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CHARTING THE COURSE: MANAGEMENT STRATEGY EVALUATION RESULTS DEVELOPED FOR THE WESTERN ATLANTIC SKIPJACK TUNA (*KATSUWONUS PELAMIS*)

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SUMMARY

*This study presents the current status of the Management Strategy Evaluation (MSE) process for the western Atlantic skipjack tuna (*Katsuwonus pelamis*) stock. The Operating Models were redesigned based on updated catch data, abundance indices, and size composition through 2024, ensuring greater structural and diagnostic robustness. Four Candidate Management Procedures were evaluated, two based on indices and empirical relationships and two derived from biomass dynamics models with linear and nonlinear control rules. Closed-loop simulations, projected for 30 years, demonstrated that all CMPs can meet the management objectives defined by the ICCAT Commission, a ≥60% probability of the stock remaining sustainable (PGK) and a ≤10% risk of overfishing (LRP). The results demonstrate classic trade-off patterns between maximizing catches and biological safety, indicating that more conservative CMPs favor greater intertemporal stability. This work reinforces the importance of calibrating management rules to balance yield, stock resilience, and socioeconomic predictability, paving the way for a possible adoption of management procedures in 2025.*

RÉSUMÉ

*Cette étude présente l'état actuel du processus d'évaluation de la stratégie de gestion (MSE) pour le stock de listao de l'Atlantique Ouest (*Katsuwonus pelamis*). Les modèles opérationnels ont été remaniés sur la base des données de capture, des indices d'abondance et de la composition par taille actualisés jusqu'en 2024 compris, afin de garantir une plus grande robustesse structurelle et diagnostique. Quatre procédures de gestion potentielles ont été évaluées, deux basées sur des indices et des relations empiriques et deux dérivées de modèles de dynamique de la biomasse avec des règles de contrôle linéaires et non linéaires. Des simulations en boucle fermée, projetées sur 30 ans, ont démontré que toutes les CMP peuvent atteindre les objectifs de gestion définis par la Commission de l'ICCAT, à savoir une probabilité ≥60% que le stock reste durable (PGK) et un risque ≤10% de surpêche (LRP). Les résultats démontrent des schémas classiques de compromis entre la maximisation des captures et la sécurité biologique, indiquant que des CMP plus conservatrices favorisent une plus grande stabilité intertemporelle. Ce travail renforce l'importance de calibrer les règles de gestion pour équilibrer la production, la résilience du stock et la prévisibilité socio-économique, ouvrant ainsi la voie à une éventuelle adoption de procédures de gestion en 2025.*

RESUMEN

*Este estudio presenta la situación actual del proceso de evaluación de estrategias de ordenación (MSE) para el stock de listado occidental (*Katsuwonus pelamis*). Los modelos operativos se rediseñaron basándose en datos actualizados sobre capturas, índices de abundancia y composición por talla hasta 2024 inclusive, lo que garantiza una mayor solidez estructural y diagnóstica. Se evaluaron cuatro procedimientos de ordenación candidatos, dos basados en índices y relaciones empíricas y dos derivados de modelos de dinámica de biomasa con normas de control lineales y no lineales. Las simulaciones de ciclo cerrado, proyectadas para 30 años, demostraron que todos los CMP pueden cumplir los objetivos de ordenación definidos por ICCAT, una probabilidad ≥60 % de que el stock siga siendo sostenible (PGK) y un riesgo ≤10 % de sobrepesca (LRP). Los resultados muestran patrones clásicos de compensación de factores entre la maximización de las capturas y la seguridad biológica, lo*

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que indica que los CMP más conservadores favorecen una mayor estabilidad intertemporal. Este trabajo refuerza la importancia de calibrar las normas de ordenación para equilibrar el rendimiento, la resiliencia del stock y la previsibilidad socioeconómica, allanando el camino para una posible adopción de procedimientos de ordenación en 2025.

KEYWORDS

MSE; western Atlantic skipjack tuna; pelagic fisheries

1. Introduction

In 2014, the Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) adopted a new Science Strategic Plan to guide its activities over the 2015-2020 period. This plan laid out a comprehensive framework encompassing goals, objectives, and strategies for achieving these objectives, along with specific performance targets. Designed as a dynamic instrument, the plan allowed for periodic revisions in response to directives issued by the Commission. In alignment with this strategy, annual work plans were developed for each of the SCRS Sub-Committees and Species Groups to provide scientifically sound advice to support the sustainable management and conservation of Atlantic tuna stocks.

A cornerstone of the Strategic Plan was the establishment of a robust advisory framework rooted in the Precautionary Approach, as articulated by FAO (1996) and widely endorsed in fisheries governance (Restrepo *et al*., 1998). This required the development of advanced stock assessment methodologies that incorporate key sources of uncertainty, as well as the integration of new datasets and scientific insights emerging from the SCRS Species Groups. Additionally, the framework emphasized the adoption of Management Strategy Evaluation (MSE) methodologies, which facilitate the simulation and assessment of various management strategies against a suite of performance objectives under conditions of uncertainty (Smith *et al*., 1999; Punt *et al*., 2016).

The initiation of MSE development for Atlantic tropical tunas commenced in 2018 through an ICCAT-funded contract. The initial phase, led by a research consortium (Merino *et al*., 2020), involved designing a phased approach to MSE implementation. However, due to changes in priorities and scheduling adjustments directed by the Commission, the subsequent phases were delayed until 2020 (Merino *et al*., 2020).

The Tropical Tuna MSE framework encompasses two major components: a multi-stock MSE involving bigeye tuna (*Thunnus obesus*), yellowfin tuna (*Thunnus albacares*), and the eastern stock of skipjack tuna (*Katsuwonus pelamis*), and a single-stock MSE focused on the western skipjack stock (*Katsuwonus pelamis*). Each stock is modeled with distinct Operating Models (OMs), which are interconnected through modules simulating fisheries dynamics and management procedures. The rationale for initially developing a single-stock MSE for western skipjack was threefold: (1) the stock is predominantly exploited (approximately 90%) by a single Contracting Party using baitboat fisheries; (2) minimal bycatch of other tropical tunas occurs in this fishery; and (3) the development of a single-stock MSE is comparatively less complex. This phased approach also serves as a capacity-building exercise, enabling stakeholders to become familiar with MSE concepts and procedures ahead of more complex multi-stock evaluations (Huynh *et al*., 2020).

In 2020, during the SCRS Tropical Tuna Species Group meeting, the first demonstration of the western skipjack MSE was presented (Huynh *et al*., 2020). This preliminary framework, reviewed by the Tropical Tuna MSE Technical Group in March 2021, included only the Brazilian baitboat and handline fleets operating in the Southwestern Atlantic, as a demonstratation of the framework openMSE (https://openmse.com). In that opportunity, the Operating Models were conditioned using Stock Reduction Analysis (SRA) via the MSEtool R package, accounting for uncertainty in natural mortality, growth, maturity, steepness, and gear selectivity. Six distinct OMs were tested, alongside candidate Management Procedures (MPs) such as fixed Total Allowable Catches (TACs), as well as index-based and model-based harvest control rules (HCRs), evaluated through closed-loop simulations.

Recommendations from this review emphasized the need to broaden the model's scope to encompass all fleets harvesting the western skipjack stock. Consequently, a revised MSE framework was developed in 2021-2022 (SCRS/2022/097; Mourato *et al*., 2022a), extending the catch time series back to 1952 and incorporating data from five fleets: PS West, BB West, LL USMX, LL Others, and HL_RR. Conditioning of OMs included catch, Catch-Per-Unit-Effort (CPUE), and size composition data. Initial simulations explored performance across alternative MPs and life-history uncertainties.

Following the 2022 western Atlantic skipjack stock assessment, the OMs were reconditioned using outputs from the Stock Synthesis model. Simulations presented during the 2022 Tropical Tuna Species Group meeting indicated that the candidate MPs performed well across key metrics - status, safety, yield, and interannual stability (SCRS/2022/180; Mourato *et al*., 2022b).

At the 27th Regular Meeting of the ICCAT Commission (November 2022), the Commission adopted conceptual management objectives for the western skipjack stock (Resolution 22-02). In 2023, these objectives were further refined to include quantitative reference levels for simulation testing within the MSE framework. Despite substantial progress, the formal adoption of an MP for western skipjack was deferred to 2024, following discussions at the 28th Regular Meeting of the Commission.

Throughout 2024, new analyses were conducted incorporating updated catch records and relative abundance indices submitted by CPCs. The Commission agreed to operational management objectives and a framework management procedure measure in 2024 (Recommendation 2024-04). Based on recommendations from Panel 1, additional scenarios were simulated, leading to the formulation of new Candidate Management Procedures to be evaluated by SCRS in 2025 to enable selection of one CMP for inclusion in Rec. 24-04. These evaluations will also consider the robustness of MPs to climate change scenarios and foster further discussions with Panel 1. The upcoming analyses and stakeholder consultations will support the potential adoption of a management measure in 2025 for implementation in 2026, marking a critical milestone in the adaptive management of the western Atlantic skipjack stock.

In this sense, this document presents the current status of the MSE framework for western Atlantic skipjack, following technical feedback received from the SCRS Tropical Tunas Species Group and Tropical Tunas MSE Technical Team throughout 2025. The operating models were reconditioned using new Stock Synthesis model outputs with updated Catch, Abundance Indices, and Size Composition data. Improvements were made to the diagnostics, life-history assumptions, and model structure, providing a more robust basis for evaluating candidate management procedures ahead of their review by SCRS and potential adoption by the Commission.

2. Material and methods

2.1 Reconditioning operating models

The reconditioning operating models were conducted by updating the Stock Synthesis (SS) models with the new Catches, Abundance Indices and Size Composition data available through 2024 (**Figure 1**). This played a central role in informing the revision and reconditioning of the OMs used in the current MSE framework for the western Atlantic Skipjack tuna stock.

The updated OMs had maintained the structure of a single-area, combined-sex with annual time steps from 1952 to 2024, and included five fishing fleets and five abundance indices as was used in the last assessment (see Cardoso *et al*., 2022). However, only three abundance indices were updated until 2024: PS_West (Venezuela), BB_West (Brazil), and LL_USMX (USA) (**Figure 2**). Although restricted to these three indices, they represent more than 98% of the catches of this stock.

Selectivity patterns were modeled as length-based and freely estimated, with dome-shaped or asymptotic forms depending on fleet characteristics. Growth and natural mortality assumptions were also maintained as was defined in the last assessment. Model diagnostics included retrospective analysis, jitter tests, and likelihood profiling, ensuring convergence and robustness of the outputs. The same reference set operating model uncertainty grid was also developed, incorporating alternative assumptions for growth and steepness (see details in Cardoso *et al*., 2022).

2.2 Performance metrics

In line with the recommendations of the MSE Tropical Tunas Technical Sub-group and the adopted conceptual management objectives focused on Safety, Stock Status, Yield, and Stability criteria (Res. 24-04), this analysis incorporated sixteen distinct performance metrics (PMs) (**Table 1**).

2.3 Development of the candidate management procedures

We utilized a subset of CMPs from the previous analysis (see Mourato *et al*., 2022b, and Sant'Ana *et al*., 2023 for details), which were based on both index- and assessment model-based harvest control rules (HCRs). As widely discussed during meetings with the MSE Tropical Tunas Technical Sub-group along this year, the group of CMPs initially proposed and evaluated were further refined and reduced to four different CMPs, two empirically based on the behavior of abundance and capture indices over time series (e.g., CE and IR) and two based on the application of harvest control rules derived from the application of biomass dynamics models and the respective state defined for the stock (e.g., SP and SPAH).

For a better understanding, below is a detailed description of the structure and behavior of each CMP developed for the Western Atlantic skipjack tuna MSE.

The CE (Constant Exploitation) CMP defines a management rule that seeks to adjust the TAC based on the ratio between historical and current exploitation rates, derived from catches and relative abundance indices, according to the equation below.

$$TAC_{(t+1)} = \frac{C_{hist}}{I_{hist}^2 m * p} * I_{curr}$$

where TAC_{t+1} represents the projected allowable catch for the next year; C_{hist} is the average historical catch estimated for a reference period; I_{hist} is the average relative abundance index for the same historical reference period; m is a precautionary adjustment factor, which seeks to reduce the allowable exploitation level to reflect existing uncertainties or more conservative management criteria; p is the calibration parameter used in the MSE tuning process, in order to align the control rule with the management objectives defined for the stock (e.g., PGK ≥ 60%; LRP ≤ 10%), and; I_{curr} is the average of the relative abundance index in the most recent period of the time series.

IR (Index Ratio) CMP structures a management measure based on the TAC scaling derived from recent catches weighted by a factor (α) that aims to reflect the relative change in the relative abundance index. This α factor modulates the TAC projection for the coming years under the following conditions:

$$TAC_{t+1} = \alpha * C_{curr} = \begin{cases} I_{curr} > I_{hist} & \Rightarrow \alpha > 1 \Rightarrow \quad TAC_{t+1} > C_{curr} \\ I_{curr} = I_{hist} & \Rightarrow \alpha = 1 \Rightarrow \quad TAC_{t+1} = \bar{C}_{curr} \\ I_{curr} < I_{hist} & \Rightarrow \alpha < 1 \Rightarrow \quad TAC_{t+1} < \bar{C}_{curr} \end{cases}$$

and this condition is applied by the equation below:

$$TAC_{(t+1)} = \alpha * C_{curr} = \left(\frac{I_{curr}}{m * I_{hist}} * p\right) * C_{curr}$$

For model-based CMPs, the response structure is more straightforward, and the harvest control rules derive directly from the reference points estimated for the stock through the implementation of biomass dynamics models. In this sense, the main distinction between both model-based CMPs (SP and SPAH) is the form of the harvest control rule defined for each. In the case of SP, the rule is based on a linear penalty function to be implemented from a Btarg to a Blim, both previously defined (**Figure 3**). In the case of SPAH, the difference lies in the penalty function, which in this case is a nonlinear function (cubic function) to address the response of the effort penalty in relation to the stock's biomass status (**Figure 4**).

A maximum TAC of 45,000 tonnes is included in all CMPs. This rule was necessary to contain the variability in simulation responses between the different operating models. This implementation sought to minimize the impacts of the significant variability observed in the factorial grid used in the last stock assessment. Other configuration alternatives for each CMP were also implemented, such as regulating the maximum variation of TAC between management periods, smoothing the relative abundance index used, implementing different control rules, as well as other specific parameters for each of the respective CMPs (see Sant'Ana *et al*., 2025).

2.4 MSE settings

The projection period for this closed-loop MSE simulation was 30 years (2016-2055), with 100 replicates. The management period for all CMPs were set at a 3-years intervals. Selectivity was based on the F-at-age in the terminal year of the historical period (e.g., 2024). A coefficient of variation of 0.4 and autocorrelation derived from the operating model conditioning were used to define the model's recruitment error structure. The stock-recruitment relationship followed the Beverton-Holt model, with the SigmaR parameter set to 0.4 across all OMs. Observation model parameters were configured according to the "Precise_unbiased" model available in the OpenMSE R package.

2.5 Tuning CMPs

All CMPs underwent an iterative adjustment procedure to identify the tuning parameter (*p*) that sought to maximize the total allowable catches (TAC), weighting the achievement of the performance indicators, LRP (Probability of breaching the limit reference point (i.e., $SSB < 0.4*SSB_{MSY}$) over years 1-30) and PGK (Probability of being in the Kobe green quadrant (i.e., $SSB \geq SSB_{MSY}$ and $F < F_{MSY}$) over years 1-30) by implementing a loss function committed to minimizing the sum of the squares of the residuals of these indicators in relation to their respective previously defined objectives (LRP ≤ 10% and PGK ≥ 60%). This approach allowed us to identify the relationship between both indicators and also to construct a proposal for prior adaptation for them based on the uncertainties observed between the operational models used in this closed simulation.

2.6 Climate change robustness tests

Robustness tests based on potential scenarios of the effects of climate change on the Western Atlantic skipjack tuna stock were designed considering possible influences on the stock's recruitment dynamics. To this end, three distinct components were proposed:

(a) a central tendency identical to the current one, but with an increase in recruitment variability over the thirty-year projection. This increase was defined as 50% additional variation to the recruitment deviation (**Figure 5A**);
(b) an increasing trend in both central tendency and variability over the thirty-year projection. The increase in variability begins with the standard deviation observed for the first year of the projection, reaching a deviation of 0.6 at the end of the series, and considering a temporal autocorrelation with rho = 0.5 (**Figure 5B**);
(c) a decreasing trend in both central tendency and variability over the thirty-year projection. The reduction in variability begins with the standard deviation observed for the last year of data, defined as variation for the first year of the projection, reaching a deviation of 0.2 at the end of the series, and also considering a temporal autocorrelation with rho = 0.5 (**Figure 5C**).

3. Results

3.1 Reconditioned operating models

The historical evolution of catches used in this new reconditioning of the operating models updated through 2024 is presented in **Figure 6**. This figure also provides a comparative analysis between the data sources used in the 2022 stock assessment, the data actually updated in T1NC, and the data used in this new reconditioning, highlighting slightly distinct patterns among the different components analyzed and culminating in the integrated summary shown, mainly, in the central panel. The last panel summarizes the data used in this reconditioning and stands out for revealing a trajectory initially characterized by strong catch growth, followed by periods of high interannual variability, with pronounced peaks and subsequent abrupt declines, configuring a typical "*boom-and-bust*" pattern. A structural regime shift is also observed, in which average catch levels after historical peaks do not return to previous levels, stabilizing at relatively lower values. This dynamic suggests a combination of factors that potentially indicate that this stock cannot withstand high levels of removal for long periods, whether due to instantaneous variations in reproductive support/productivity patterns linked to density-dependent phenomena, or environmental variability as central determinants. Thus, the summary panel provides an integrated view that not only reflects the accumulated fishing pressure on the system but also highlights the need for management approaches that consider both the resilience of short-lived stocks and medium-scale environmental fluctuations, resulting in insights for understanding the patterns observed in both the stock assessment and the closed-loop simulations presented here.

Figures 7-9 provide an integrated and comparative view between the trajectories estimated in the last stock assessment and this new reconditioning of the operating models based on the update of the input data available up to 2024. The three figures in question allow for the interpretation of both their historical trajectory and the condition relative to the biological reference points estimated at both time points (i.g. Stock Assessment 2022 and Reconditioning 2025). **Figure 7** (SSB) highlights the temporal evolution of spawning biomass, revealing a pattern of sharp decline after periods of initial abundance, followed by smaller-amplitude oscillations that reflect a regime of lower productivity and greater stock vulnerability, given the maximum removals by fishing also noted during this period. Also regarding the SSB dynamics, a greater distinction is possible between the results of the last assessment and the updated operating models, especially for the h = 0.6 and growth quantiles 50%, and 75%. **Figure 8** (SSB/SSB_{MSY}) complements this interpretation by situating the observed biomass in relation to the maximum sustainable yield reference level, showing prolonged periods in which the stock remained above the sustainability threshold, with limited and isolated moments when it crossed this threshold. For this quantity, both in the 2022 assessment and in this new reconditioning of the operating models, the observed patterns were quite similar, with no major differences. Finally, **Figure 9** (F/F_{MSY}) explains the fishing pressure exerted. As with the SSB/SSB_{MSY} ratio, there were few moments in which pressures above levels considered sustainable were observed. Here again, the patterns observed in the 2022 stock assessment were quite similar to the updated trajectories through 2024. The similarity between the results observed in the 2022 assessment and this reconditioning can also be evidenced by **Figure 10**, which shows, for the same reference year, 2020, the results observed at both time points for both quantities (SSB/SSB_{MSY} and F/F_{MSY}) for all nine uncertainty grid scenarios. **Figure 11** shows that, due to the current stock condition, which, when compared with the 2022 state, shows increase in biomass, there is also a clear increase in stock productivity, showing relative increases in the estimated maximum sustainable yield for each combination of uncertainty grid factors.

