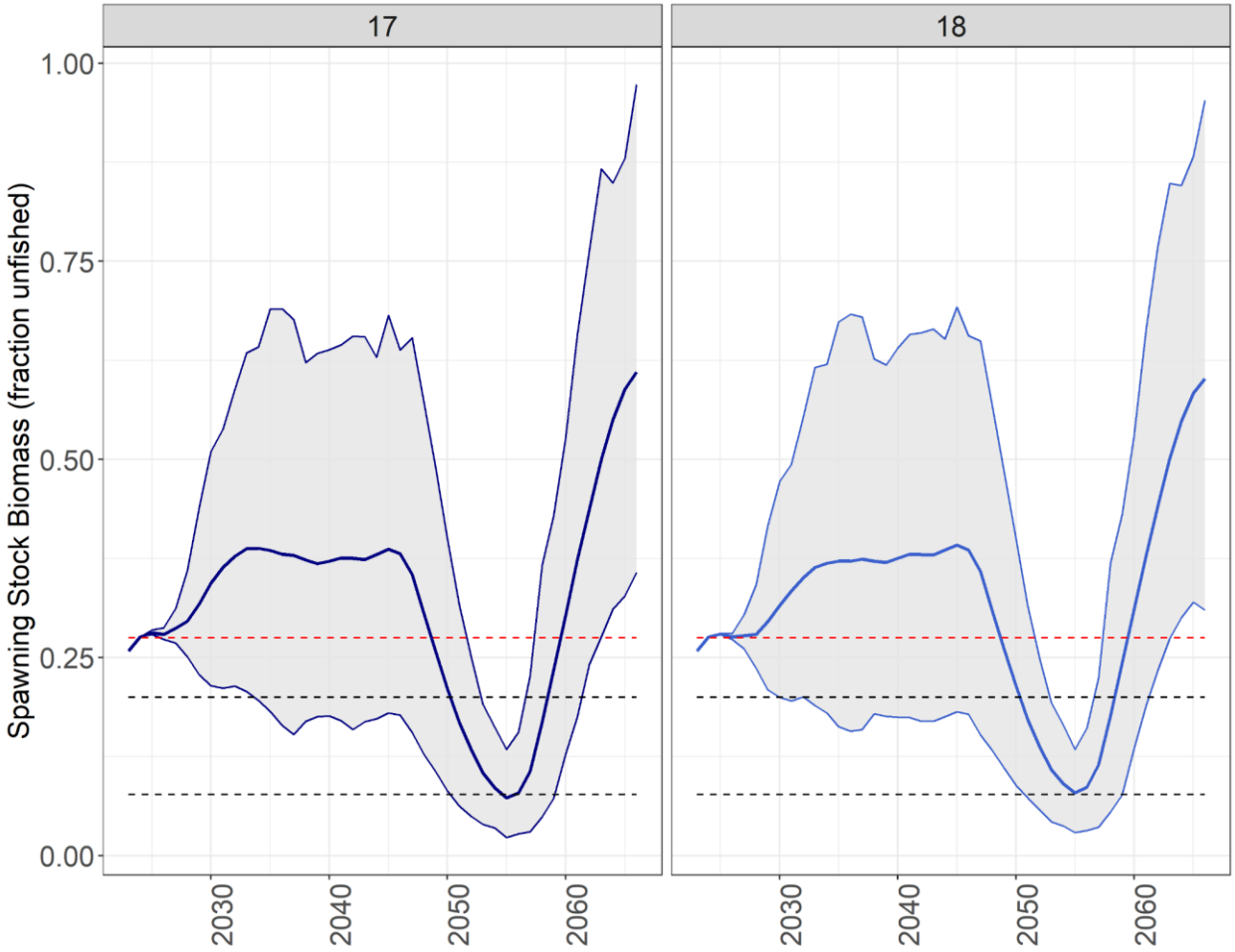


Figure 28. Trends in median relative spawning stock biomass (SSB/unfished SSB, thick solid color lines) for operating model 1 across all iterations for the recruitment drop robustness test for each HCR. The grey shading represents trends in the 5th to 95th quantile range. The lowest black dotted line represents the lowest control point of (7.7%$SSB_{F=0}$), the highest black dotted line represents the highest control point (20%$SSB_{F=0}$), and the dashed red line represents the SSB associated with the respective F_{TARGET} ($F_{27.5\%SPR}$).

