SCRS/2021/161 Collect. Vol. Sci. Pap. ICCAT, 78(7): 310-324 (2021)

EVALUATION OF THE PERFORMANCE OF SOME CANDIDATE MANAGEMENT PROCEDURES TO PRIORITIZE THE KEY UNCERTAINTIES IN THE NORTH ATLANTIC SWORDFISH OPERATING MODELS

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SUMMARY

The North Atlantic swordfish MSE has an operating model (OM) uncertainty grid with 6 axes of uncertainty, each with 2 to 3 levels. A recent analysis found a potential issue with the size composition data used to condition the OMs. A preliminarily attempt to address this issue resulted in the addition of another axis of uncertainty, doubling the grid to 432 OMs. This analysis evaluated the performance of 4 cMPs across these uncertainties to determine which were most consequential for the performance and selection of the cMPs. The results indicate that the 3 levels of natural mortality and 3 levels of steepness have the biggest impact on cMP performance. The inclusion of the environmental covariate had almost no impact on the OM conditioning or the performance of the cMPs. A further analysis evaluated the impact of 6 additional uncertainty scenarios, and found that implementation error, data lag, and patterns in recruitment deviations were most consequential for cMP performance. The Swordfish Species Group is recommended to discuss appropriate assumptions for these uncertainties to be included in the Reference OMs.

RÉSUMÉ

La MSE de l'espadon de l'Atlantique Nord compte une grille d'incertitude du modèle opérationnel (OM) avec 6 axes d'incertitude, ayant chacun 2 à 3 niveaux. Une analyse récente a fait apparaître un problème potentiel avec les données de composition des tailles utilisées pour conditionner les OM. Une tentative préliminaire pour résoudre ce problème a abouti à l'ajout d'un autre axe d'incertitude, doublant la grille à 432 OM. Cette analyse a évalué les performances de 4 CMP à travers ces incertitudes afin de déterminer celles qui étaient les plus significatives pour les performances et la sélection des CMP. Les résultats indiquent que les 3 niveaux de mortalité naturelle et les 3 niveaux de pente ont le plus grand impact sur les performances des CMP. L'inclusion de la covariable environnementale n'a pratiquement aucun impact sur le conditionnement des OM ou sur la performance des CMP. Une autre analyse a permis d'évaluer l'impact de six scénarios d'incertitude supplémentaires et a fait apparaître que les erreurs de mise en œuvre, les décalages dans les données et les schémas d'écart du recrutement avaient la plus grande influence sur les performances des CMP. Il est recommandé au Groupe d'espèces sur l'espadon de discuter des hypothèses appropriées pour ces incertitudes à inclure dans les OM de référence.

RESUMEN

LA MSE para el pez espada del Atlántico norte tiene una matriz de incertidumbre de modelos operativos con 6 ejes de incertidumbre, cada uno con 2 a 3 niveles. Un análisis reciente halló un posible problema con los datos de composición por tallas utilizados para condicionar los OM. Un intento preliminar de solucionar este tema tuvo como resultado el añadido de otro eje de incertidumbre, doblando la matriz hasta 432 OM. Este análisis evaluó el desempeño de 4 cMP entre las incertidumbres para determinar cuáles eran los más relevantes para el desempeño y la selección de los cMP. Los resultados indican que los 3 niveles de mortalidad natural y los 3 niveles de inclinación son los que mayor impacto tienen en el desempeño de los cMP. La inclusión de la covariable medioambiental casi no tenía impacto en el condicionamiento del OM

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o el desempeño de los cMP. Un análisis posterior evaluó el impacto de 6 escenarios de incertidumbre adicionales, y halló que el error de implementación, el desfase en los datos y los patrones en las desviaciones del reclutamiento eran más relevantes para el desempeño de los cMP. Se recomienda al Grupo de especies de pez espada que discuta los supuestos adecuados para estas incertidumbres con el fin de incluirlas en los OM de referencia.

KEYWORDS

Management Strategy Evaluation, simulation, performance metrics, candidate management procedures

1 Introduction

Management strategy evaluation (MSE) was developed as a transparent and objective method for evaluating the performance of candidate management procedures (cMPs) against pre-defined performance metrics, and is now widely recommend as best practice for selecting appropriate modes of management for a fishery (Butterworth 2007; Punt *et a*l. 2016). A primary advantage of the MSE approach is the ability to evaluate how the performance of cMPs is affected by uncertainty in the knowledge of the system dynamics and the conditions that the system will experience in the future.