Reconditiond OMs in 2025, before and after being imported to MSE structure are illustrated in **Figures 12-14**. **Figure 12** presents the corresponding spawning biomass (in metric tons) over time, highlighting the absolute magnitude of changes across scenarios. The close overlap between before and after importation process suggests internal consistency, with the updated model retaining similar biomass trends while integrating revised input data (including Catches, Relative Abundance Combined Index and Size Composition data up to 2024). **Figure 13** shows the time series of SSB/SSB_{MSY} for nine combinations of steepness (h = 0.6, 0.7, 0.8) and growth scenarios (25%, 50%, and 75% growth quantiles). Overall, the process of importing data to MSE structure (dashed lines) align closely with the original OMs defined in SS model (solid lines). **Figure 14** illustrates the time series of F/F_{MSY}, showing a similar pattern on the data imported from the SS model. Together, these figures support the conclusion that the reconditioned SS model offers a robust representation of population dynamics consistent with previous OM configurations, while incorporating the most recent data.

Figure 15 presents the time series of the simulated the truncated recruitment deviations for the nine different Operational Models (OMs), organized according to three growth levels (quantiles 25%, 50%, and 75%) and three levels of steepness (h = 0.6, 0.7, 0.8). Each panel shows the mean and dispersion of the projected simulations, compared to the historical recruitment deviations estimated in the assessment models. In general, the simulated recruitment deviation projections for each of the uncertainty grid scenarios were within the limits observed for historical data. Only in the scenarios with growth parameters based on the 75% quantile were simulations slightly exceeding these limits.

Model diagnostics were conducted for all nine scenarios used in the reconditioning process, as shown in **Appendix 1**. These included standard residuals plots, runs tests for residual autocorrelation, hindcasting (retrospective prediction skill), and five-year retrospective peel analyses. The updated models demonstrated improved overall fit and internal consistency compared to the 2022 stock assessment (Cardoso *et al*., 2022), with residuals appearing more randomly distributed and reduced bias in both catch and index fits. Hindcast skill metrics also indicated greater predictive reliability, particularly in recent years, and the retrospective patterns showed limited terminal year bias across all scenarios. These improvements reflect enhanced model performance following the incorporation of new data (up to 2024) and updated structural assumptions, strengthening the reliability of these scenarios for MSE implementation.

3.2 Closed-loop simulations

The process of adjusting the candidate management procedures (CMPs) was conducted with the aim of maximizing projected catches for the next 30 years (2026-2055), while simultaneously respecting the management objectives and performance limits established by the ICCAT commission in 2024, which are: (a) a minimum 60% probability of maintaining the stock above sustained levels in the medium term (PGK ≥ 60%) and a maximum 10% risk of overfishing (LRP ≤ 10%). This specific exercise used new operational models (OMs) defined on the uncertainty grid of the last assessment of this stock (Cardoso *et al*., 2022), representing different hypotheses about productivity, natural mortality, and growth dynamics, ensuring that the adjusted CMPs were robust not only to a single scenario, but to a broad spectrum that aimed to describe the potential uncertainty existing in defining the status of this stock. **Figure 16** (PGK ~ LRP) clearly illustrates the tradeoffs in the decision-making process. In the two-dimensional space between the probability of stocks maintained in the green quadrant and LRP breaching risk, it can be seen that to achieve PGK values close to 60%, the expected LRP values would be around 0.15 (≃15%). LRP values of up to 10% result in PGK above 70%, still meeting the requirements proposed by the Commission, but planned above them. **Figure 17** (TAC ~ LRP) deepens the interpretation by translating this relationship into direct yield terms. Strategies that maintain high TACs tend to be associated with risk levels of breaching LRP above 10%, configuring explicit trade-offs between short-term production and biological safety, while CMPs that maintain more moderate TACs ensure greater stability and respect risk limits. Taken together, the results confirm a classic pattern identified in several long-term MSE processes around the world (Punt *et al*., 2014; Butterworth, 2007), in which maximizing catches without risk criteria tends to produce unsustainable trajectories. An integrated reading of the two **Figures 16-17** suggests that the choice of CMPs should prioritize alternative solutions capable of keeping the LRP within the limits accepted by the ICCAT Commission and still guaranteeing a PGK above 60%, even if this implies forgoing maximum TAC volumes in the short and medium term. Thus, the analysis confirms that adjusting CMPs should not be understood as a mere pursuit of maximum yield, but as the construction of a compromise between exploitation and conservation, where risk constraints become central determinants of stock resilience and the integration of the management process in light of all the uncertainty contained in these simulations.

As previously discussed, the tuning of candidate management procedures (CMPs) was carried out to maximize projected catches, but conditioned on adherence to two objectives previously defined by the ICCAT Commission: (a) maintaining a minimum probability of 60% of the stock remaining in a sustainable condition (PGK ≥ 60%) and ensuring a maximum risk of 10% of breaching the LRP (LRP ≤ 10%). This process was conducted in light of the nine operational models of the uncertainty grid from the last assessment, in order to incorporate different structural hypotheses regarding productivity and stock growth dynamics. The trajectories presented in **Figures 18-20** summarize the simulated responses in a closed environment in an integrated manner.

In the panel dedicated to the projections for SSB/SSB_{MSY} (**Figure 18**), it is observed that the median relative spawning biomass begins at levels above 2, declines to values close to 1 around 2030–2035, and gradually stabilizes between 1.5 and 2.5 until the end of the projection (2055). This pattern can be observed for the four CMPs evaluated, with SP showing the most abrupt oscillations over the projected thirty years, while SPAH exhibited a more constant and stable behavior. In general, the trajectories for all CMPs tested indicate a transition from an initially "super-dense" and sustainable stock to a state closer to the SSB_{MSY} reference point, followed by smooth recovery. The dark gray shaded bands (10^{th}–90^{th} percentiles) show that, although there is a risk of values below 1, the probability of the stock remaining persistently in a biological overfishing condition is low when compared with all uncertainty estimated in the simulations. This pattern is consistent with the results of LRP ≤ 0.10 (lower margin represented by the colors: red – short period; green – medium period; blue – long period) observed throughout the projection. This also confirms the effectiveness of the adjusted CMPs in maintaining biomass around or above SSB_{MSY}, despite the strong environmental and structural variability observed in the data (Butterworth & Punt, 1999; Punt *et al*., 2016).

The F/F_{MSY} panel (**Figure 19**) shows a complementary dynamic where fishing mortality relative to the mortality that generates maximum sustainable yield starts at values below the reference point (= 1), remaining consistently below F_{MSY} in most of the time series projected for each of the CMPs. Only in the case of the SP CMP does F/F_{MSY} reach the threshold in the middle of the projection (≃2040). The median trajectory is dampened after 2030–2040, tending to decline after this period for all CMPs evaluated. This pattern is typical of CMPs based on catch control rules that respond to stock status, automatically reducing F when SSB approaches critical levels. This behavior has been documented in other MSE processes for skipjack, such as in the Western and Central Pacific, where the adoption of CMPs linked to relative stock status resulted in rapid reductions in F below F_{MSY} and subsequent stability (WCPFC, 2022; Scott *et al*., 2018).

Initially, TACs show a positive adjustment trend in their values until 2035, followed by a decline with subsequent stabilization in subsequent periods (**Figure 20**). Numerical metrics corroborate this interpretation. AvC (projected average catch) ranges from 26,000 to 41,000 metric tons, depending on the assessed CMP, demonstrating that, even respecting risk constraints, yield remains high in absolute terms. VarC (interannual variability of the TAC) shows values relatively lower than those defined by the ICCAT Commission in the management objectives (≤ 25% change), reflecting the prioritization of socioeconomic stability, an important characteristic for reducing market uncertainty and increasing the predictability of the fishing industry. In parallel, a PGK ≥ 0.60 indicates a greater than 60% probability of the stock remaining sustainable, while a LRP ≤ 0.10 confirms that the probability of falling below critical biological limits is less than 10% (**Table 2**). These results demonstrate the classic pattern described by Butterworth (2007) and confirmed in several recent applications of MSE, where maximization of return should not be sought in isolation, but always conditioned by risk metrics.

The consistency across the **Figures 18-20** suggests that the tuning achieved a robust balance between exploitation and conservation. By sacrificing immediate TAC gains in exchange for stability and low risk, the calibrated CMPs allow biomass to be maintained at safe levels, fishing mortality to sustainable levels, and a consistent average yield over projected time. This pattern converges with what has been observed in the Indian Ocean, where skipjack CMPs tested in closed-loop simulations (MSE) indicated that rules conditioned on state indicators allow gradual stock rebuilding, provided the derived measures (TACs) are effectively implemented (IOTC, 2019; Pilling *et al*., 2021). In summary, the trajectories confirm that the adjusted CMPs not only meet the formal performance criteria but also reproduce a typical signature, convergence to $F<F_{MSY}$, TAC stability with controlled variance, and SSB rebuilding or maintaining above SSB_{MSY}, ensuring stock resilience and credibility of the management process as a whole.

The Kobe time series for the four sets of CMPs (**Figures 21-24**) depicts the projected sustainability trajectory, simultaneously combining relative biomass (SSB/SSB_{MSY}) and relative fishing mortality (F/F_{MSY}) over the next three projected decades. For CE and IR, the U-shaped profile, with the percentage of green quadrant starts high after the implementation of the CMPs, troughs between 2033–2039 at levels slightly below the 60%, and then rises monotonically again from 2040 onward, ending the horizon with PGK typically higher than 60%, approaching 70–80%. **Figures 25-26** presents the Kobe plot for the last projection year where this pattern can be confirmed. The transient increase in the yellow/orange bands in this mid-period reflects the system's adjustment (increasing F, decreasing SSB) after the initial upward trend observed for the TAC. Thus, the stock moves from a comfortably sustainable condition, undergoing a reduction in high PGK probabilities until reaching the minimum threshold at the beginning of the long-term period (between 2034 and 2040), then rebuilding high PGK probabilities.

In SP, this "trough" behavior is slightly deeper and longer-lasting (PGK momentarily reaching 50–55% around 2038–2042), demonstrating that CMPs in this set trade slightly more short-term yield for slightly higher risk to reach the stipulated threshold. However, the trajectory reverses after 2042, with green regaining share and red remaining residual, reaching ~77% of being in the green quadrant in the last year of projection (**Figure 27**). SPAH, on the other hand, reproduces a similar pattern as SP, but slightly more cushioned and with greater long-term stability (less deep trough and slightly earlier recovery), consistent with the logic of this set's "softer" HCR. In this case, the probability of being in a green quadrant of the Kobe plot for the last projected year was around 64% (**Figure 28**). The integrated reading of the four CMPs behaviour over time, therefore, is: (*i*) there is a post-implementation adjustment in all CMPs, expressed by the temporary increase in yellow/orange when the system migrates to more conservative exploitation levels; (*ii*) this adjustment is milder in CE/IR CMPs and more pronounced in SP, with SPAH in an intermediate position; (*iii*) in the long run, all conclude with a predominance of green and low red, that is, with most simulations in the "non-overfishing and non-overfished" state, while the borderline states tend to decrease as the series progresses. In short, the Kobe series indicate that the CMPs, as configured in each set, lead to a transient accommodation followed by stabilization under sustainable conditions, with differences in valley depth and duration that reflect the degree of aggressiveness/lenience of each set of rules.

3.3 Climate change robustness test

The robustness tests revealed systematic changes in the performance of the CMPs when the stock productivity was affected by different climate change scenarios. In the Climate Change Scenario 01 (**Table 3**), where variability in recruitment deviations is uniformly increased 50%, a slight overall improvement was observed in PGK values (≈ 0.77 – 0.83) together with increased average catches, indicating that the stock remains robust under a increase in productivity. The model-based CMPs (SP and SPAH) continued to show the best trade-off between yield and biological safety, while empirical CMPs (CE and IR) exhibited slightly higher catch variability (VarC ≈ 0.11 – 0.13). Under Scenario 02 (**Table 4**), with temporally autocorrelated increases and a positive trend, PGK values decreased slightly (0.84 – 0.90), with increased averaged catches, especially for CE and IR. Nevertheless, the risk of falling below the LRP (≤ 0.05) remained low, suggesting good resilience of stock for all CMPs. In the Scenario 03 (**Table 5**), characterized by autocorrelated decreases with a negative trend, all CMPs showed a marked decrease in performance. PGK values dropped to 0.43 – 0.50, while LRP probabilities increased up to 0.37. Average catches declined sharply (AvC ≈ 23,000 – 28,000 t), reflecting a structural reduction in stock productivity. Overall, the results demonstrate that the SP and SPAH procedures exhibit the greatest stability and robustness under climate-induced productivity shifts, maintaining balanced trade-offs between yield and conservation objectives even as environmental conditions deteriorate. In contrast, the empirical MPs (CE and IR) proved more vulnerable to declining productivity, showing larger fluctuations in catch and higher risks of falling below biological reference points under severe scenarios. The system as a whole remains robust up to Scenario 02, but its performance degrades markedly under Scenario 03, which appears to define the threshold of management robustness under extreme climate change impacts.

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Table 1. General description of the operational management objectives and respective performance indicators defined for the western Atlantic skipjack tuna MSE.

Management objectives	Corresponding performance indicators
Status The stock should have a 60% or greater probability of occurring in the green quadrant of the Kobe matrix over the medium-term (4-10 years) using a 30-year projection period.	**PGK_{short}**: Probability of being in the Kobe green quadrant (i.e., $SSB \geq SSB_{MSY}$ and $F < F_{MSY}$) in year 1-3 **PGK_{medium}**: Probability of being in the Kobe green quadrant (i.e., $SSB \geq SSB_{MSY}$ and $F < F_{MSY}$) in year 4-10* **PGK_{long}**: Probability of being in the Kobe green quadrant (i.e., $SSB \geq SSB_{MSY}$ and $F < F_{MSY}$) over years 11-30 **PGK**: Probability of being in the Kobe green quadrant (i.e., $SSB \geq SSB_{MSY}$ and $F < F_{MSY}$) over years 1-30 **POF**: Probability of $F > F_{MSY}$ over years 1-30 **PNOF**: Probability of $F < F_{MSY}$ over years 1-30
Safety There should be no greater than 10% probability of the stock falling below B_{LIM} ($0.4 * B_{MSY}$) at any point during the 30-year projection period.	**LRP_{short}**: Probability of breaching the limit reference point (i.e., $SSB < 0.4 * SSB_{MSY}$) over years 1-3 **LRP_{medium}**: Probability of breaching the limit reference point (i.e., $SSB < 0.4 * SSB_{MSY}$) over years 4-10 **LRP_{long}**: Probability of breaching the limit reference point (i.e., $SSB < 0.4 * SSB_{MSY}$) over years 11-30 **LRP_{all}**: Probability of breaching the limit reference point (i.e., $SSB < 0.4 * SSB_{MSY}$) over years 1-30
Yield Maximize overall catch levels.	**AvC_{short}**: Median catches (t) over years 1-3 **AvC_{medium}**: Median catches (t) over years 4-10 **AvC_{long}**: Median catches (t) over years 11-30
Stability Any changes in TAC between management periods should be 25% or less.	**$VarC_{medium}$**: Variation in TAC (%) between management cycles over years 4-10 **$VarC_{long}$**: Variation in TAC (%) between management cycles over years 11-30 **Var_{all}**: Variation in TAC (%) between management cycles over years 1-30

*Tuning objective to be used for candidate MP development.

Table 2. Performance metrics for each Candidate Management Procedure showing the averaged statistics across all nine reference set of OMs. CE – Constant Exploitation; IR – Index Ratio; SP – Surplus Production Model with Linear HCR; SPAH – Surplus Production Model with Non-linear HCR.

MP	PGK	PGK_short	PGK_mid	PGK_long	LRP	LRP_short	LRP_mid	LRP_long	POF	PNOF	AvC	AvC_short	AvC_mid	AvC_long	VarC	VarC_mid	VarC_long
CE	0.71	0.95	0.68	0.68	0.10	0.00	0.03	0.13	0.24	0.76	31,640.63	32,129.52	40,161.90	26,157.76	0.14	0.11	0.13
IR	0.71	0.97	0.79	0.66	0.10	0.00	0.01	0.14	0.24	0.76	30,844.34	30,844.34	34,959.98	27,663.01	0.10	0.11	0.10
SP	0.71	1.00	0.89	0.61	0.10	0.00	0.00	0.14	0.25	0.75	30,298.89	27,217.88	30,321.19	28,152.37	0.12	0.11	0.12
SPAH	0.69	0.99	0.86	0.60	0.10	0.00	0.01	0.14	0.26	0.74	33,833.18	28,265.68	31,931.10	35,404.71	0.07	0.08	0.06

Table 3. Performance metrics for each Candidate Management Procedure showing the averaged statistics across all nine reference set of OMs for the Climate Change Robustness Scenario 01. CE – Constant Exploitation; IR – Index Ratio; SP – Surplus Production Model with Linear HCR; SPAH – Surplus Production Model with Non-linear HCR.

MP	PGK	PGK_short	PGK_mid	PGK_long	LRP	LRP_short	LRP_mid	LRP_long	POF	PNOF	AvC	AvC_short	AvC_mid	AvC_long	VarC	VarC_mid	VarC_long
CE	0.77	0.95	0.82	0.73	0.06	0.00	0.01	0.08	0.20	0.80	35,262.30	32,129.52	40,161.90	33,750.00	0.13	0.11	0.12
IR	0.76	0.97	0.89	0.70	0.06	0.00	0.01	0.09	0.21	0.79	34,970.52	30,844.34	34,964.13	38,373.21	0.09	0.13	0.08
SP	0.79	0.98	0.95	0.72	0.06	0.00	0.00	0.08	0.19	0.81	33,747.52	27,217.88	30,321.95	37,586.78	0.10	0.11	0.09
SPAH	0.83	0.98	0.94	0.77	0.04	0.00	0.00	0.05	0.16	0.84	35,605.84	28,265.68	31,933.87	37,124.11	0.05	0.08	0.04

Table 4. Performance metrics for each Candidate Management Procedure showing the averaged statistics across all nine reference set of OMs for the Climate Change Robustness Scenario 02. CE – Constant Exploitation; IR – Index Ratio; SP – Surplus Production Model with Linear HCR; SPAH – Surplus Production Model with Non-linear HCR.