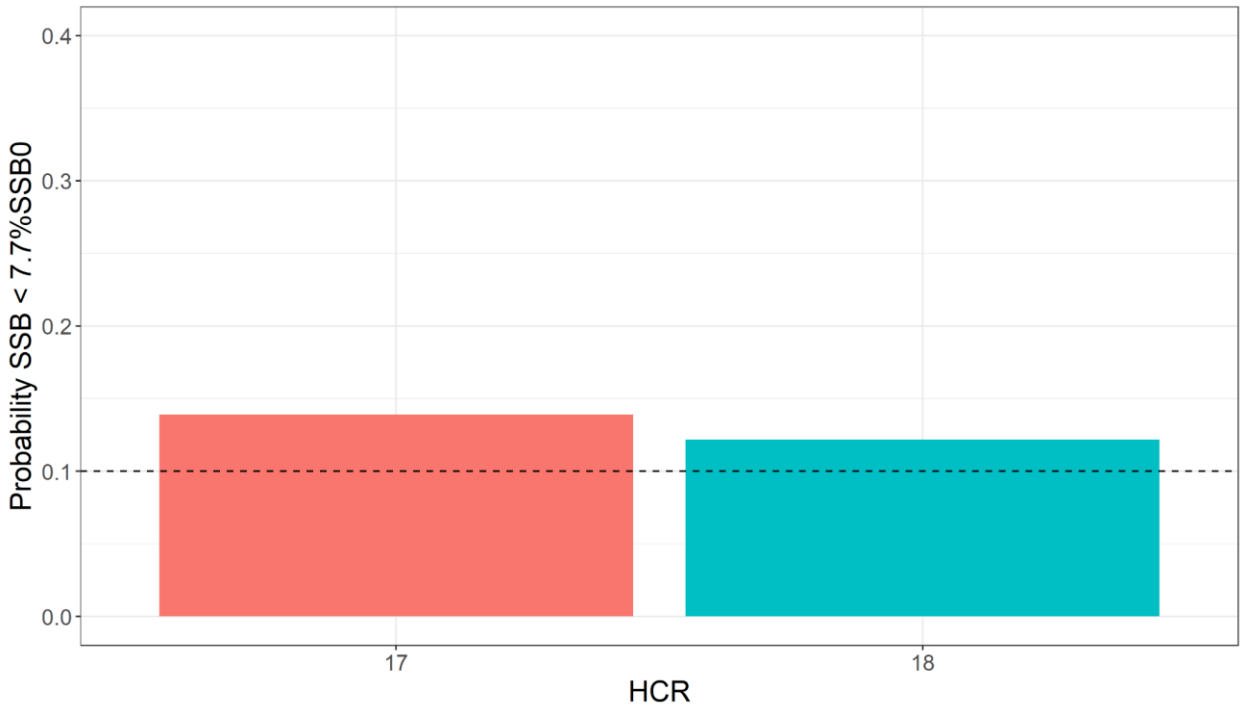


Figure 29. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 2nd control point of 7.7%$SSB_{F=0}$ for operating model 1 across all iterations and evaluation years (2047-2066) for the recruitment drop robustness test.