A central component of the MSE approach is the development of a suite of operating models (OMs) that describe alternative hypotheses of the system dynamics. Over the last few years, the Swordfish Species Working Group (hereafter Group) has developed and refined an operating model uncertainty grid that spans the range of uncertainties in the North Atlantic swordfish fishery (Hordyk, Schirripa, and Rosa 2021). The current uncertainty grid includes six axes of uncertainty, each with two or three levels, resulting in a grid with 216 OMs (**Table 1**). Recently the Group identified a potential issue with some of the size composition data that was used in the OM conditioning, where the length frequency data for some fleets appeared to have an unexplained shift to smaller size classes immediately after the introduction of the minimum size regulation in 1993 (Hordyk, Schirripa, and Rosa 2021). This potential issue is currently being investigated by the Secretariat and the contracting parties that are responsible for the data preparation. In the meantime, while the issue is still unresolved, the uncertainty regarding the size composition data can be considered as another axis of uncertainty, resulting in doubling the size of the uncertainty grid to 432 OMs.

In addition to the uncertainties in the assumed values of biological parameters (**Table 1**), the Group has also identified six other uncertainties to consider when evaluating the performance of the cMPs, namely:

1. Alternative assumptions regarding the spatial structure of the stock;
2. Cyclic trends or regime shifts in recruitment;
3. Effect of the minimum size recommendation and assumptions of discard mortality;
4. Future increases in catchability;
5. Implementation error in the total allowable catch (TAC);
6. Lags in data available to the cMPs.

The large number of operating models and the additional uncertainty scenarios can make interpretation of the MSE results difficult, as stakeholders need to examine the predicted cMP performance in several hundred operating models.

Operating models are typically first examined to identify any that are poor or implausible descriptions of the fishery dynamics (often termed ‘red-faced tests’), which can then be down-weighted or removed from the grid. The remaining OMs can then be split into two groups, a core group of OMs, commonly referred to as Reference OMs, that span that core uncertainties and are most consequential in terms of the selection of an appropriate cMP, and the remaining OMs into a set of Robustness OMs. This paper describes an approach to evaluate which uncertainties in the OM uncertainty grid are most consequential for the selection of cMPs; that is, which uncertainties most affect the performance of the cMPs.

First, the estimated stock status from the fitted operating models are examined to identify any OMs that are considered poor representations of the fishery dynamics. Next, four cMPs (two empirical index-target methods and two versions of a surplus production stock assessment model) are evaluated across the 432 OMs, and pair-wise comparisons across the levels in each axis of uncertainty are used to determine which axes and levels are most consequential in terms of cMP performance. A smaller set of OMs that include the most consequential axes of uncertainty are then evaluated for the 6 additional uncertainties described above, and the results used to rank these uncertainties in terms of importance in cMP performance.

The results from this analysis can be used to create a set of small Reference OMs that span the uncertainties that matter most for cMP selection, and to define the baseline assumptions of the additional uncertainties that can be evaluated with Robustness OMs.

2 Methods

2.1 MSE Framework

The closed-loop simulation modelling was conducted with the custom SWOMSE R package, available in the ICCAT GitHub repository (https://github.com/ICCAT/nswo-mse), using the openMSE modelling framework as the primary dependency (Hordyk, Huynh, and Carruthers 2021). A full description of the current specifications of the swordfish MSE is available in the Trial Specifications document (https://iccat.github.io/nswo-mse/TS/Trial_Specs.html).

The Group has proposed a management schedule for swordfish that includes a 3-year management cycle, with the TAC remaining constant in between the management advice updates (**Table 2**).

2.2 Performance Metrics

The following performance metrics are currently being used for the swordfish MSE:

1. Safety: the probability the spawning biomass (SB) < SB_{lim} must be less than 5-10%, where SB_{lim} is defined as $0.4SB_{MSY}$;
2. Stock Status: the probability of occurring in the green quadrant of the Kobe matrix (SB/SB_{MSY}>1 and F/F_{MSY} <1), with an acceptable range of 50-60%;
3. Stability: average annual variability in yield in the range of 15-25%, with the higher variability allowed if the stock is in a declined state, and lower variability if the stock is in a healthy state;
4. Yield: maximize the average yield while meeting the other performance objectives.

The performance metrics are calculated for two time periods: Short – the first 10 years of the projection period, and Medium – years 11 – 30 of the projection period.