MP	PGK	PGK_short	PGK_mid	PGK_long	LRP	LRP_short	LRP_mid	LRP_long	POF	PNOF	AvC	AvC_short	AvC_mid	AvC_long	VarC	VarC_mid	VarC_long
CE	0.84	0.93	0.76	0.85	0.04	0.00	0.03	0.05	0.13	0.87	40,161.90	32,129.52	40,161.90	42,187.50	0.11	0.11	0.10
IR	0.87	0.95	0.84	0.86	0.03	0.00	0.02	0.04	0.12	0.88	37,118.14	30,844.34	34,960.70	43,601.95	0.08	0.11	0.07
SP	0.88	0.98	0.91	0.86	0.03	0.00	0.01	0.04	0.10	0.90	37,536.79	27,217.88	30,318.48	41,842.71	0.07	0.11	0.06
SPAH	0.90	0.98	0.90	0.89	0.02	0.00	0.01	0.03	0.09	0.91	35,961.55	28,265.68	31,929.02	37,713.19	0.05	0.08	0.03

Table 5. Performance metrics for each Candidate Management Procedure showing the averaged statistics across all nine reference set of OMs for the Climate Change Robustness Scenario 03. CE – Constant Exploitation; IR – Index Ratio; SP – Surplus Production Model with Linear HCR; SPAH – Surplus Production Model with Non-linear HCR.

MP	PGK	PGK_short	PGK_mid	PGK_long	LRP	LRP_short	LRP_mid	LRP_long	POF	PNOF	AvC	AvC_short	AvC_mid	AvC_long	VarC	VarC_mid	VarC_long
CE	0.50	0.91	0.63	0.40	0.28	0.00	0.08	0.37	0.40	0.60	23,477.62	32,129.52	40,161.90	17,289.48	0.16	0.12	0.16
IR	0.49	0.93	0.73	0.36	0.30	0.00	0.06	0.42	0.43	0.57	25,071.89	30,844.34	34,958.94	18,345.25	0.14	0.11	0.15
SP	0.45	0.97	0.81	0.28	0.36	0.00	0.04	0.50	0.49	0.51	27,217.88	27,217.88	30,314.98	17,664.63	0.15	0.11	0.17
SPAH	0.43	0.96	0.79	0.25	0.37	0.00	0.04	0.52	0.52	0.48	28,265.68	28,265.68	31,904.17	20,745.68	0.11	0.07	0.13

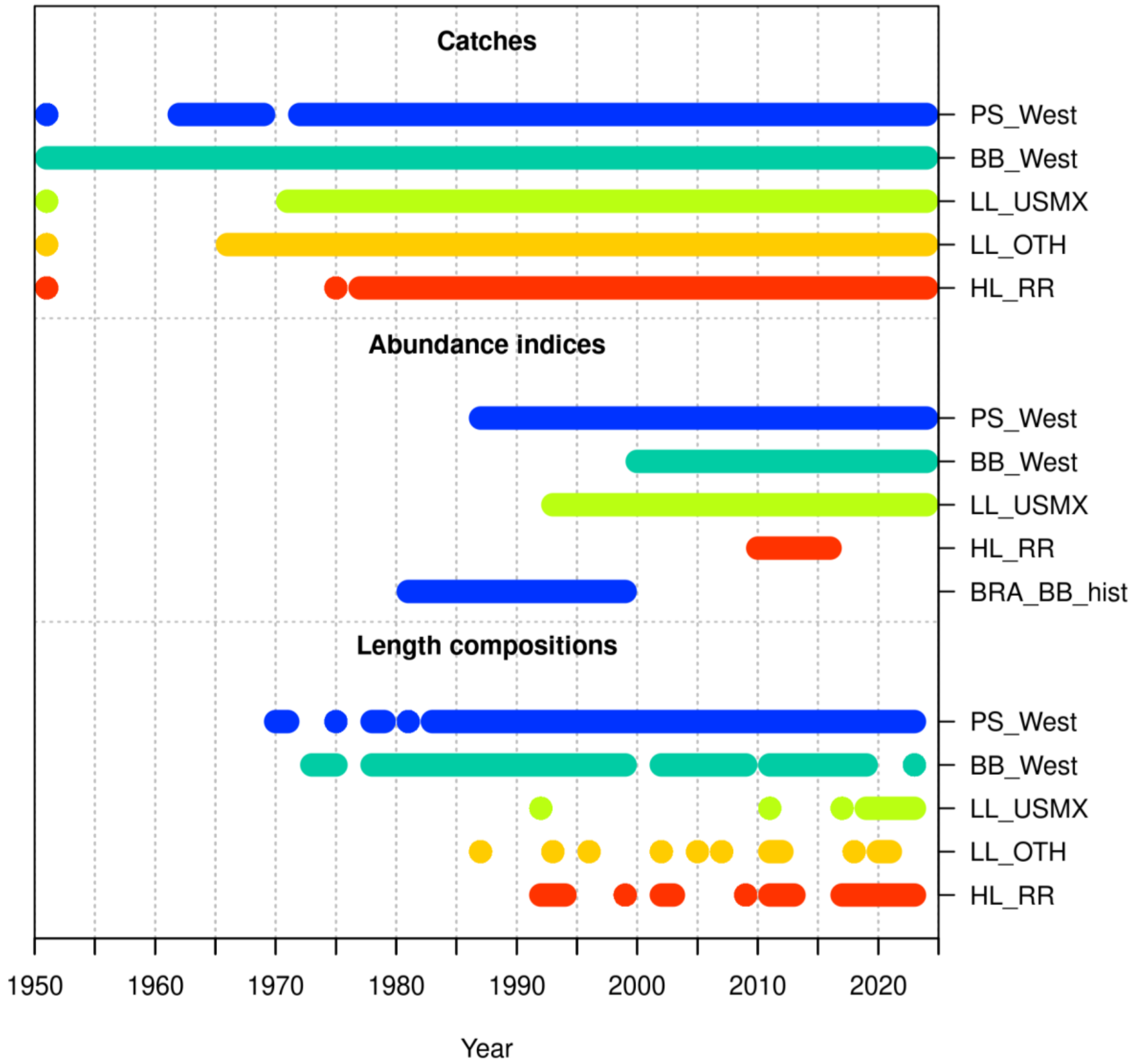

Figure 1. Time series of data available for reconditioning the Western Atlantic skipjack tuna operating models broken down by fleet and data type.

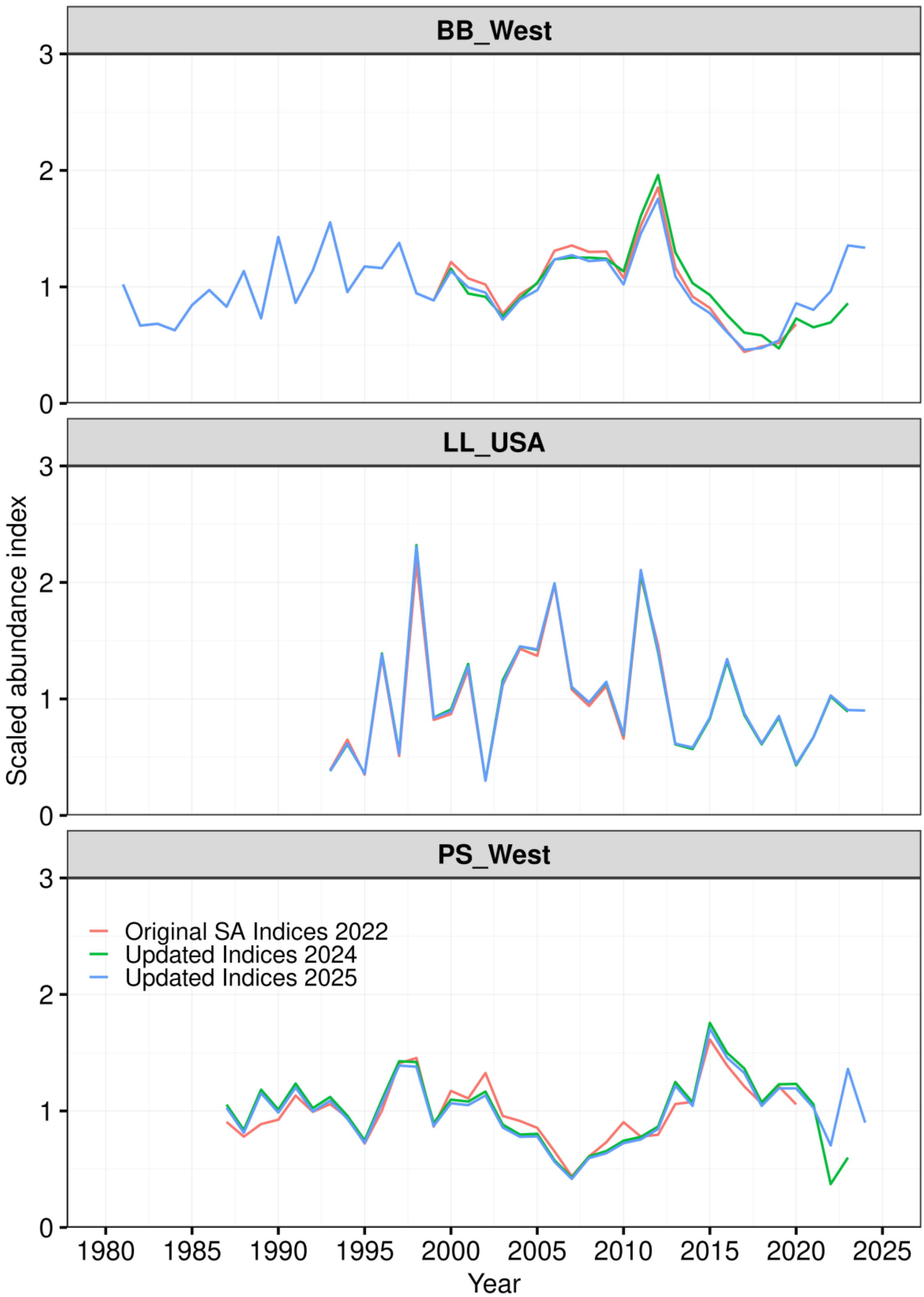

Figure 2. Time series of scaled abundance indices for three fisheries: BB_West (top), LL_USA (middle), and PS_West (bottom). Lines represent the original Stock Assessment indices from 2022 (red), updated indices from 2024 (green), and updated indices from 2025 (blue).

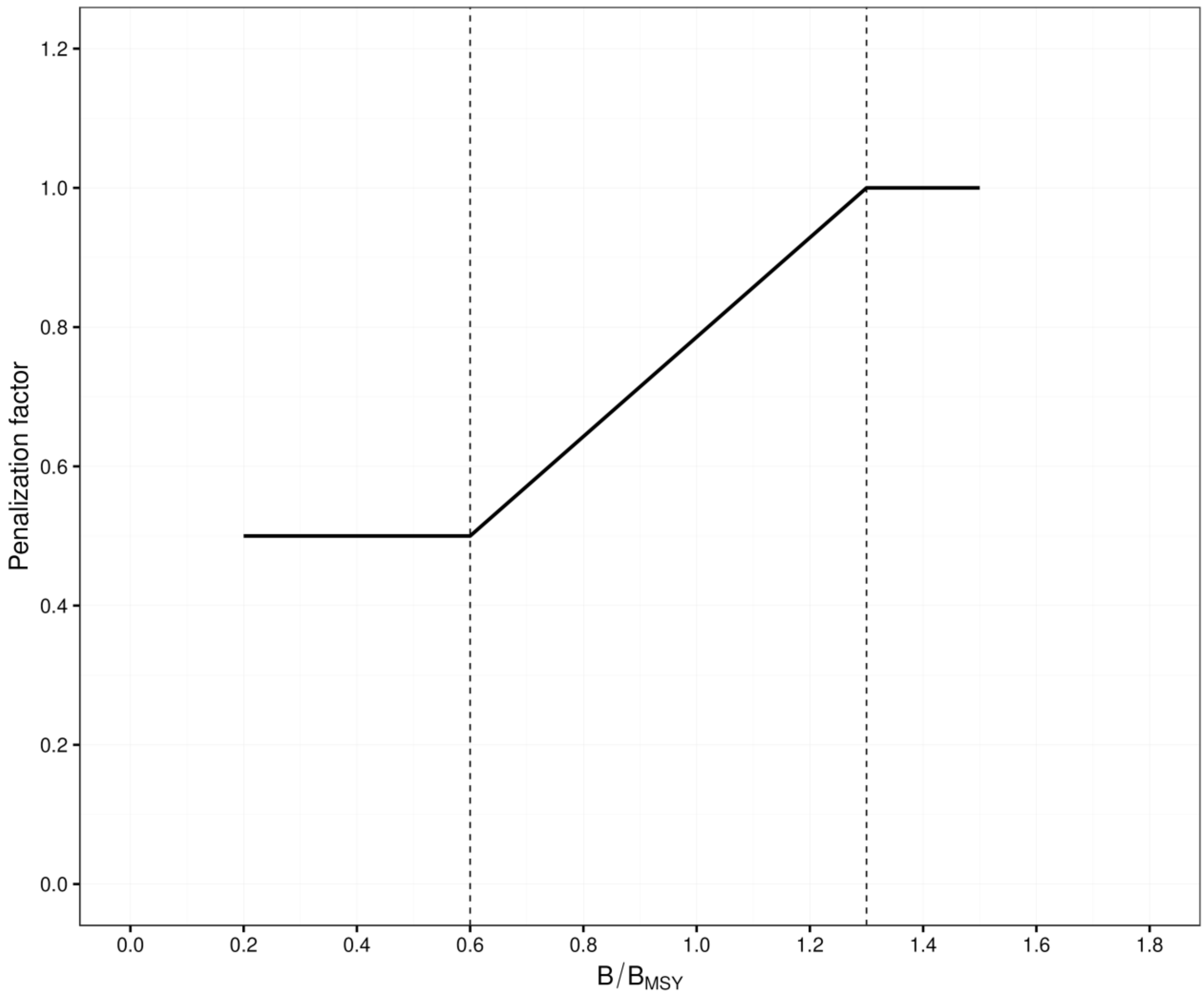

Figure 3. Penalization function applied as a function of stock biomass relative to B_{MSY}. The function defines a linear scaling factor that adjusts the harvest control rule (HCR) performance based on the current biomass status. Below 0.6 B_{MSY}, the penalization factor remains constant at 0.5, indicating reduced acceptability of management performance under low stock levels. Between 0.6 (B_{LIM}) and 1.3 (B_{TARGET}) B_{MSY}, the factor increases linearly, reaching a maximum of 1.0 at 1.3 B_{MSY} or higher, where no penalization is applied. Vertical dashed lines denote the biomass thresholds at 0.6 (B_{LIM}) and 1.3 (B_{TARGET}) B_{MSY}, which mark the limits of the linear transition zone.

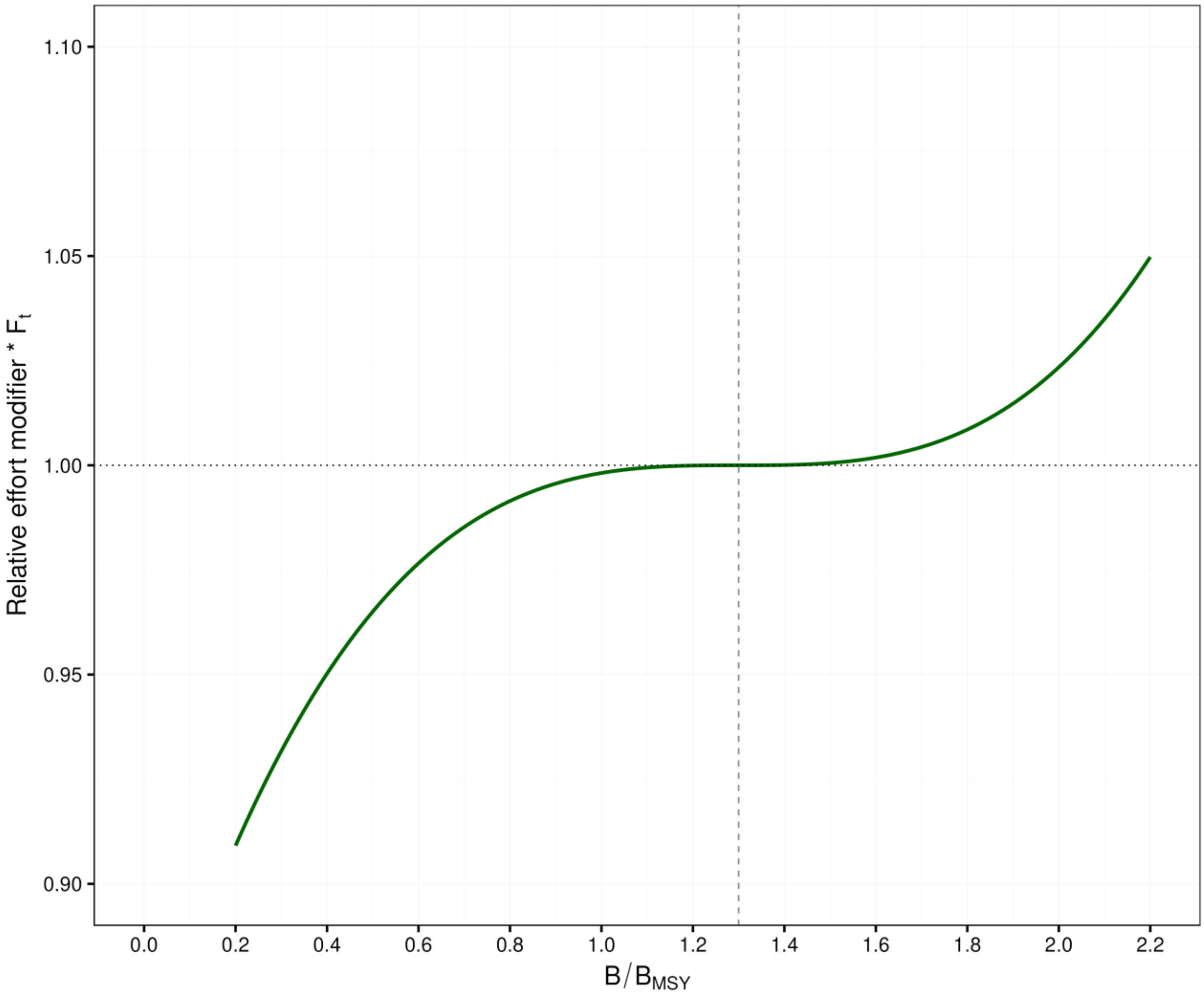

Figure 4. Effort adjustment function as a continuous multiplier of fishing mortality (F_t) based on relative biomass (B/B_{MSY}). The curve represents a symmetric, non-linear modification of fishing effort around the target biomass level (B/B_{MSY} = 1.3, indicated by the vertical dashed line). Below B/B_{MSY} = 1.0, the multiplier is reduced, reaching a minimum around B/B_{MSY} = 0.2, thus penalizing fishing effort under low biomass conditions. Above B/B_{MSY} = 1.3, effort is slightly increased, peaking gradually with increasing biomass. The function is centered at a neutral value of 1.0 (horizontal dotted line), indicating no adjustment when the stock is near the target reference point.