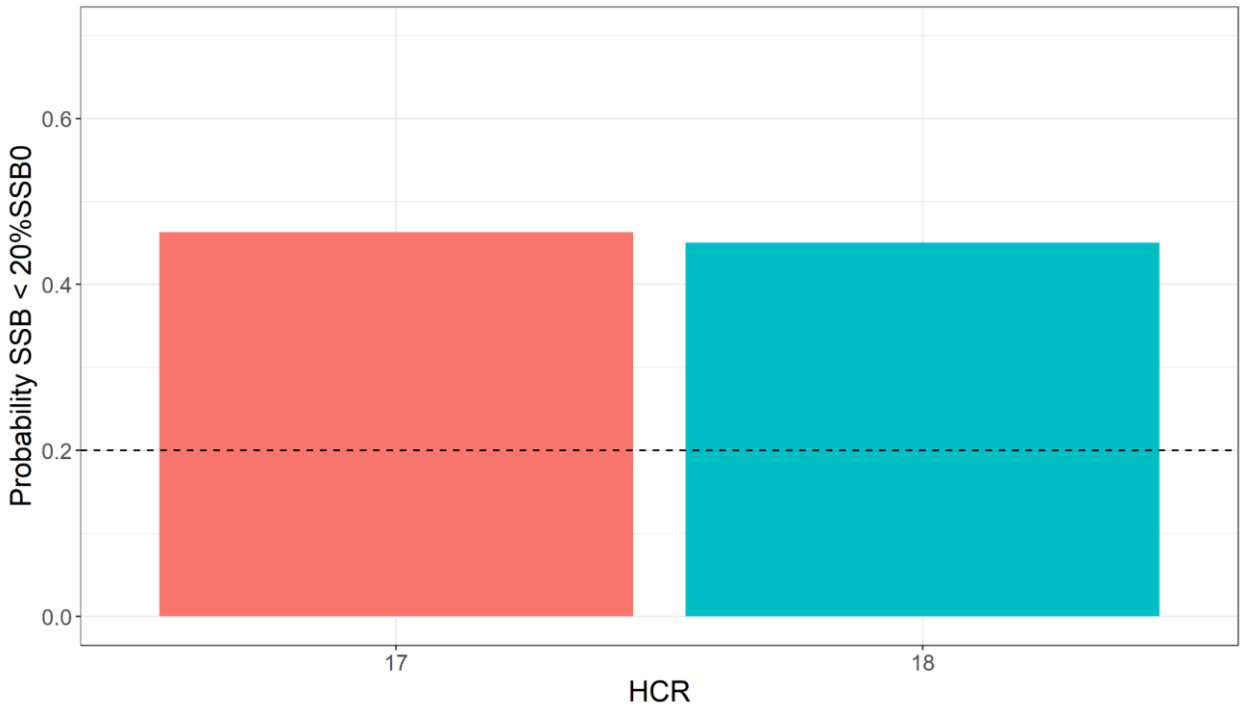


Figure 30. Probability, for each harvest control rule (HCR), of spawning stock biomass (SSB) being below the 1st control point of 20%$SSB_{F=0}$ for operating model 1 across all iterations and evaluation years (2047-2066) for the recruitment drop robustness test.