For the purposes of evaluating the impact of the OM uncertainties on cMP selection, in this paper we focus on the performance metrics for the Medium time period. The results for all performance metrics are available in the updated Shiny app in the SWOMSE package (accessed with Shiny() after loading the SWOMSE package).

2.3 Management Procedures

The Group has not finalized the development of the cMPs for the swordfish fishery. For this analysis, four cMPs were selected that span a range of management methods that might be applied to this fishery. The first two cMPs were two versions of an empirical harvest control rule that uses the combined index to iteratively adjust the TAC (Itarget1 and Itarget4; Geromont and Butterworth 2015). The second set of cMPs used a surplus production assessment model with the TAC set at the estimated FMSY and 75% of the estimated FMSY (SP_MSY and SP_75MSY; Huynh, Carruthers, and Hordyk 2021).

An MSE was run for each of the 432 operating models, with 48 simulations with stochastic recruitment and observation processes in each MSE run.

2.4 Evaluation of Uncertainty Grid on Performance of cMPs

The four cMPs were evaluated in each of the 432 operating models, spanning the 6 axes of uncertainty in the OM grid (**Table 1**) and the two versions of the length composition data. The results are summarized as boxplots showing the distribution of the median performance metric values for each level in the 7 axes of uncertainty. Axes which show a large difference in the median performance metrics across the levels are most consequential in terms of cMP performance.

2.5 Evaluation of Additional Uncertainties of Reference OMs

Based on the results from the analysis of the uncertainty grid, a smaller grid of 9 operating models was constructed from the three levels of M and h (the two axes found to be most consequential) and assuming the following levels of the remaining axes of uncertainty:

1. size: original unadjusted size composition data;
2. sigmaR: highest level (0.6);
3. lambda: equal weighting of CPUE and length composition data (lambda=1);
4. catchability: assumed 1% annual increase in catchability for historical period; and
5. env: include the environmental covariate

This set of 9 operating models was used to evaluate the relative importance of the 6 additional uncertainty scenarios.

The uncertainty OMs were developed by modifying these OMs to include the assumptions considered in the additional uncertainty scenarios (**Table 3**).

Scenario 1 modified the operating model to include 2 spatial areas of equal size, with age-based movement and a 90% probability of remaining in an area between years. Scenario 2 added a sinusoidal pattern to the recruitment deviations in the projection years, with an amplitude of 60-80% and a period of 20 – 25 years. Scenario 3 considered the consequences of removing the size limit so that all caught fish are retained. Scenario 4 modeled a 1% average annual increase in catchability, and assumed that this was not accounted for when generating the index of abundance. Scenario 5 added implementation error to the management advice so that the catches were 40% higher than the TAC. Scenario 6 added a 5-year lag to data provided to the cMPs (default assumption in all other OMs is that data is available from the previous year).

The results were summarized by comparing the median Status and Yield performance metrics of the uncertainty OMs against the results from the reference OMs.

3 Results

3.1 Evaluation of Uncertainties on Estimated Stock Status

Figure 1 shows the distributions of the estimated stock status (SB/SB_{MSY}) in the terminal year for each level in the axes of uncertainty, color coded by the three levels of weighting for the CPUE data (lambda). This result reveals that down-weighting the CPUE data (lamba=0.05) resulted in the estimated stock status considerably higher than the SB/SB_{MSY} ~ 1 reported in the previous stock assessment (Anon. 2017), especially when natural mortality was in the highest level (**Figure 1)**. This result may suggest that using the length data alone in the OM conditioning is not appropriate as it results in implausible predictions of the stock dynamics. Ignoring the CPUE data in the OM conditioning also raises another important issue, where the indices of abundance are not considered suitable for the OM conditioning but are used for setting management advice.

Down-weighting the length composition data (lambda=20) tended to result in a more pessimistic estimate of the predicted stock status compared to equal weighting (lambda=1) and down-weighting the CPUE data (lambda=0.05). However, there was less variance in the estimates and the stock was estimated to be a very high levels in fewer OMs (**Figure 1**).

The two versions of the size composition data did not have a large impact on the predicted stock status, except when CPUE were down-weighted (lambda=0.05) and the adjusted size composition data was used (**Figure 1**). Other than the CPUE weighting, the factors that most impacted the predicted stock status were the three levels of the natural mortality rate (M), three levels of steepness (h), and the assumptions regarding catchability in the historical period (catchability; **Figure 1**).