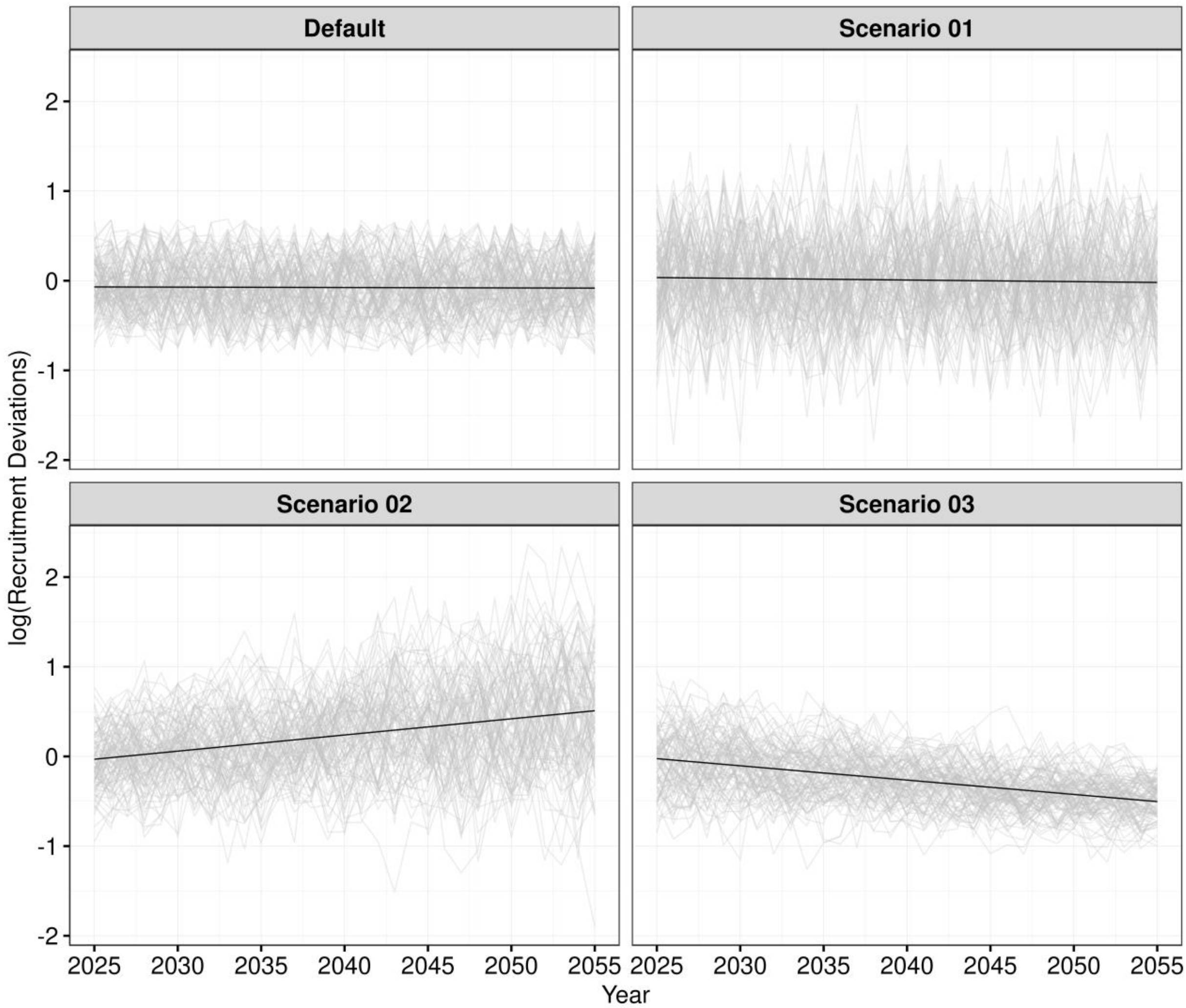

Figure 5. Projection outcomes under alternative recruitment deviation scenarios for climate change possible effects evaluated in Robustness tests. Scenario 01 represents a 50% increase in recruitment deviation variability maintained throughout the projection period. Scenario 02 incorporates temporally autocorrelated increases in recruitment deviations with an overall positive trend over time. Scenario 03 illustrates the opposite pattern, with temporally autocorrelated reductions in recruitment deviations and a negative trend along the time series.

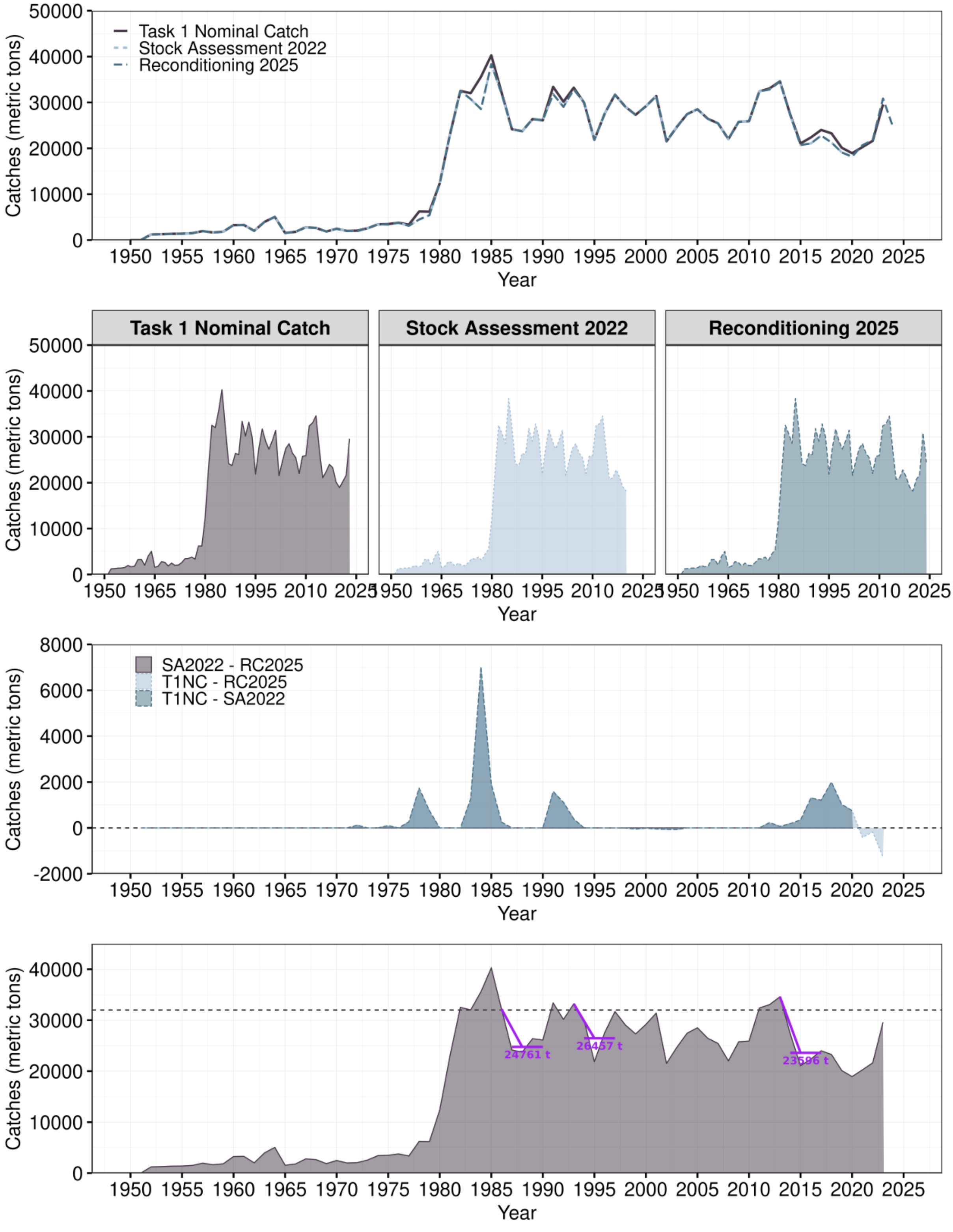

Figure 6. Comparative overview of catch time series and derived differences across multiple data sources used in the Management Strategy Evaluation (MSE) for western Atlantic skipjack tuna. The top panel presents the total nominal catches (Task 1), the catch series used in the 2022 stock assessment, and the updated catch reconstruction for the 2025 MSE reconditioning. The middle row displays the same three series as separate area plots to highlight structural patterns and magnitudes in each source. The third panel shows the pairwise differences between these series. The bottom panel demonstrates the behavior of catches directly after the occurrence of maximum production peaks.

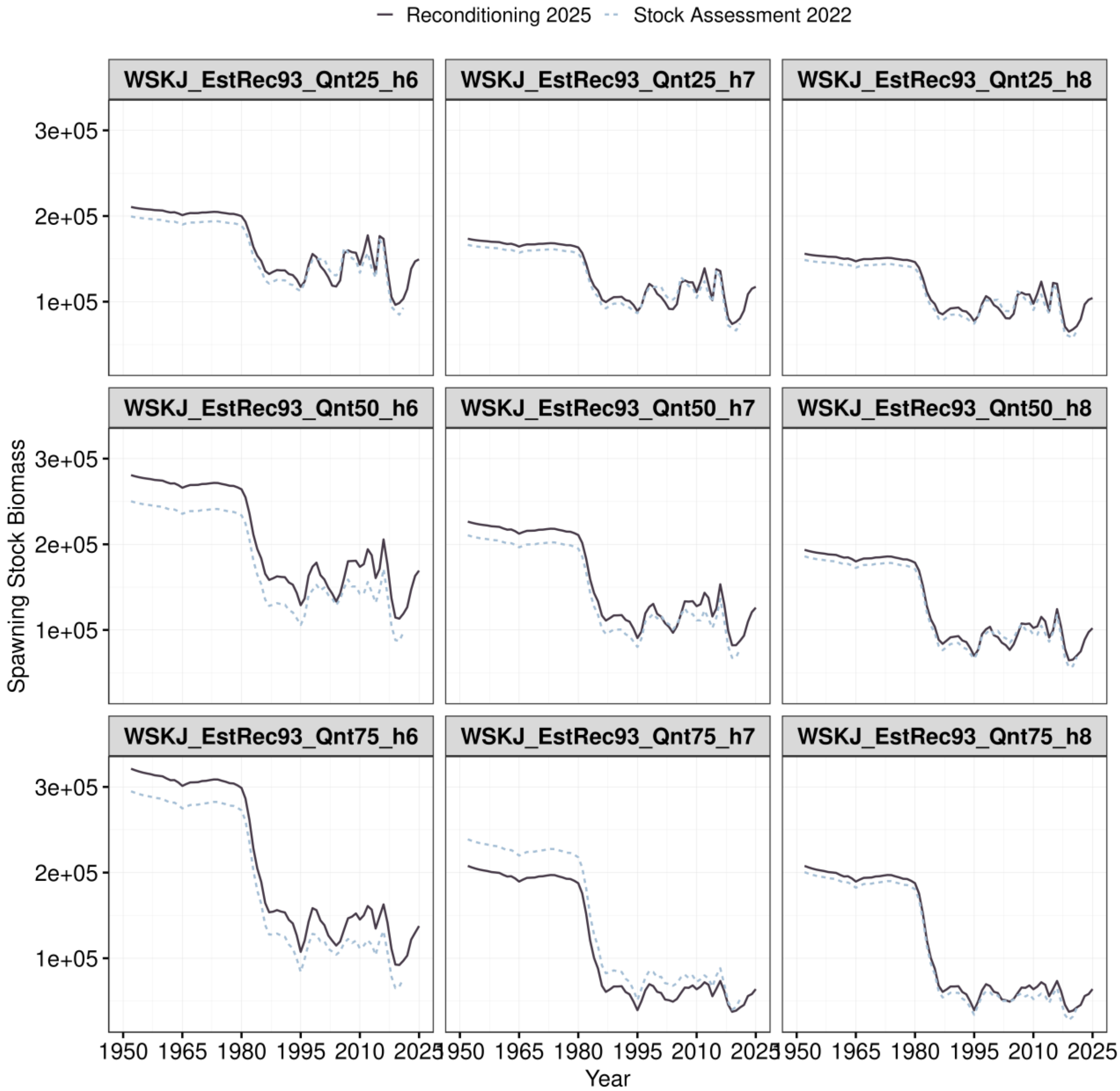

Figure 7. Time series of spawning stock biomass (SSB) for western Atlantic skipjack tuna (WSKJ), comparing outputs from the 2022 stock assessment (dashed blue lines) and the 2025 reconditioning (solid black lines), under the uncertainty grid defined in the last stock assessment.

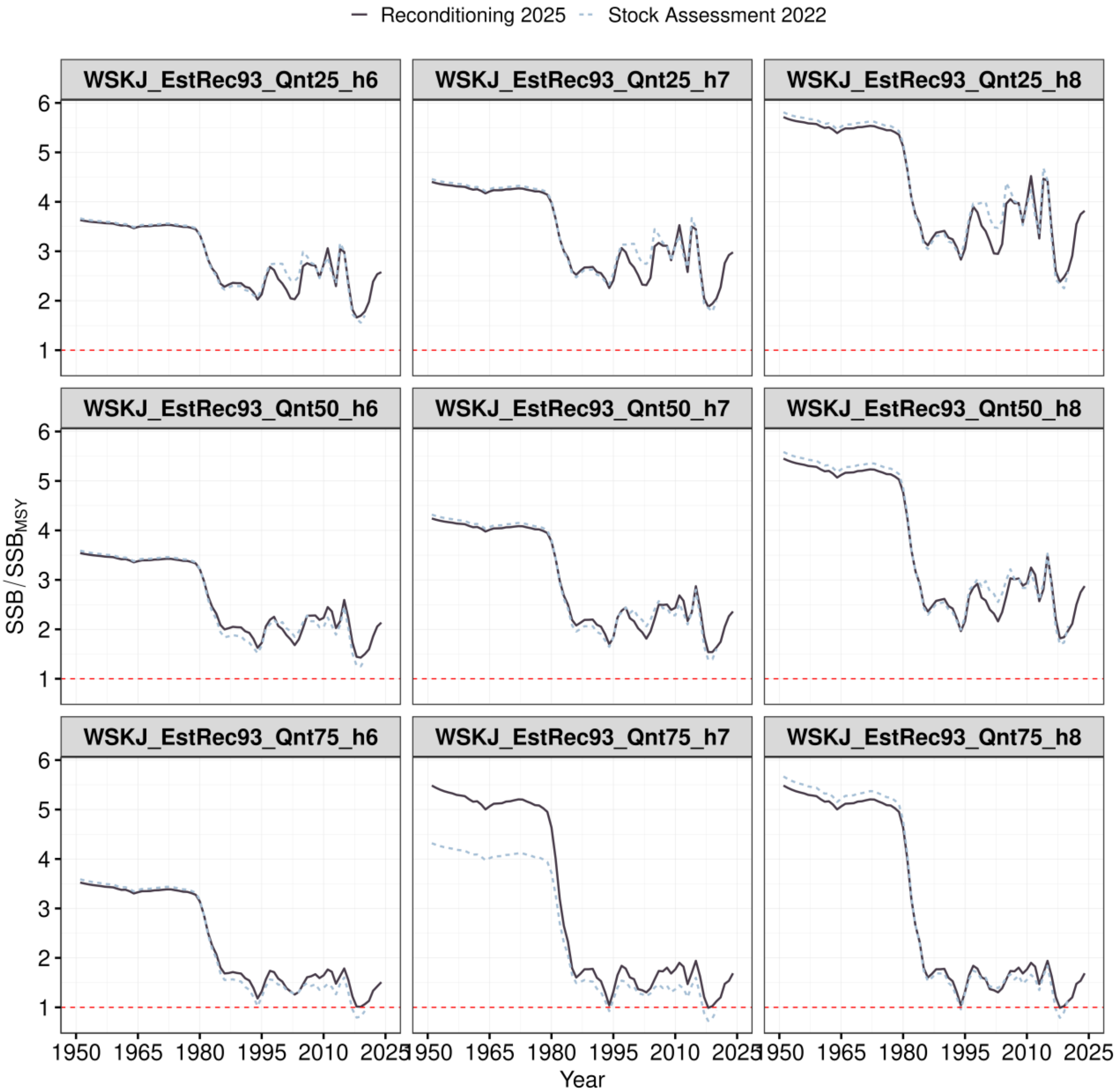

Figure 8. Time series of spawning stock biomass relative to SSB_{MSY} for western Atlantic skipjack tuna (WSKJ), comparing outputs from the 2022 stock assessment (dashed blue lines) and the 2025 reconditioning (solid black lines), under the uncertainty grid defined in the last stock assessment.

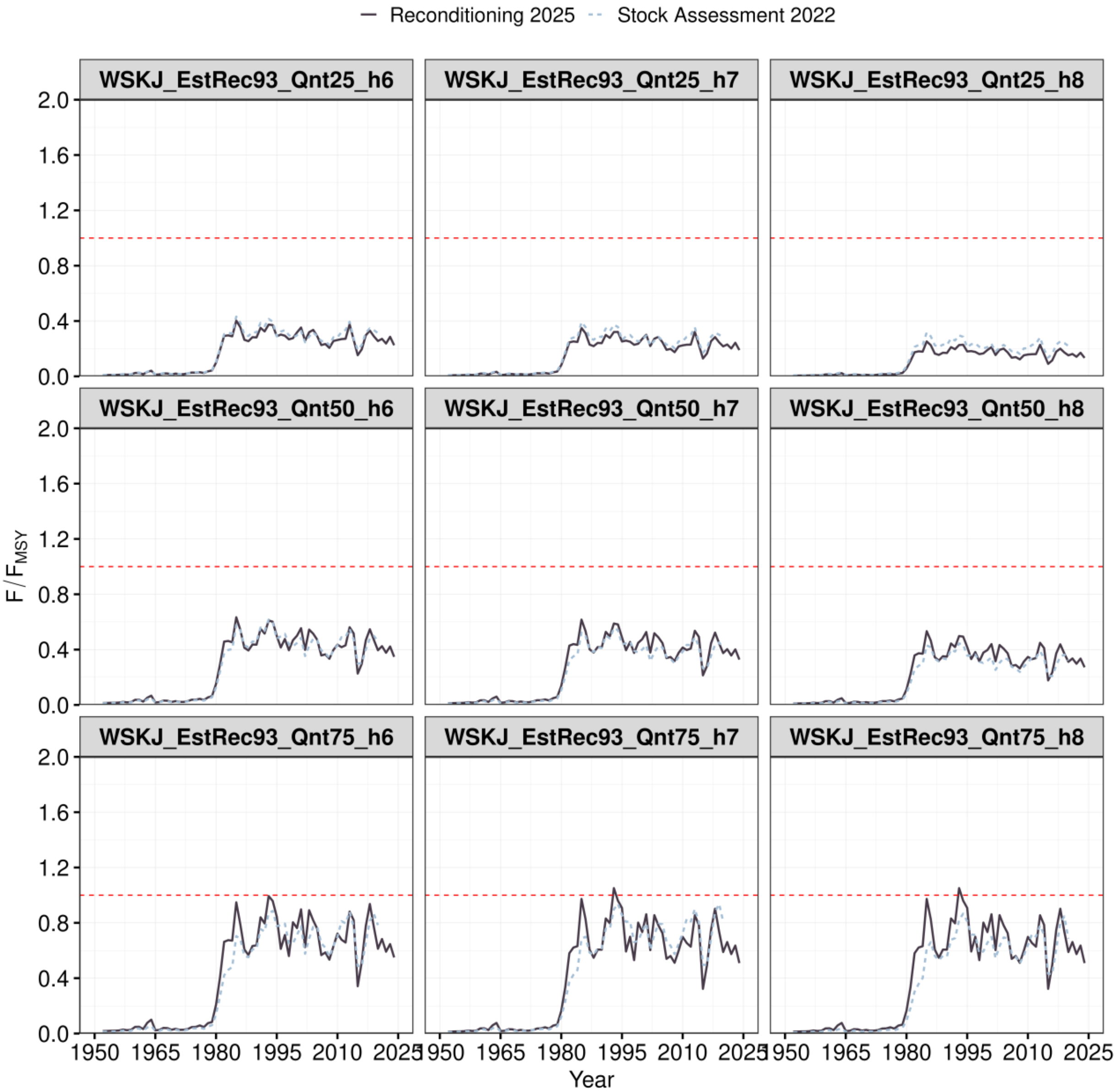

Figure 9. Time series of fishing mortality relative to F_{MSY} for western Atlantic skipjack tuna (WSKJ), comparing outputs from the 2022 stock assessment (dashed blue lines) and the 2025 reconditioning (solid black lines), under the uncertainty grid defined in the last stock assessment.