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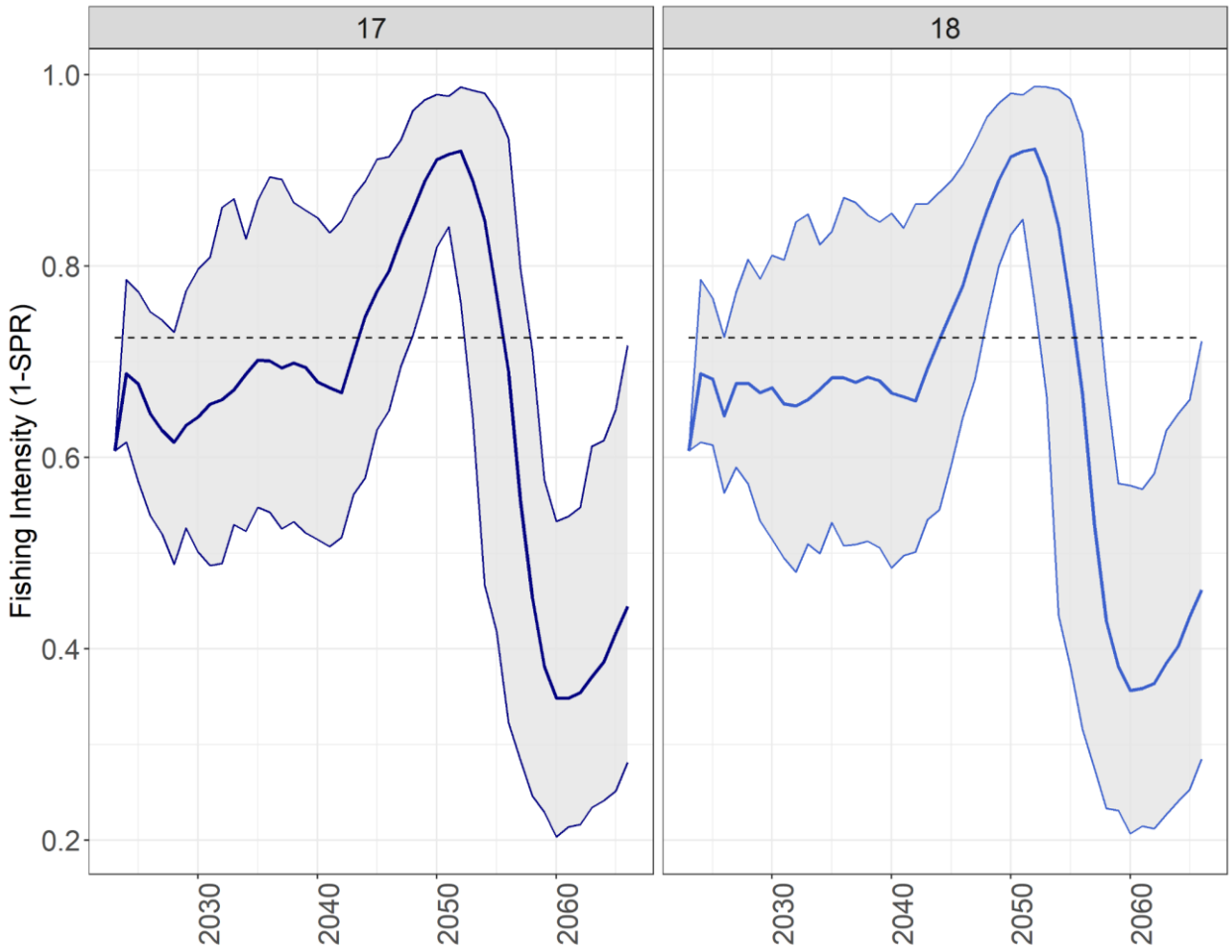


Figure 31. Trends in median fishing mortality (F, 1-SPR, thick solid color lines) for operating model 1 across all iterations for the recruitment drop robustness test for each HCR. The grey shading represents trends in the 5th to 95th quantile range. The dashed red line represents the F_{TARGET} ($F_{27.5\%SPR}$).

Discussion

Implication of the newly agreed interim management procedure

Simulation testing based on the reference set confirmed that the HCR parameterized with $F_{27.5\%SPR}$ as F_{TARGET}, 20%$SSB_{F=0}$ as the 1st control point, and 7.7%$SSB_{F=0}$ as the 2nd control point fully satisfied the management objectives for the newly agreed Interim Management Procedure, MP (JWG 2026b). By the end of projection years, the HCR (both HCRs 17 and 18) successfully maintains F at or below F_{TARGET} with a probability of at least 50 percent (Status; Figure 5), maintains SSB above the 2nd control point with a probability of at least 90% (Safety; Figure 2),

gradually achieves the equitable balance in proportional fishery impact between WCPO and EPO (Yield; Figure 11), increases average annual catch across the WCPO and EPO (Yield; Figure 12), and effectively limits the changes in overall catch limits between management periods (Yield; Figures 8 and 9).