3.2 Evaluation of Uncertainty Grid on Performance of cMPs

The Safety performance metric was greater than 95% across all the axes of uncertainty (**Figure 2**). This result suggests that the axes of uncertainty do not have a significant impact on the ability of the cMPs to maintain the stock above the limit reference point of $0.4SB_{MSY}$.

The axes of uncertainty had a greater impact on the Status performance metric, especially for M, sigmaR, h, lambda, and catchability (**Figure 3**). The OMs conditioned with the adjusted size data tended to have a higher probability of remaining in the green quadrant of the Kobe matrix, although almost all OMs had greater than 60% probability for the Medium timeframe (**Figure 3**). The performance of the cMPs was almost identical across the two levels of the environmental covariate (**Figure 3**).

The median values of the Stability performance metric were less than 25% in almost all cases, suggesting that this performance metric is not significantly impacted by the uncertainties in the OMs (**Figure 4**).

Figure 5 shows the maximum difference in the median values of the performance metrics for the four cMPs and across the 7 axes of uncertainty. This result highlights that the axes relating to M and h are most consequential in terms of cMP performance, especially related to the Status performance metric and the cMPs that use the surplus production stock assessment model. The two levels for catchability coefficient had the third largest impact on cMP performance, while the inclusion of the environmental covariate had almost no impact (**Figure 5**).

3.3 Evaluation of Additional Uncertainties of Reference OMs

Compared to the base case model with no spatial structure, the OM with movement by age across the two areas resulted in lower probability of the stock being in the green quadrant of the Kobe matrix, especially for the cMPs that included the surplus production model (**Figure 6**). For example, the SP_75MSY cMP had >50% probability for the Status performance metric in the base case OM, but <50% probability when the OM included spatial structure.

A similar result was observed for the scenario where a cyclic pattern in recruitment deviations was included, with all cMPs have lowing probability and median yield compared to the base case OM (**Figure 6**).

Removing the size limit so that all selected fish are retained had the opposite outcome, with increased probability for the Status performance metric and higher median yield for all cMPs (**Figure 6**). This result may appear counter-intuitive, but can be explained by the fact that the actual removals from the fishery are lower when the size limit is removed, as only retained fish count toward the TAC and discarding means the removals are higher than the TAC when the size limit is in place. It should be noted, however, that the scenario where the size limit is removed assumes there is no discarding of fish for other reasons (e.g., high-grading).

A 1% increase in catchability in the projection period resulted in higher average catches but slightly lower probability for the Status performance metric for all cMPs (**Figure 6**). Likewise, the addition of implementation error in the prescribed TACs resulted in higher catches and a corresponding decrease in the Status performance metric for all cMPs except Itarget4 (**Figure 6**). Finally, lagging the data to the cMPs by 5 years resulted in poorer performance in both Status performance metric and yield (**Figure 6**).

Figure 7 shows the median difference in the Status performance metric for the 6 uncertainty scenarios and across the 9 operating models. This result shows that the Movement by Age scenario had the greatest negative impact on the Status performance metric when M was in the highest level, but resulted in slightly better performance in the other operating models (**Figure 7**). This suggests that the interaction between the movement pattern and the dynamics of the shorter-lived population results in poorer performance of the cMPs.

The Cyclic Recruitment Deviations scenario resulted in a marked decrease in performance of the Status performance metric in all OMs except when M=0.1 and steepness was in the lower levels (**Figure 7**). The Implementation Error scenario had the similar performance, resulting in lower probability of the Status performance metric in all OMs.

In summary, these results suggest the spatial movement patterns are only an important factor in cMP performance in OMs where natural mortality is high. In general, however, the cyclic pattern in recruitment deviations and implementation error in the TAC advice are most consequential for cMP performance. Finally, while the Data Lag scenario ranked close to last in terms of impact on the Status performance metric, it did result in a decrease across all OMs, which indicates that the assumption of the data lag should be considered for the operating models used to evaluate the cMPs.

4 Discussion

The two axes with three levels of M and h respectively had the greatest overall impact on both the estimated stock status and the performance of the cMPs, suggesting that these uncertainties are most consequential for the performance of the cMPs. However, the biological plausibility of the M and h levels should still be evaluated. Selecting one level from each of the remaining axes of uncertainty allows the construction of a smaller set of Reference OMs that can be used to evaluate the cMP performance.