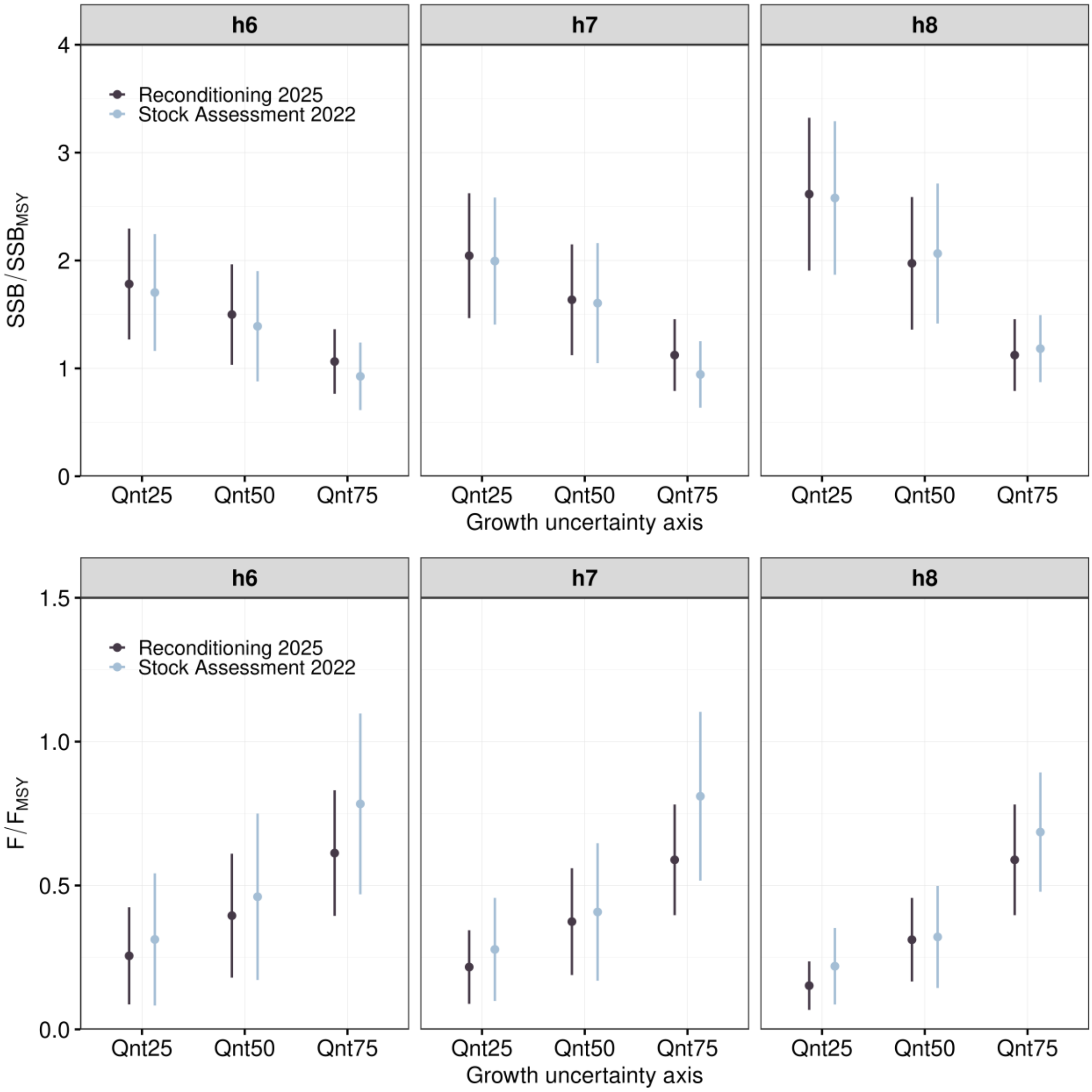

Figure 10. Comparison of stock status indicators for the year 2020 between the 2022 stock assessment (blue) and the 2025 reconditioning (black) for western Atlantic skipjack tuna (WSKJ), across uncertainty grid defined in the last stock assessment. The top panels show the median values and 95% confidence intervals for SSB/SSB_{MSY}, while the bottom panels show the corresponding to F/F_{MSY}.

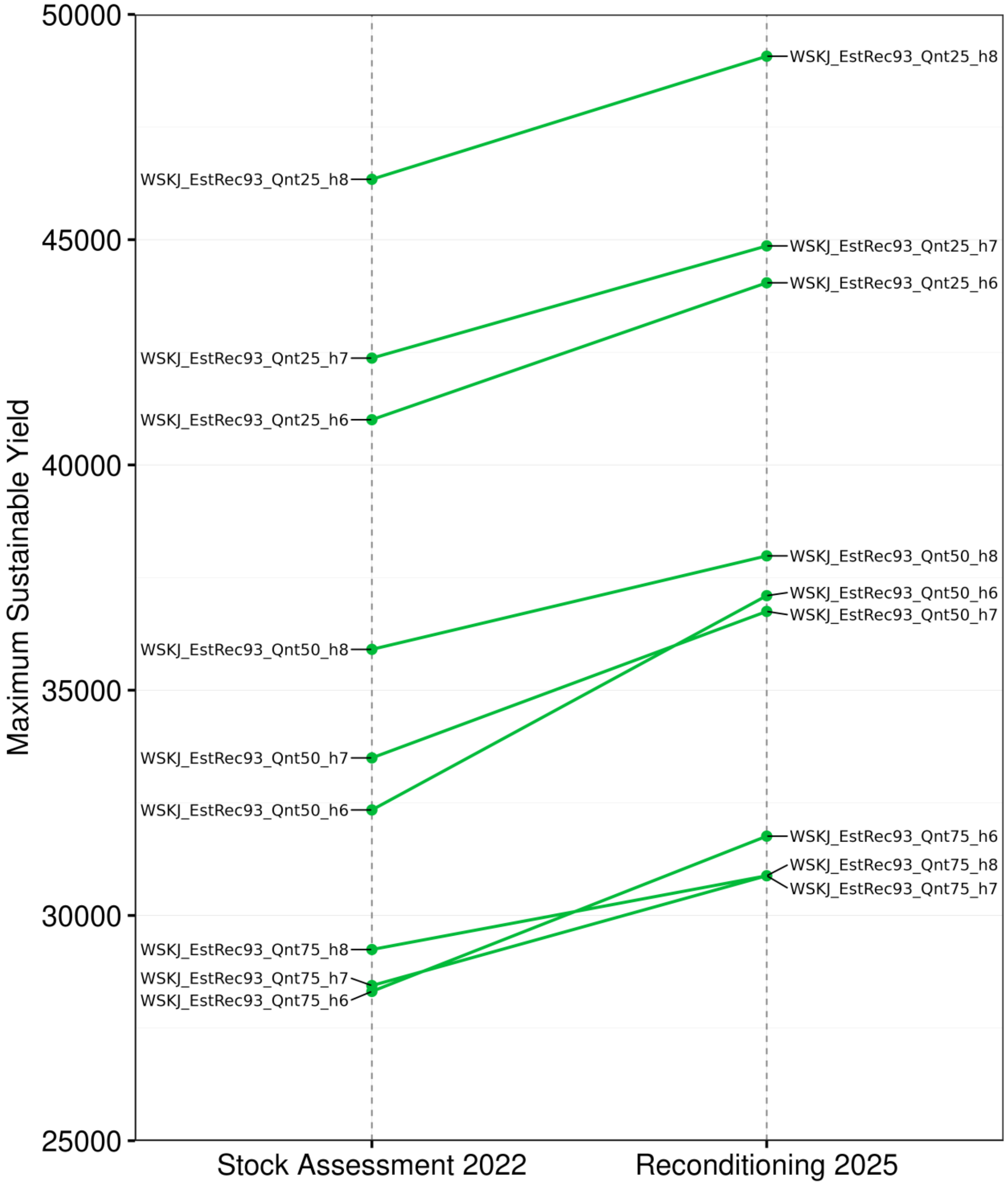

Figure 11. Comparison of estimated Maximum Sustainable Yield (MSY) values for western Atlantic skipjack tuna (WSKJ) under the 2022 stock assessment (left) and the 2025 reconditioning (right) across uncertainty grid defined in the last stock assessment.

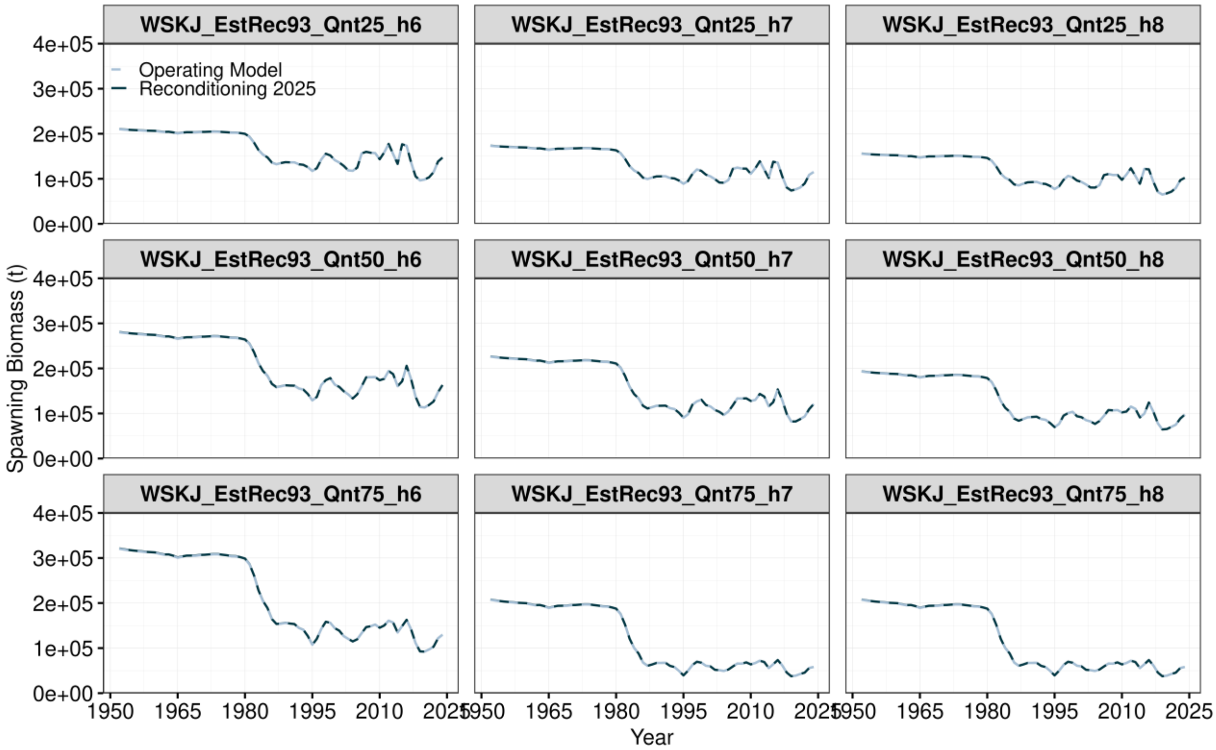

Figure 12. Comparison between spawning biomass trajectories from the 2025 reconditioning (solid black lines) and the corresponding Operating Model (OM) inputs (dashed blue lines) across uncertainty grid defined in the last stock assessment.

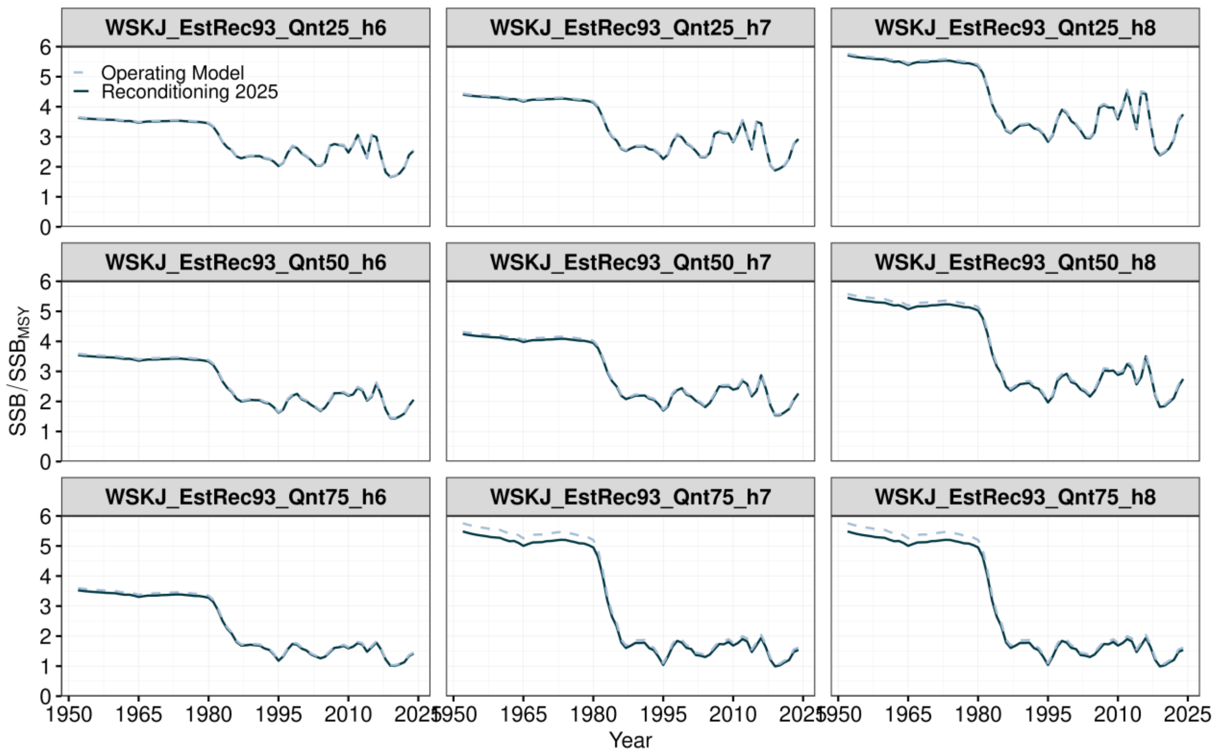

Figure 13. Comparison between spawning biomass relative to SSB_{MSY} trajectories from the 2025 reconditioning (solid black lines) and the corresponding Operating Model (OM) inputs (dashed blue lines) across uncertainty grid defined in the last stock assessment.

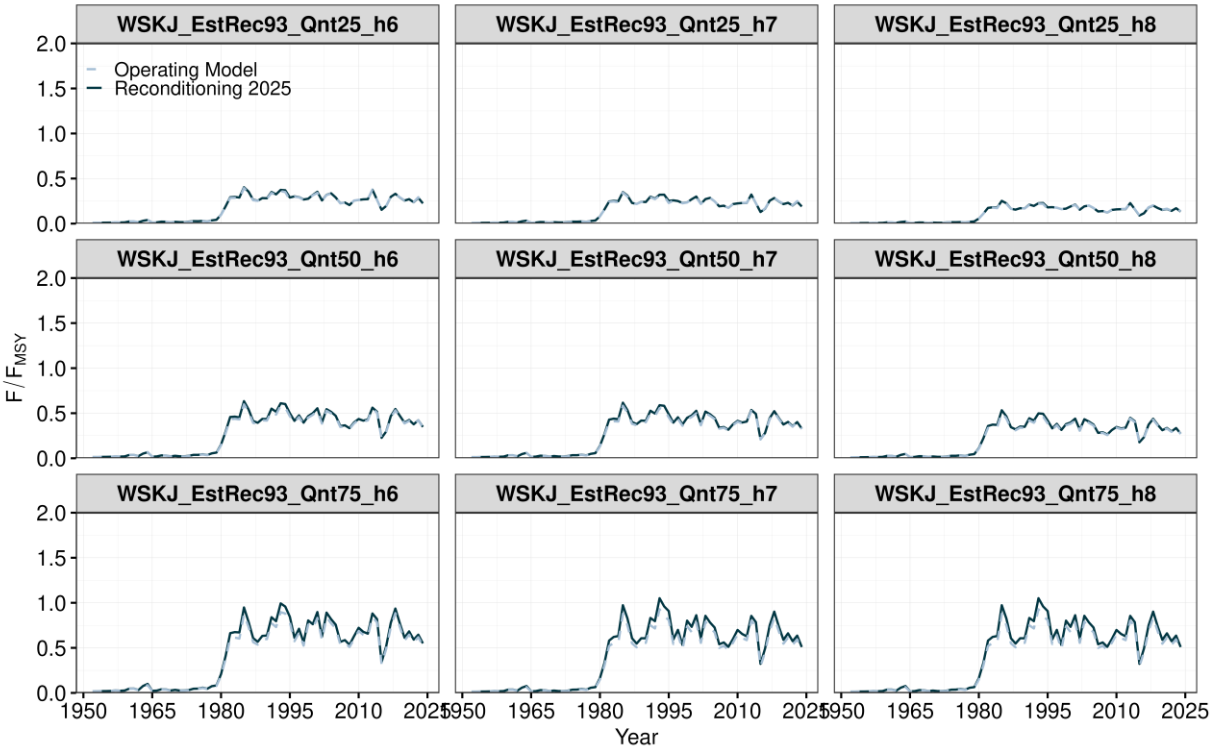

Figure 14. Comparison between fishing mortality relative to F_{MSY} trajectories from the 2025 reconditioning (solid black lines) and the corresponding Operating Model (OM) inputs (dashed blue lines) across uncertainty grid defined in the last stock assessment.