The agreed Interim MP establishes a gradual reallocation of fishery impact ratio between WCPO and EPO (80:20 W:E impact ratio in 2027-2028, 79:21 W:E impact ratio in 2029-2030, and 78:22 W:E impact ratio in 2031-2032). While the closed-loop MSE grid evaluated static endpoints of an 80:20 ratio (HCR 17) and a 70:30 ratio (HCR 18), simulation testing confirmed that both HCRs exhibit virtually identical performance across key management objectives. Because the agreed ratio of 78:22 represents a modest 2 percentage point shift toward the EPO by 2032—far closer to the 80:20 baseline than the 10 percentage point reallocation tested under HCR 18—the resulting stock biomass trajectory, safety probability, and fleet-specific yield dynamics under the agreed procedure are expected to fall between the two tested benchmarks, remaining heavily aligned with the performance profile of HCR 17.

Although not reaching equilibrium state in 2032 (i.e., the year that the MP will need to be reviewed), this harvest control rule (including both HCRs) is able to maintain SSB well above the 2nd control point with a probability of at least 90% (Figure 4), maintain F below F_{TARGET} with a probability of at least 50 percent (Figure 7), increase average annual catch across the WCPO and EPO (Figure 12), and limit the changes in overall catch limits between management periods by default by 2032 in the reference set.

One of the important considerations in evaluating MPs is the operational trade-off introduced by stability constraints on inter-period catch adjustments. In earlier simulations without a TAC change limit, median fishing intensity increases rapidly from initial management levels to reach F_{TARGET} early in the projection period, allowing median SSB to stabilize around target levels faster (Tommasi and Lee 2023). By contrast, enforcing a 25% cap on TAC changes constrains initial quota increases, producing a more gradual ramp-up in catch (Figure 12). Both capped and uncapped scenarios led SSB to stabilize at or above the target equilibrium biomass (SSB associated with F_{TARGET}) by the final projection years. The newly agreed MP incorporates a temporary stability cap increase—permitting up to a 35% adjustment during the initial 2027–2028 cycle. By relaxing the quota constraint from 25% to 35% in the first cycle, the MP allows fishing intensity to adjust more responsively from initial low catch levels toward F_{TARGET}. Based on the contrast

between uncapped and 25%-capped runs, this temporary 35% provision is expected to fall between the two tested limits— it will slightly accelerate convergence toward target fishing intensity and reduce the degree of temporary SSB overshooting, while meeting the long-term target level.

Under the doubling discards scenario, both HCRs 17 and 18 performed comparably well across the Safety, Status, and Stability metrics, successfully satisfying all benchmark criteria. In contrast, under the catchability changes scenario, neither HCR met the Safety or Status criteria when calculated across the 20-year period, but rebuilt SSB above target levels in the later years of the simulation. Furthermore, results from the "recruitment drop" robustness test revealed that neither HCR 17 nor 18 was fully resilient to a chronic drop in recruitment, likely due to the absence of a recruitment index within the MP. Therefore, the ISC has recommended monitoring of both longline CPUE and recruitment indices - reviewed alongside routine CPUE updates - as part of the exceptional circumstances protocol (ISC 2026).

Caveat and Considerations for Implementation

While decisions regarding the adoption and implementation of management (CMM or Resolutions) remain strictly under the policy authority, it would be prudent to confirm that catch limits specified in negotiated implementation measures can reasonably be generated by the adopted MP under stock conditions estimated by the EM. MSE performance benchmarks assume that real-world catch removals follow the TAC generated by the MP. Setting quotas that diverge from mathematically calculated TAC outputs could introduce unaccounted operational uncertainty into the closed-loop feedback dynamics tested in the simulation framework, potentially reducing the predictability of the safety, status, and yield outcomes projected by the MSE.

To ensure catch limits remain biologically grounded, the MP relied on an age-structured production model with estimated recruitment deviates (ASPM-R+) in Stock Synthesis as the EM to derive fishery-specific catch allocations for WCPO large fish, WCPO small fish, and EPO fleet segments. Reviewing adopted implementation measures in light of EM outputs under stock conditions provided supporting evidence that fleet allocations remain aligned with terminal age-structure availability while supporting intended management objectives.

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