For example, the inclusion of the environmental covariate in the OM conditioning had almost no impact on either the estimated stock status or the performance of the cMPs, and therefore this axis of uncertainty could be eliminated or moved to the Robustness OMs. In general, the adjustment of the size composition data resulted in slightly more optimistic predictions of the stock status, but overall the impact was relatively minor. The original size composition data resulted in slightly lower probabilities for the Status performance metric, which suggests that, while there remains uncertainty on the size composition data, it would be more prudent to use the unadjusted data (**Figure 3**).

The higher level of recruitment variability resulted in moderately lower estimates of stock status and a lower probability for the Status performance metric, indicating that the OMs with higher recruitment variability are more consequential for cMP selection (**Figure 3)**. Similarly, the inclusion of a 1% annual increase in catchability resulted in more variable performance of the cMPs (**Figure 3**).

Finally, the down-weighting of the CPUE indices raises an issue where the indices are not trusted for OM conditioning but are used to set management advice. Down-weighting the length composition data (lambda=20) resulted in greater variability in the Status performance metric and generally a lower estimate of stock status (**Figure 1**). However, these OMs do not use the length composition data at all in the OM conditioning, which may not be considered a reasonable assumption given this data was used in the stock assessment and has been proposed to use in cMPs. This suggests that the levels of the CPUE/length composition weighting (lambda) should be revisited to ensure they are considered plausible.

In terms of the 6 additional uncertainty scenarios, the results from this analysis suggests that the assumptions related to spatial structure and movement pattern are relatively inconsequential for the performance of the cMPs except in cases where natural mortality is assumed to be high. This suggests that alternative assumptions related to spatial structure and movement pattern could be evaluated in robustness tests, but are not expected to have a great impact on the cMP performance for the Reference grid.

Cyclic patterns in recruitment deviations had a larger impact of the performance of the cMPs. This highlights that the baseline assumptions for the recruitment deviations (variance and any cyclic patterns) should be considered for the Reference grid. As discussed above, given that the cMP performance is more variable at higher levels of recruitment variability, one approach could be to use this assumption in the Reference grid, and develop Robustness OMs to consider alternative scenarios for patterns in recruitment deviations.

The addition of implementation error in the TAC recommendations negatively impacted the performance of the cMPs. The current OM grid assumes no implementation in the TACs. However, this result highlights that this assumption should be considered by the Group.

Similarly, while the addition of a data lag had relatively minor impact on the Status performance metric compared to the other uncertainty scenarios, it did result in lower probabilities for all cMPs. The current assumption in the MSE is that the data provided to the cMPs is available from the previous year. However, this is unlikely to be true for the swordfish fishery, as CPUE indices and length composition data often take time to prepare. Therefore, the Group should also consider this assumption to determine the appropriate data lag to use in the evaluation of the cMPs.

5 Acknowledgements

The members of the Swordfish Species Working Group are thanked for their contribution to this work. This work was carried out under the provision of the ICCAT Science Envelope and the ICCAT – EU Grant Agreement – Strengthening the scientific basis for decision-making in ICCAT. The contents of this paper do not necessarily reflect the point of view of ICCAT or other funders and in no ways anticipate ICCAT future policy in this area.

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Table 1. The six axes of uncertainty (columns) and the levels for each factor (rows) in the operating model (OM) uncertainty grid for the North Atlantic Swordfish MSE. The full factorial design of these factors and levels results in a grid of 216 OMs.

Natural Mortality (M)	**Recruitment variability (sigmaR)**	**Steepness (h)**	**CPUE Lambda**	**1% Annual Increase in Catchability**	**Environmental Covariate**
0.1	0.2	0.60	0.05	FALSE	FALSE
0.2	0.6	0.75	1	TRUE	TRUE
0.3		0.90	20		

Table 2. The proposed management schedule for the North Atlantic swordfish fishery, with the management procedure applied every 3rd year and a stock assessment every 6th year. The operating models will only be re-conditioned if there is strong evidence that reconditioning is necessary. The exceptional circumstances (EC) protocols are still in developed and are expected to be applied every time the fishery data is updated.

Year	Stock assessment	Recondition OMs*	MP run	MP advice implemented	Exceptional circumstances evaluated	Combined index (or other dependent indices)	Other CPUEs	Use/review catch	EC indicators
0	?		X		X	X	X	X	X
1				X	X				X
2					X				X
3			X		X	X		X	X
4				X	X				X
5					X				X
6	X		X		X	X	X	X	X

Table 3. The six additional uncertainty scenarios evaluated for smaller grid of nine operating models (three levels of natural mortality and three levels of steepness).