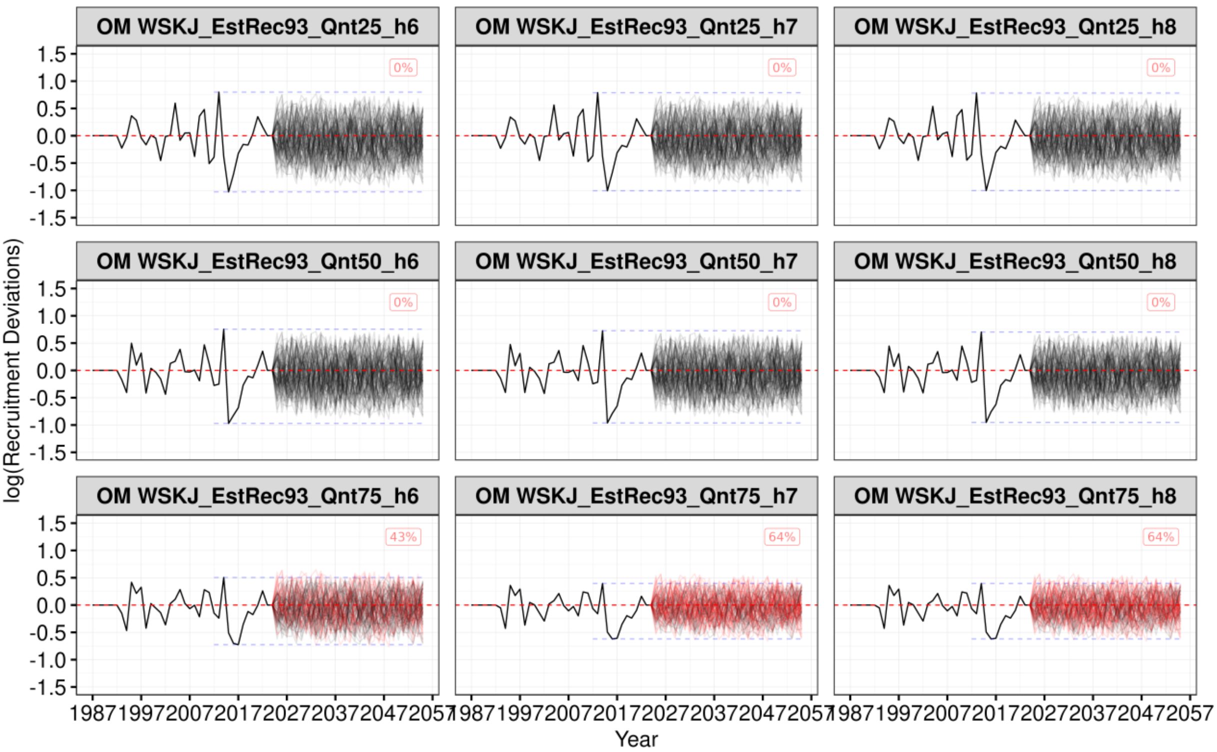

Figure 15. Recruitment deviations (log-scale) for the nine simulation scenarios. Black lines represent historical deviations, while the shaded lines represent projected deviations.

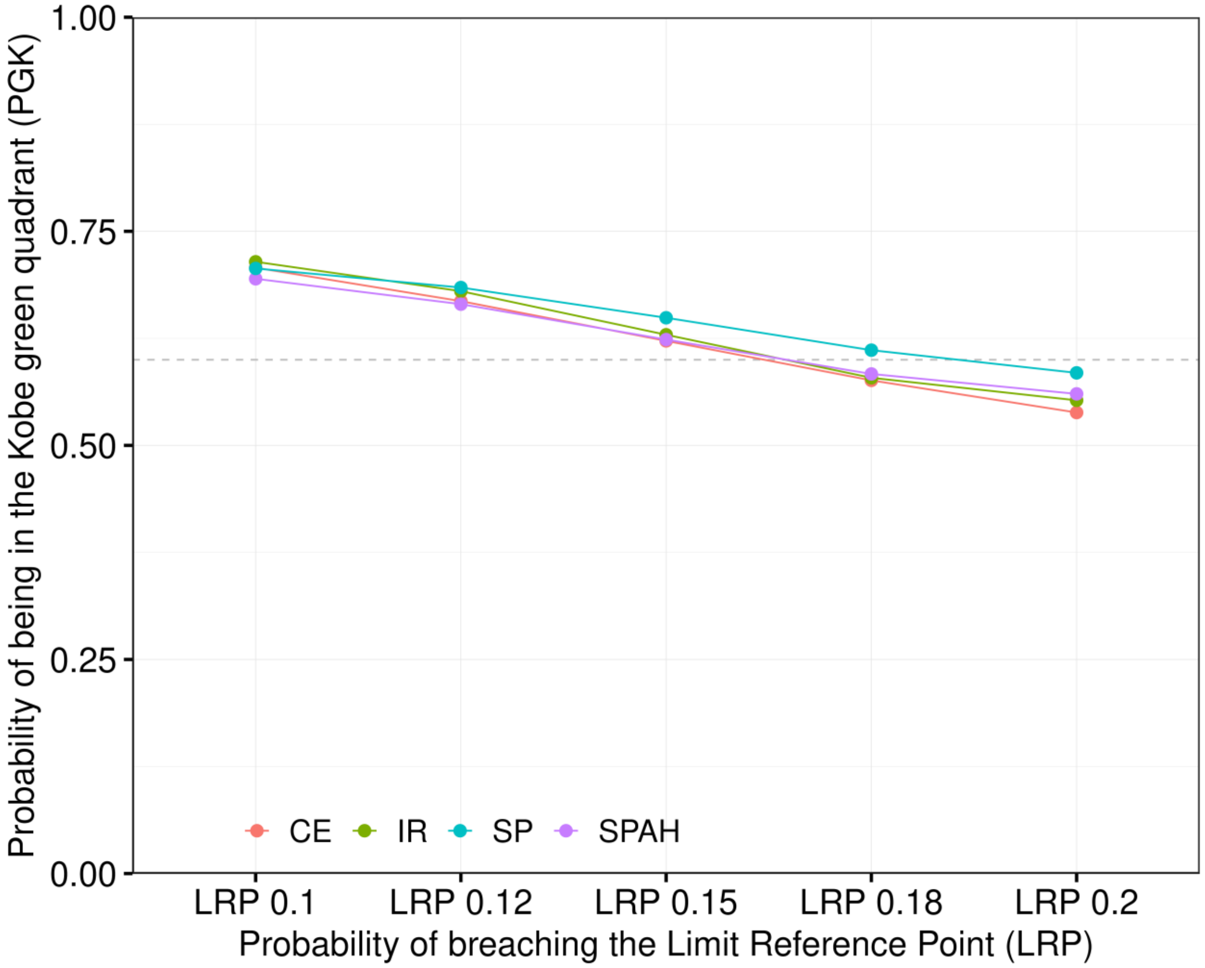

Figure 16. Trade-off analysis between the probability of being in the Kobe green quadrant (PGK) and the probability of breaching the Limit Reference Point (LRP) for western Atlantic skipjack tuna under four candidate management procedures. Each line shows the PGK performance as the acceptable LRP risk threshold increases from 0.10 to 0.20. The dashed horizontal line marks the ICCAT minimum acceptable PGK level (0.60), serving as a benchmark for evaluating management robustness under different risk tolerances.

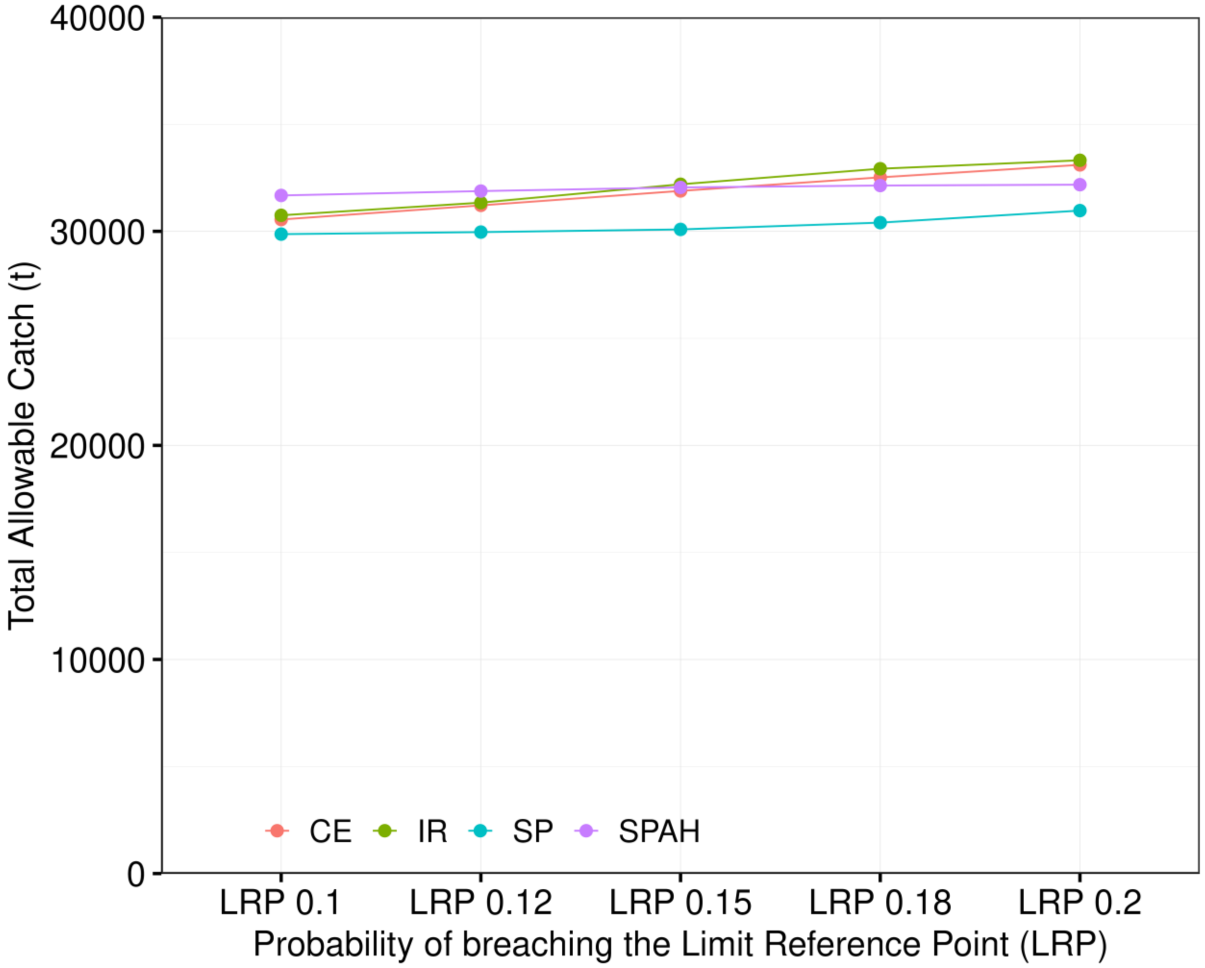

Figure 17. Expected Total Allowable Catch (TAC, in metric tons) under four candidate management procedures as a function of the acceptable probability of breaching the Limit Reference Point (LRP).

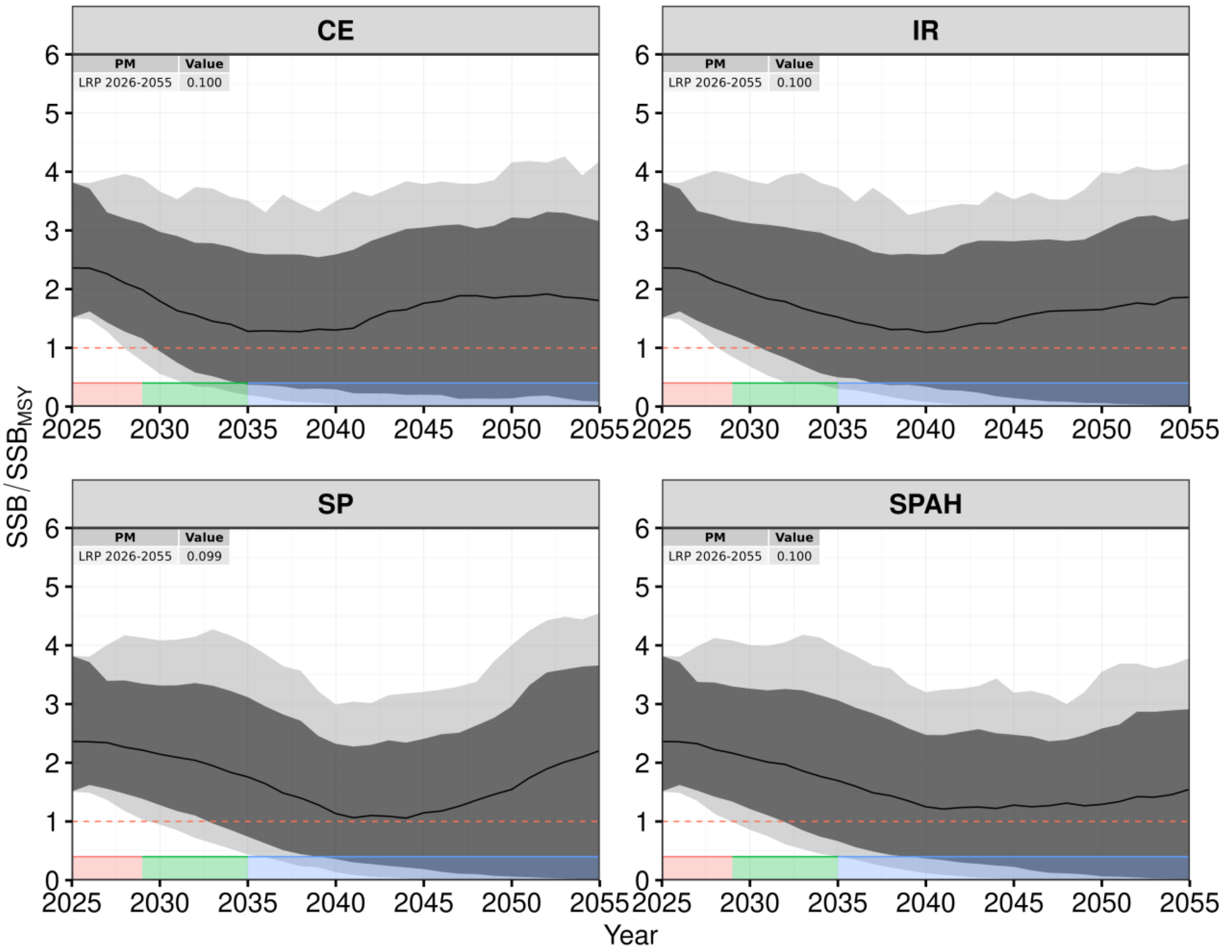

Figure 18. Projected spawning stock biomass relative to SSB_{MSY} (SSB/SSB_{MSY}) for western Atlantic skipjack tuna under four candidate management procedures, projected for the period 2026-2055. The black line represents the median trajectory, while shaded areas correspond to 80% and 95% quantiles respectively. The horizontal dashed red line denotes the limit reference point (SSB_{MSY} = 1). Colored bars at the bottom indicate the reference B_{LIM} (0.4*SSB_{MSY}) for each time projection period (red color: short; green color: medium; blue color: long).

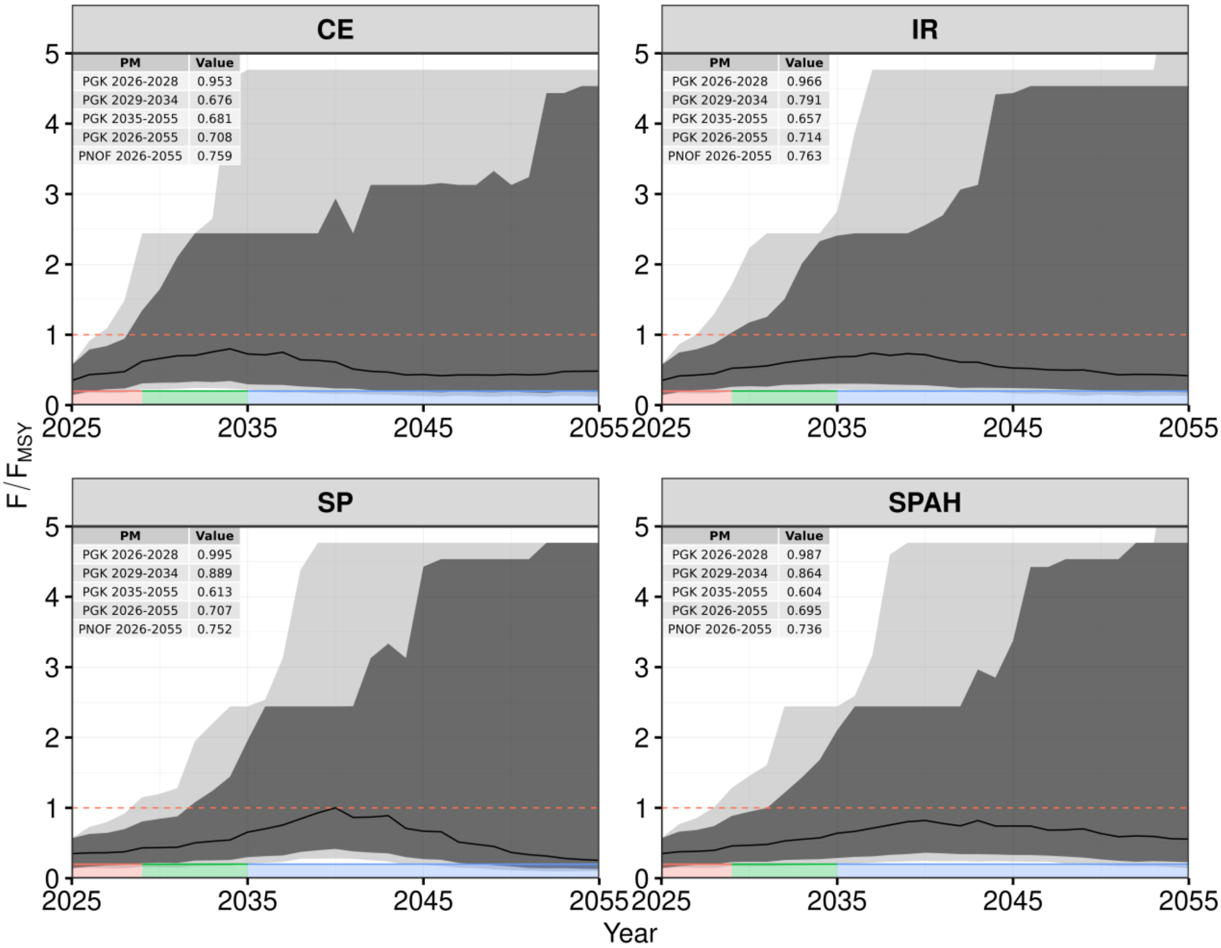

Figure 19. Projected fishing mortality relative to F_{MSY} (F/F_{MSY}) for western Atlantic skipjack tuna under four candidate management procedures, projected for the period 2026-2055. The black line represents the median trajectory, while shaded areas correspond to 80% and 95% quantiles respectively. The horizontal dashed red line denotes the limit reference point (F_{MSY} = 1). Colored bars at the bottom indicate the reference of the time projection period (red color: short; green color: medium; blue color: long).