	Uncertainty Scenario	**Description**
1	Movement by Age	Two areas of equal size with age-based ontogenetic movement with 90% probability of remaining in area (spatial scenario 12 in Hordyk 2020).
2	Cyclic Recruitment Deviations	Additional sinusoidal pattern in recruitment deviations in projection years, with amplitude of 60-80% and time period of 20 – 25 years (recruitment scenario 4 in Hordyk 2020).
3	Remove Size Limit	Removal of the size regulation in the projection years so that all caught fish are retained.
4	Increasing Catchability	1% annual increase in catchability in the projection years (catchability scenario 1 in Hordyk 2020).
5	Implementation Error	Catches are 40% higher than the TAC (implementation error scenario 3 in Hordyk 2020).
6	Data Lag	Data provided to the cMPs is lagged by 5 years.

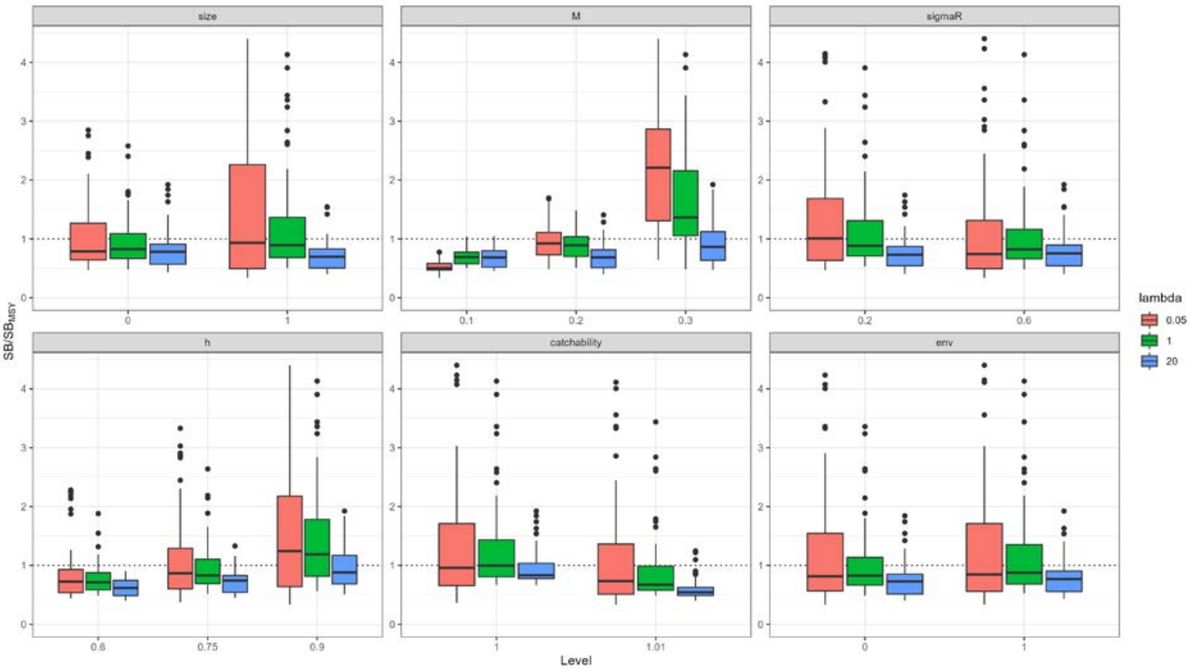

Figure 1. Boxplots of the estimated stock status (SB/SB_{MSY}) in 2017 from the conditioned operating models for the 6 axes of uncertainty in the OM grid and the two versions of the size composition data. The plots are color-coded by the three levels of the relative weighting for the CPUE data (lambda), and faceted by: size – the two versions of the size composition data (0=original, 1=adjusted); M – three levels of natural mortality; sigmaR – two levels of recruitment variance; h – three level of steepness; catchability – two levels related to the assumption of catchability in the historical period (1=no increase, 1.01=1% annual increase in catchability); and env – two levels of including the Atlantic multidecadal oscillation (AMO) in the OM conditioning (0=not included, 1=included).