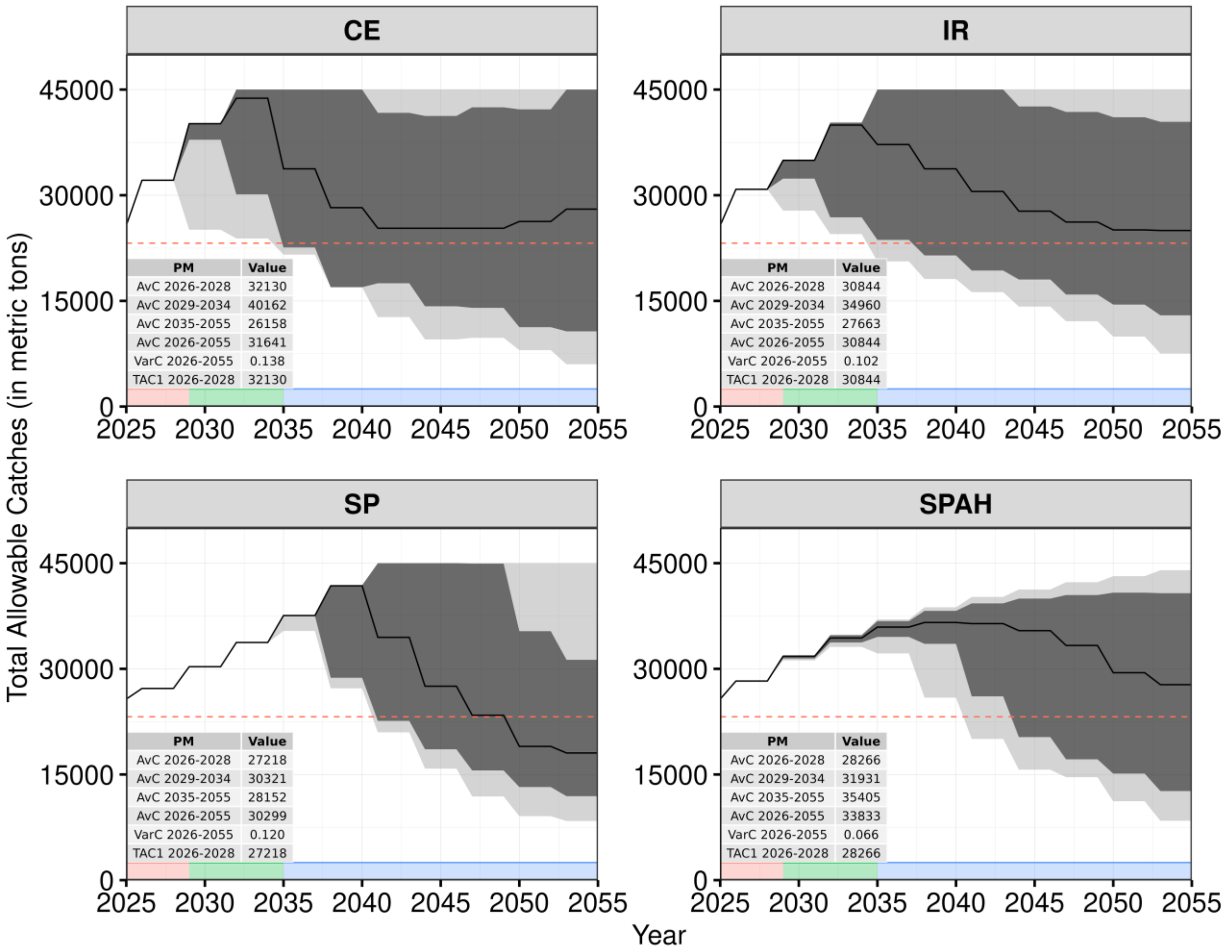

Figure 20. Projected total allowable catches (TAC) for western Atlantic skipjack tuna under four candidate management procedures, projected for the period 2026-2055. The black line represents the median trajectory, while shaded areas correspond to 80% and 95% quantiles respectively. The horizontal dashed red line denotes the average catches for the last 5 years of the historical period. Colored bars at the bottom indicate the reference of the time projection period (red color: short; green color: medium; blue color: long).

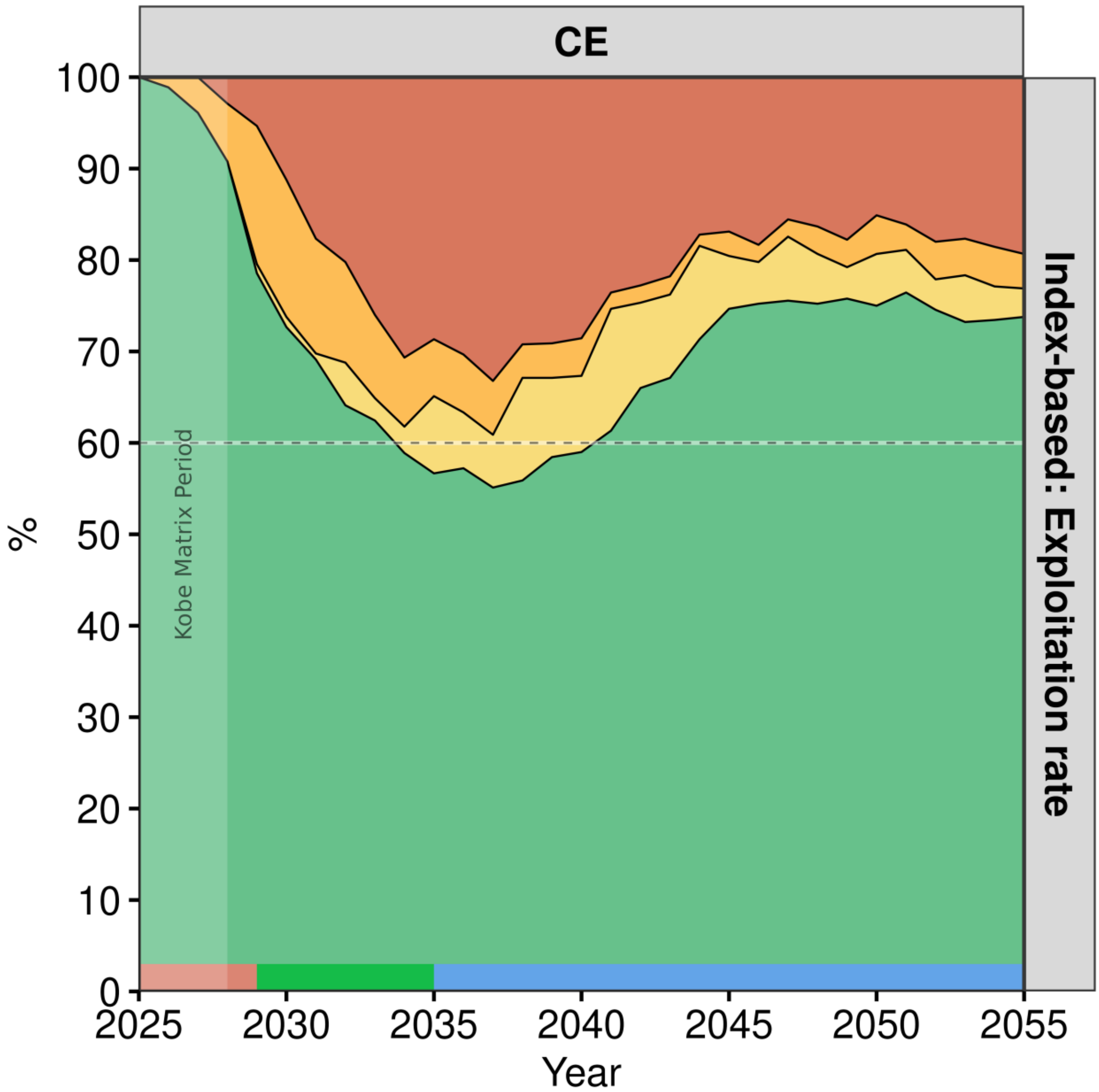

Figure 21. Probability of stock status outcomes for western Atlantic skipjack tuna under the CE candidate management procedure, expressed as the proportion of simulations falling within Kobe quadrants from 2026 to 2055. The stacked areas represent the probabilities of being in the green, yellow, orange and red zones. The horizontal dashed line indicates the ICCAT Commission performance benchmark of at least 60% probability of being in the green quadrant (PGK). Colored bar at the bottom indicates the reference of the time projection period (red color: short; green color: medium; blue color: long).

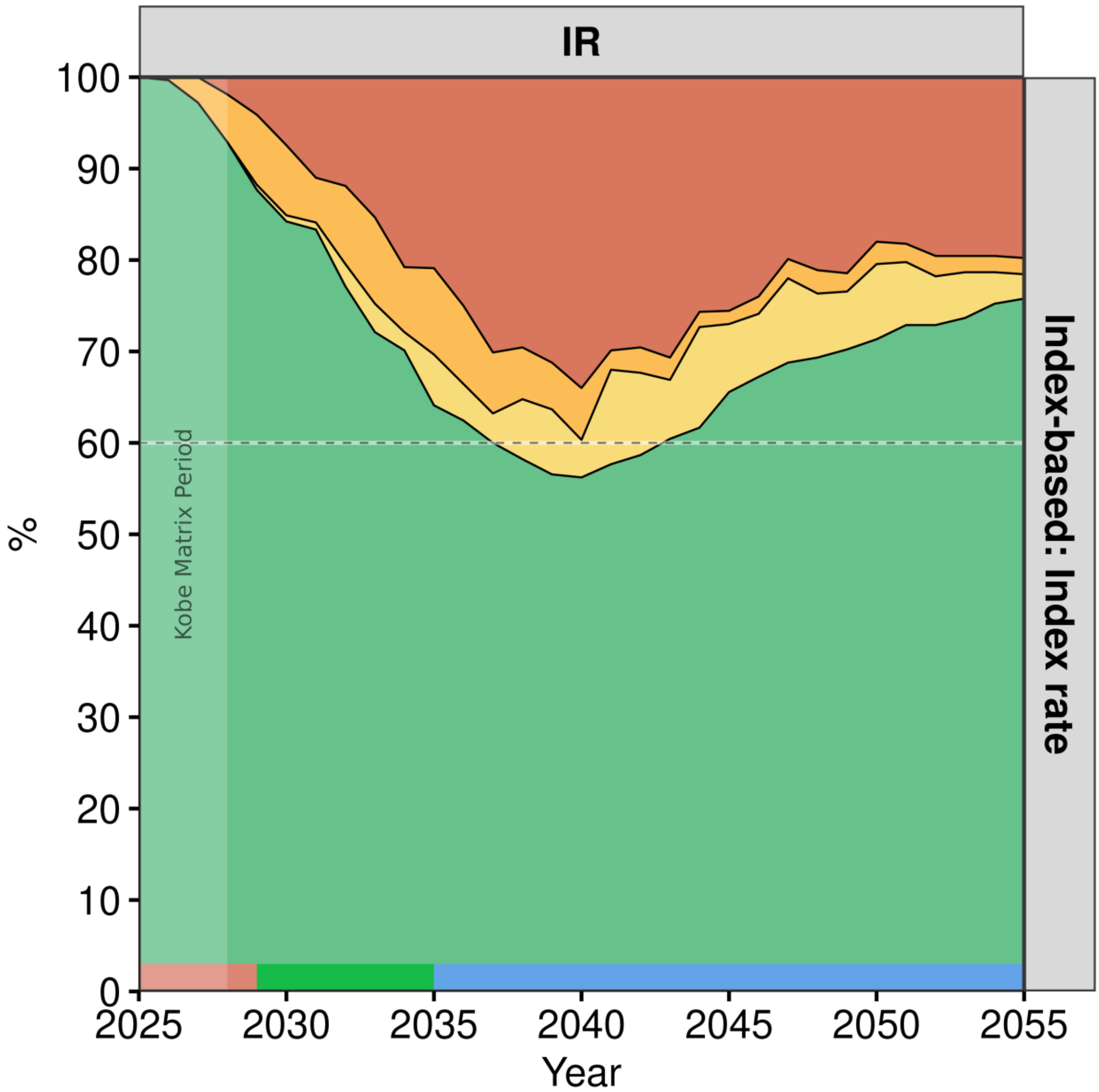

Figure 22. Probability of stock status outcomes for western Atlantic skipjack tuna under the IR candidate management procedure, expressed as the proportion of simulations falling within Kobe quadrants from 2026 to 2055. The stacked areas represent the probabilities of being in the green, yellow, orange and red zones. The horizontal dashed line indicates the ICCAT Commission performance benchmark of at least 60% probability of being in the green quadrant (PGK). Colored bar at the bottom indicates the reference of the time projection period (red color: short; green color: medium; blue color: long).

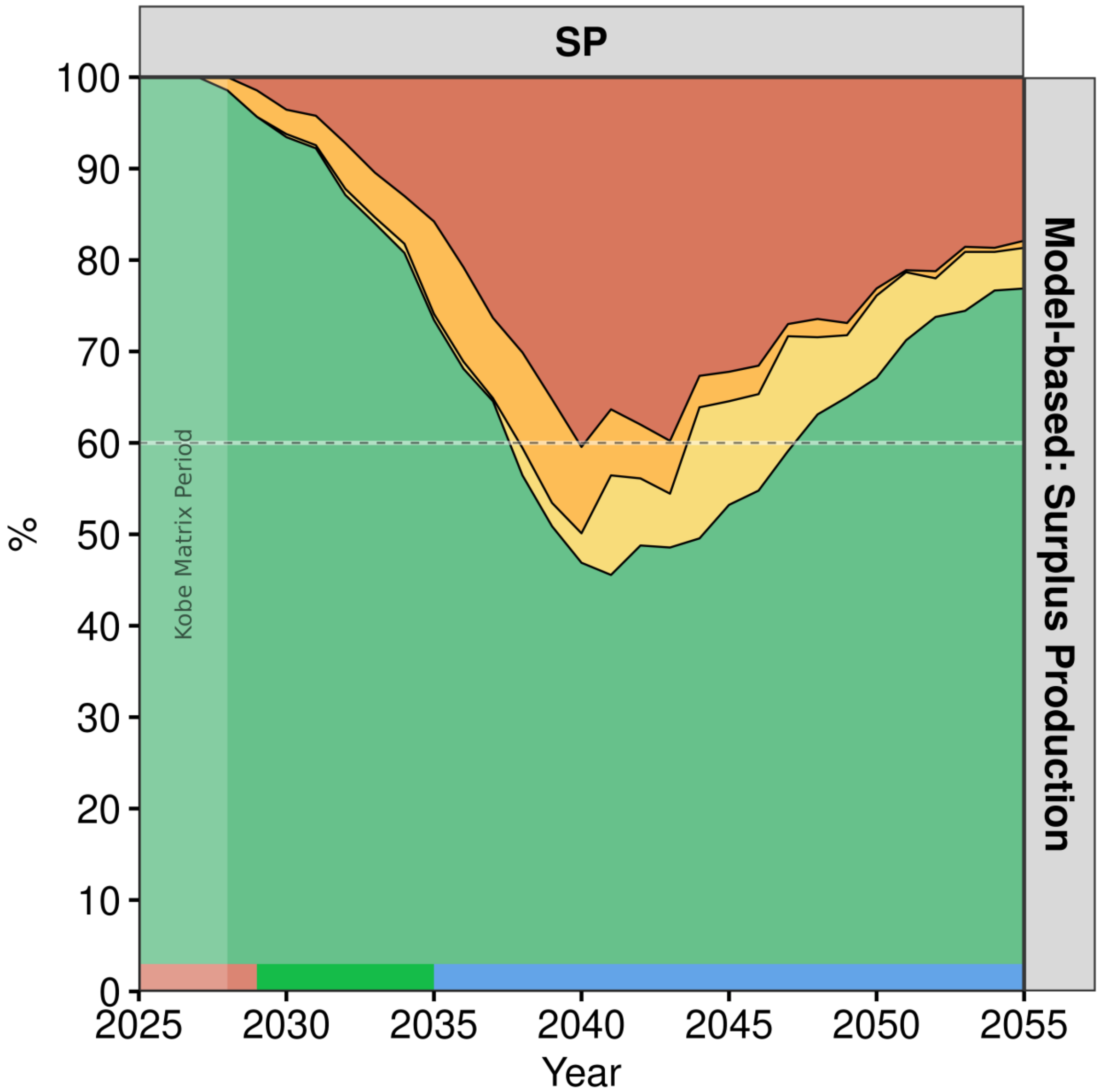

Figure 23. Probability of stock status outcomes for western Atlantic skipjack tuna under the SP candidate management procedure, expressed as the proportion of simulations falling within Kobe quadrants from 2026 to 2055. The stacked areas represent the probabilities of being in the green, yellow, orange and red zones. The horizontal dashed line indicates the ICCAT Commission performance benchmark of at least 60% probability of being in the green quadrant (PGK). Colored bar at the bottom indicates the reference of the time projection period (red color: short; green color: medium; blue color: long).

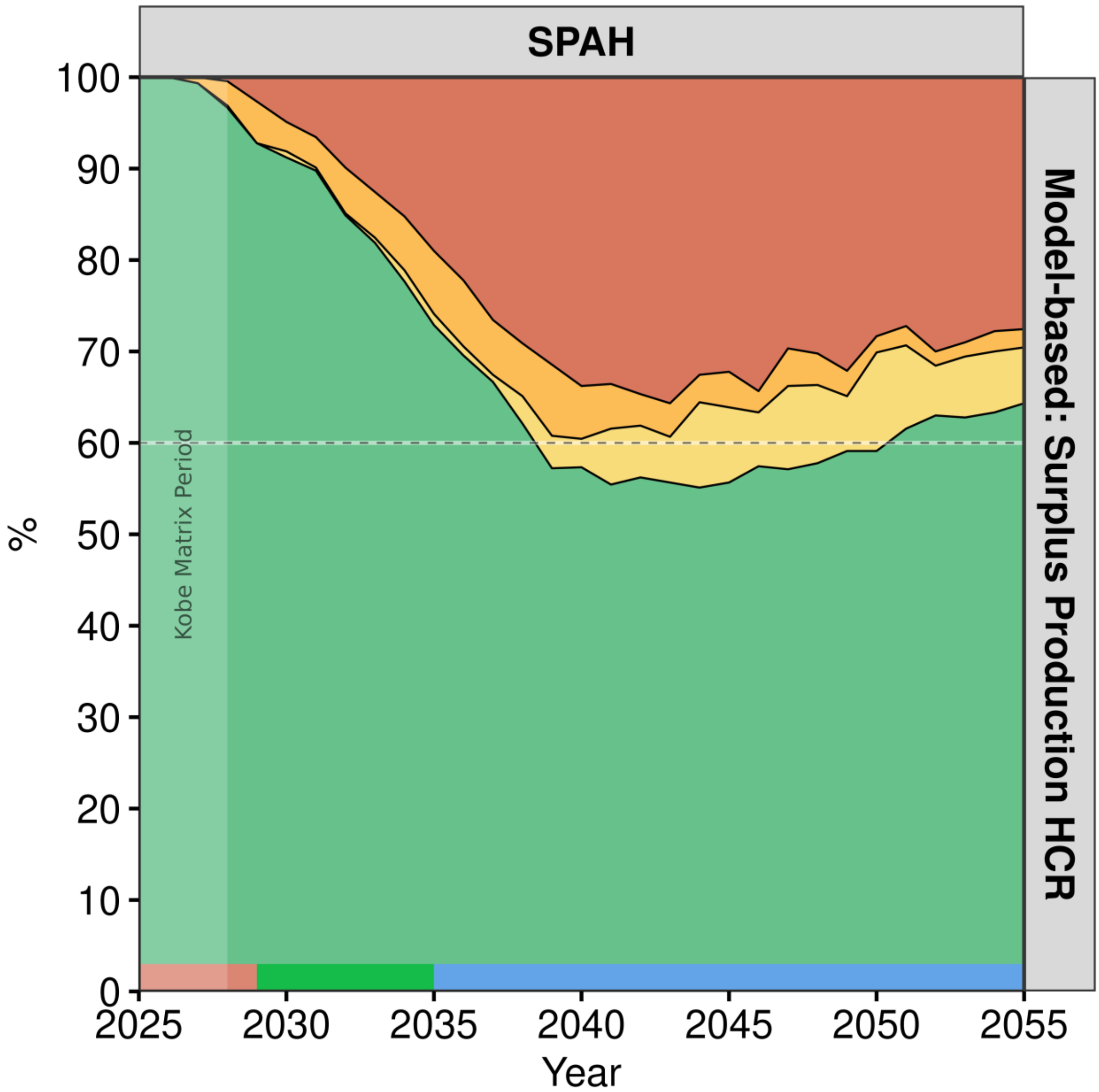

Figure 24. Probability of stock status outcomes for western Atlantic skipjack tuna under the SPAH candidate management procedure, expressed as the proportion of simulations falling within Kobe quadrants from 2026 to 2055. The stacked areas represent the probabilities of being in the green, yellow, orange and red zones. The horizontal dashed line indicates the ICCAT Commission performance benchmark of at least 60% probability of being in the green quadrant (PGK). Colored bar at the bottom indicates the reference of the time projection period (red color: short; green color: medium; blue color: long).

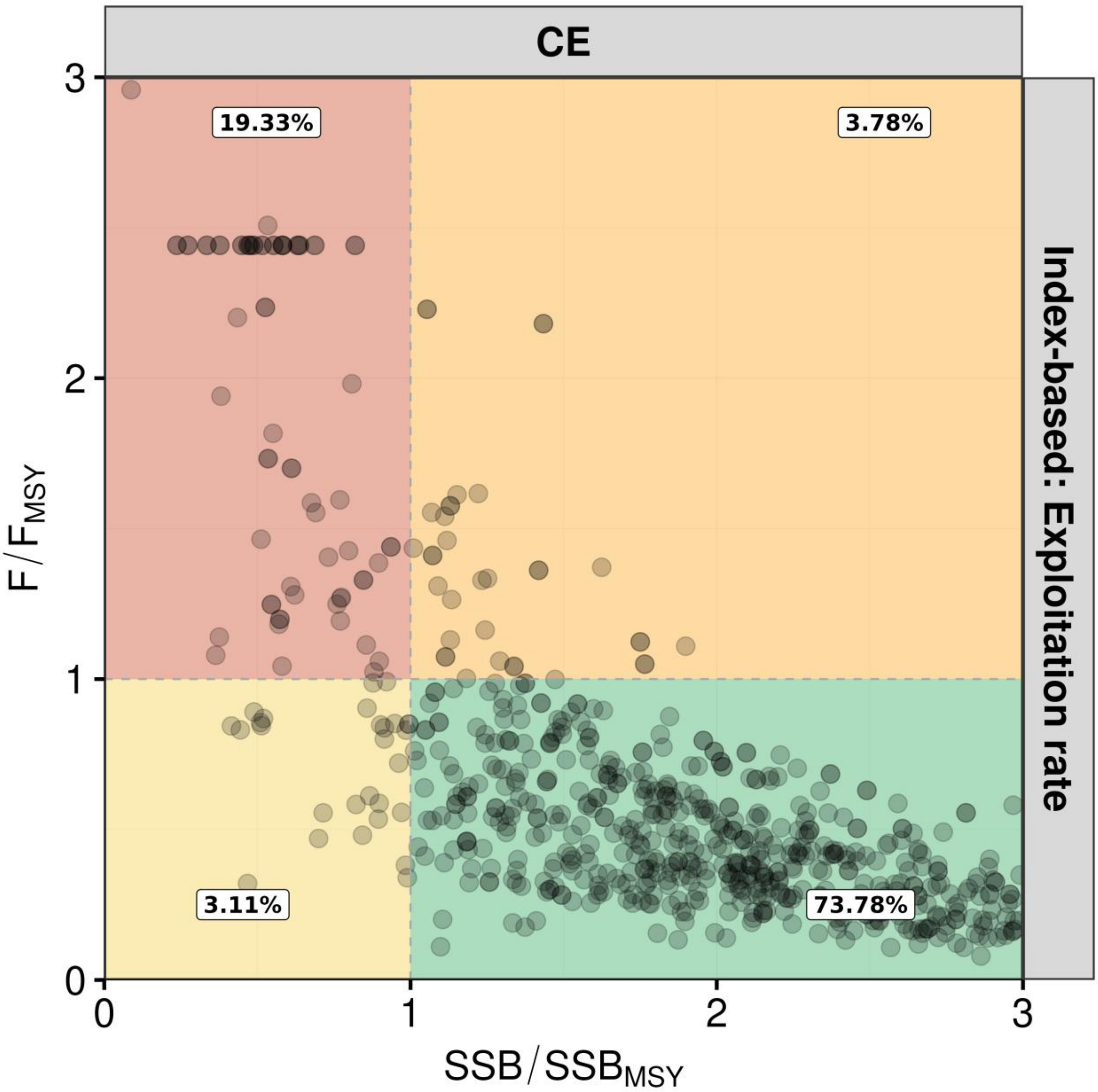

Figure 25. Kobe plot summarizing the distribution of stock status outcomes in 2055 for western Atlantic skipjack tuna under the CE management procedure. Each point corresponds to a simulated trajectory for the last projected year across uncertainty grid defined in the last stock assessment. Quadrant colors denoting stock status.

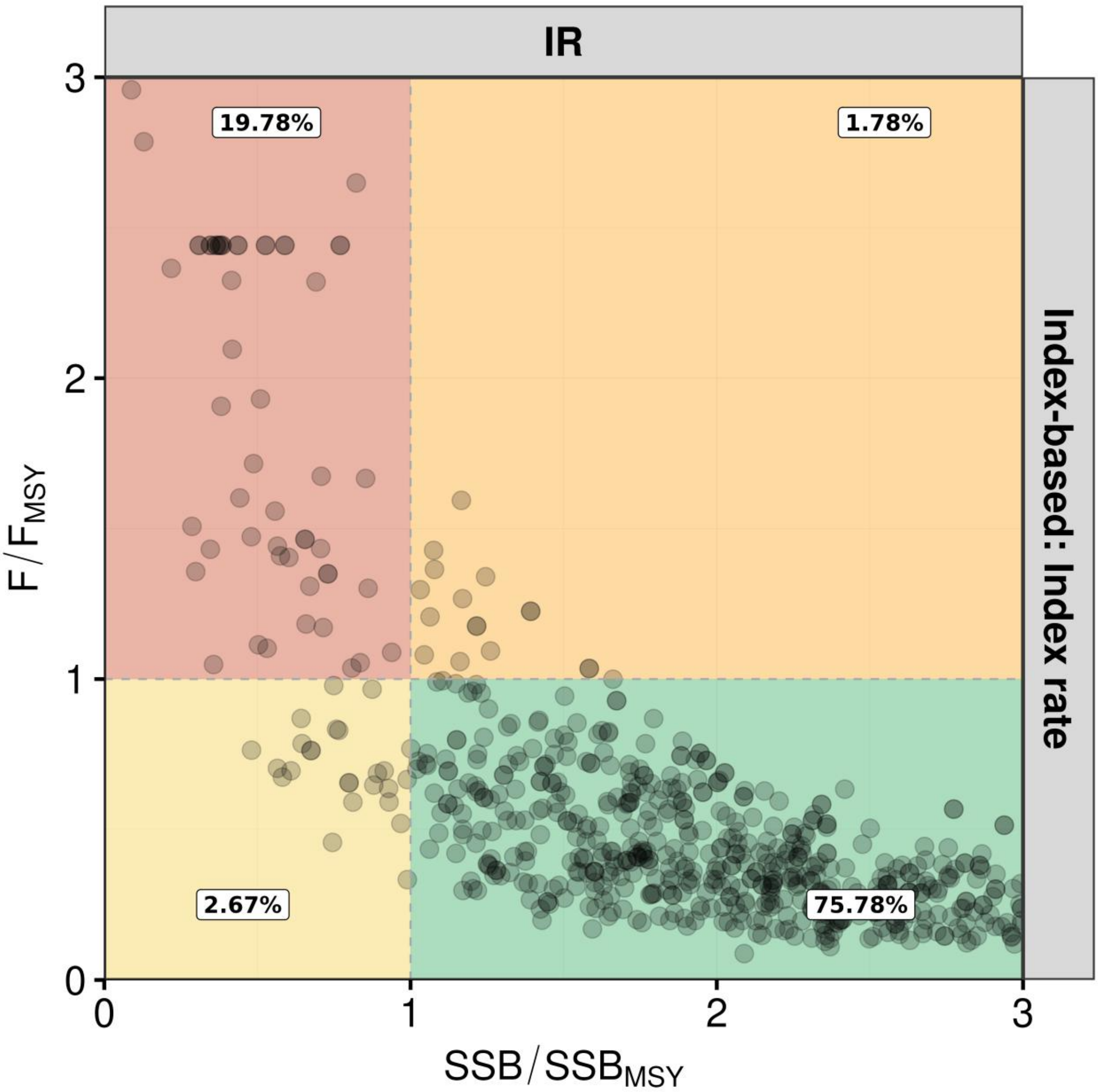

Figure 26. Kobe plot summarizing the distribution of stock status outcomes in 2055 for western Atlantic skipjack tuna under the IR management procedure. Each point corresponds to a simulated trajectory for the last projected year across uncertainty grid defined in the last stock assessment. Quadrant colors denoting stock status.

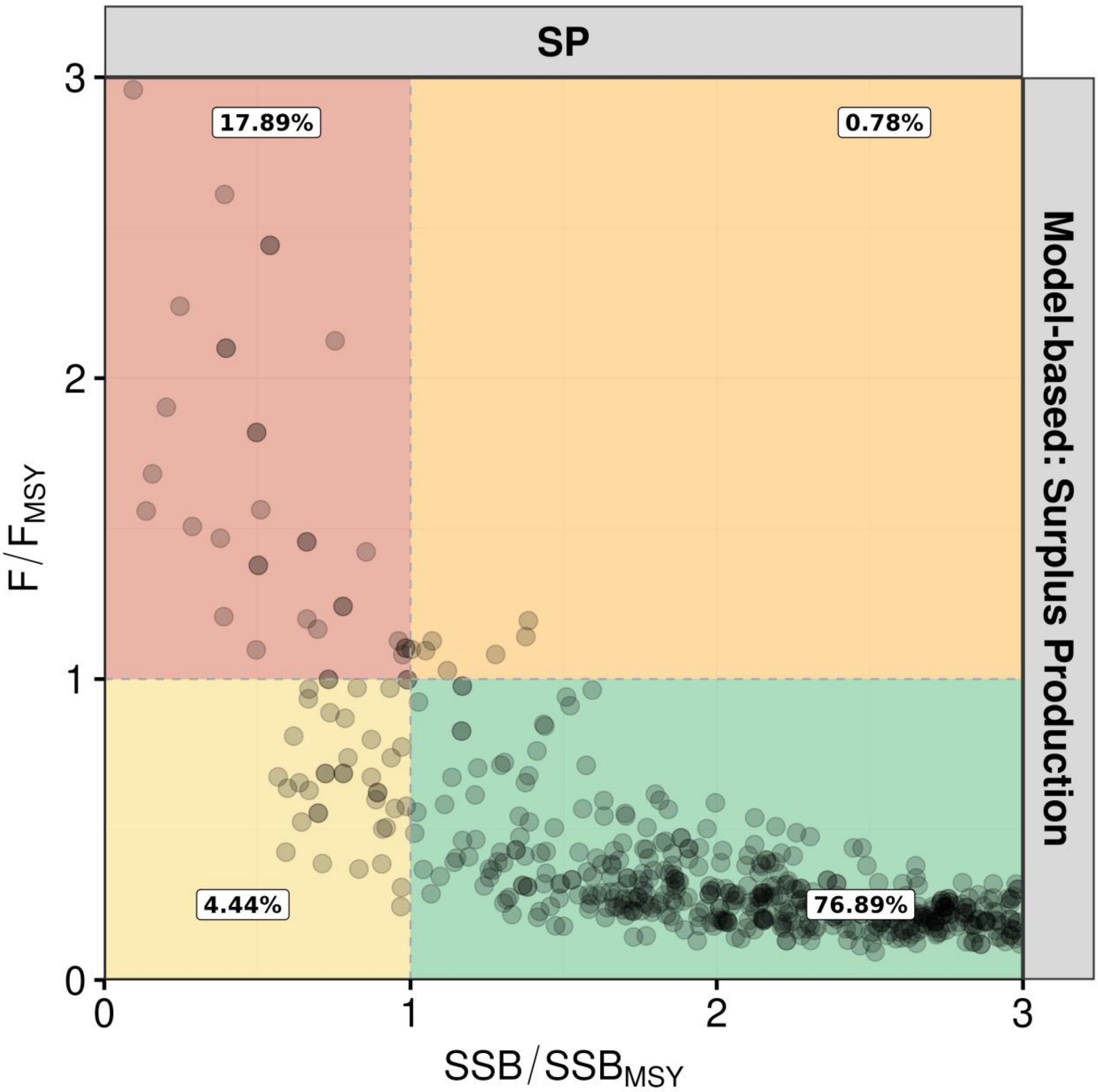

Figure 27. Kobe plot summarizing the distribution of stock status outcomes in 2055 for western Atlantic skipjack tuna under the SP management procedure. Each point corresponds to a simulated trajectory for the last projected year across uncertainty grid defined in the last stock assessment. Quadrant colors denoting stock status.

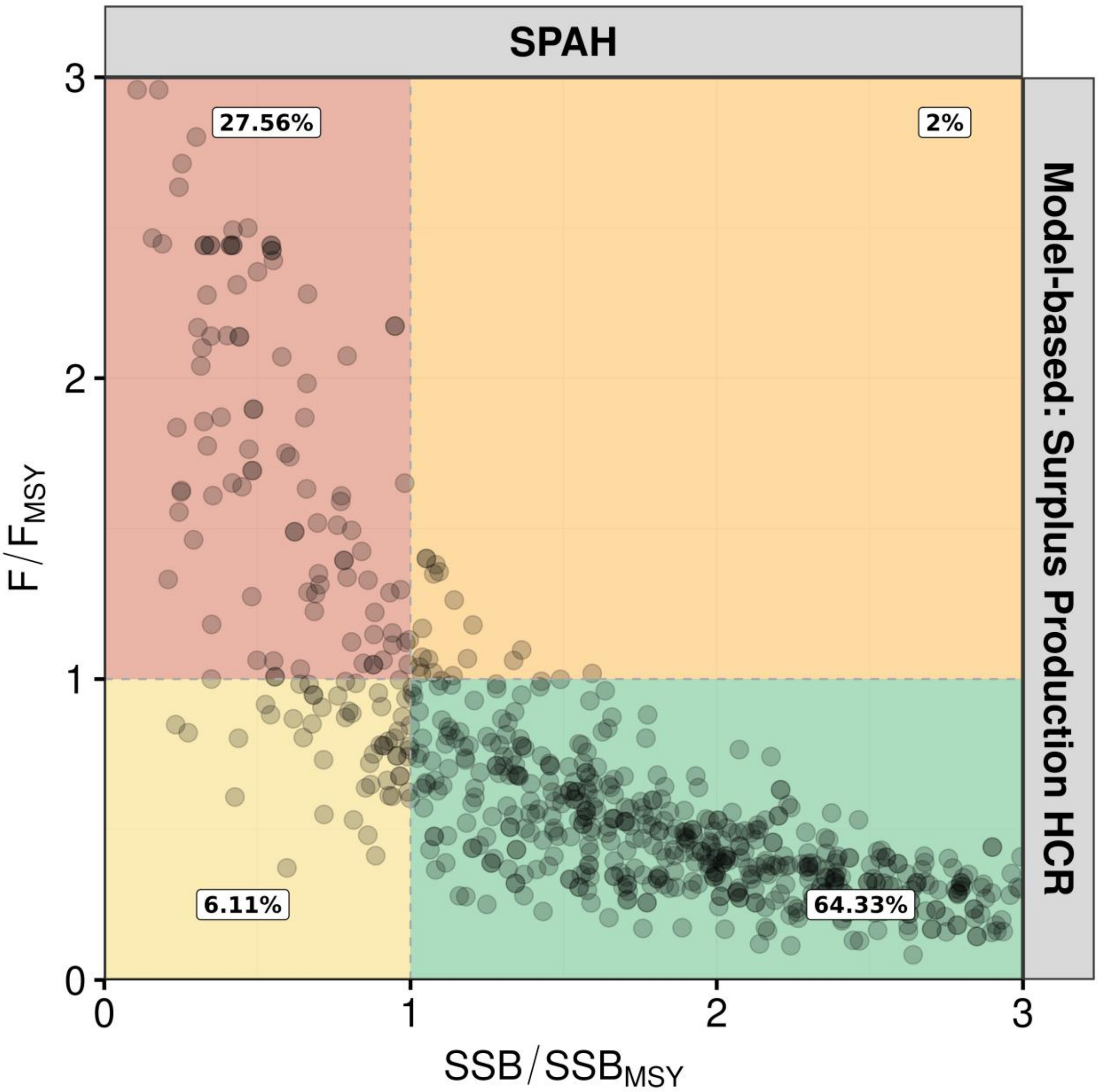

Figure 28. Kobe plot summarizing the distribution of stock status outcomes in 2055 for western Atlantic skipjack tuna under the SPAH management procedure. Each point corresponds to a simulated trajectory for the last projected year across uncertainty grid defined in the last stock assessment. Quadrant colors denoting stock status.