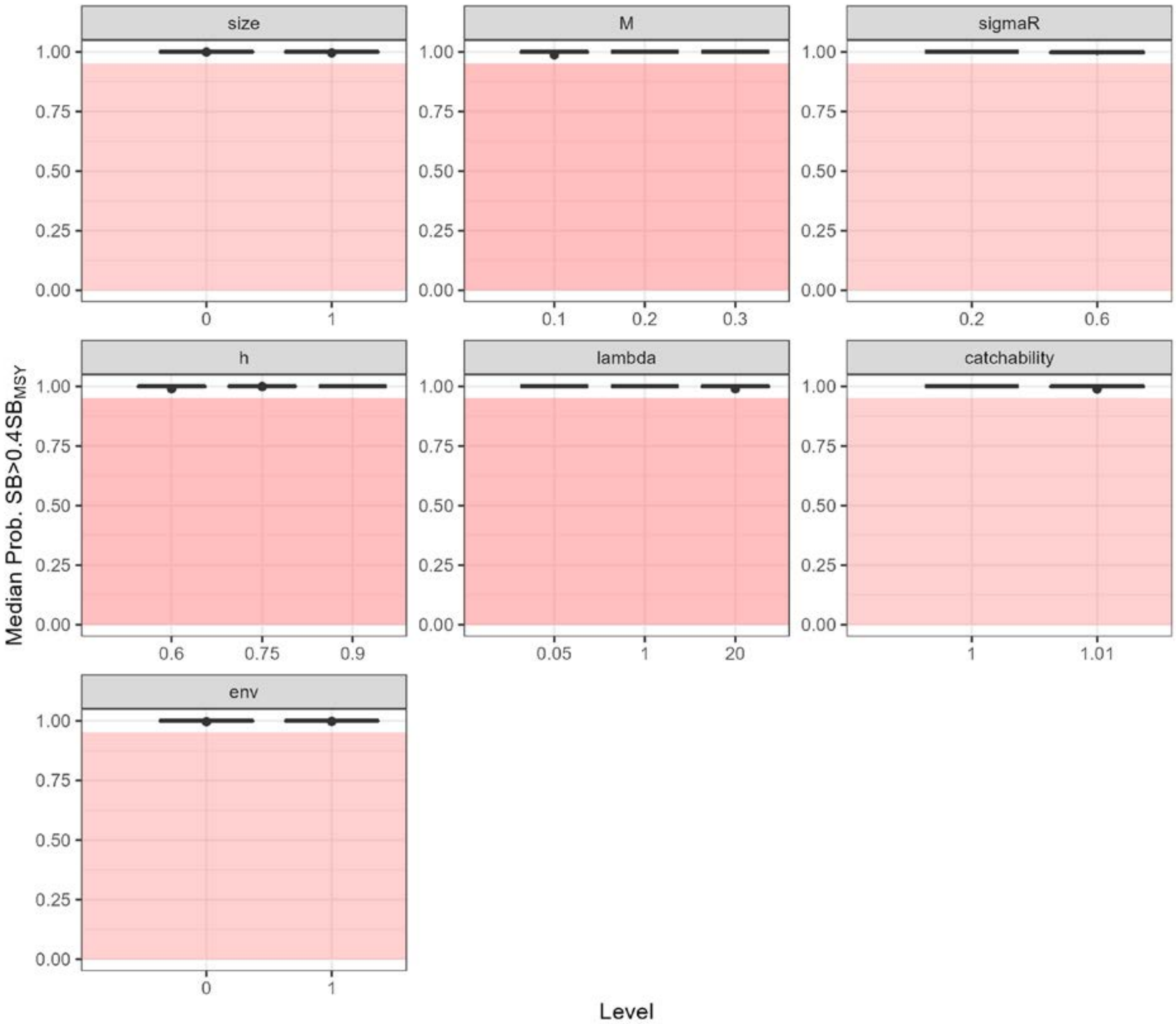

Figure 2. Median value of the Safety performance metric (Medium time-span) across the levels for the 7 axes of uncertainty: size – the two versions of the size composition data (0=original, 1=adjusted); M – three levels of natural mortality; sigmaR – two levels of recruitment variance; h – three level of steepness; lamba - the three levels of the relative weighting for the CPUE data; catchability – two levels related to the assumption of catchability in the historical period (1=no increase, 1.01=1% annual increase in catchability); and env – two levels of including the Atlantic multidecadal oscillation (AMO) in the OM conditioning (0=not included, 1=included). The red shading indicates the region where the probability is considered unacceptably low (<95%).

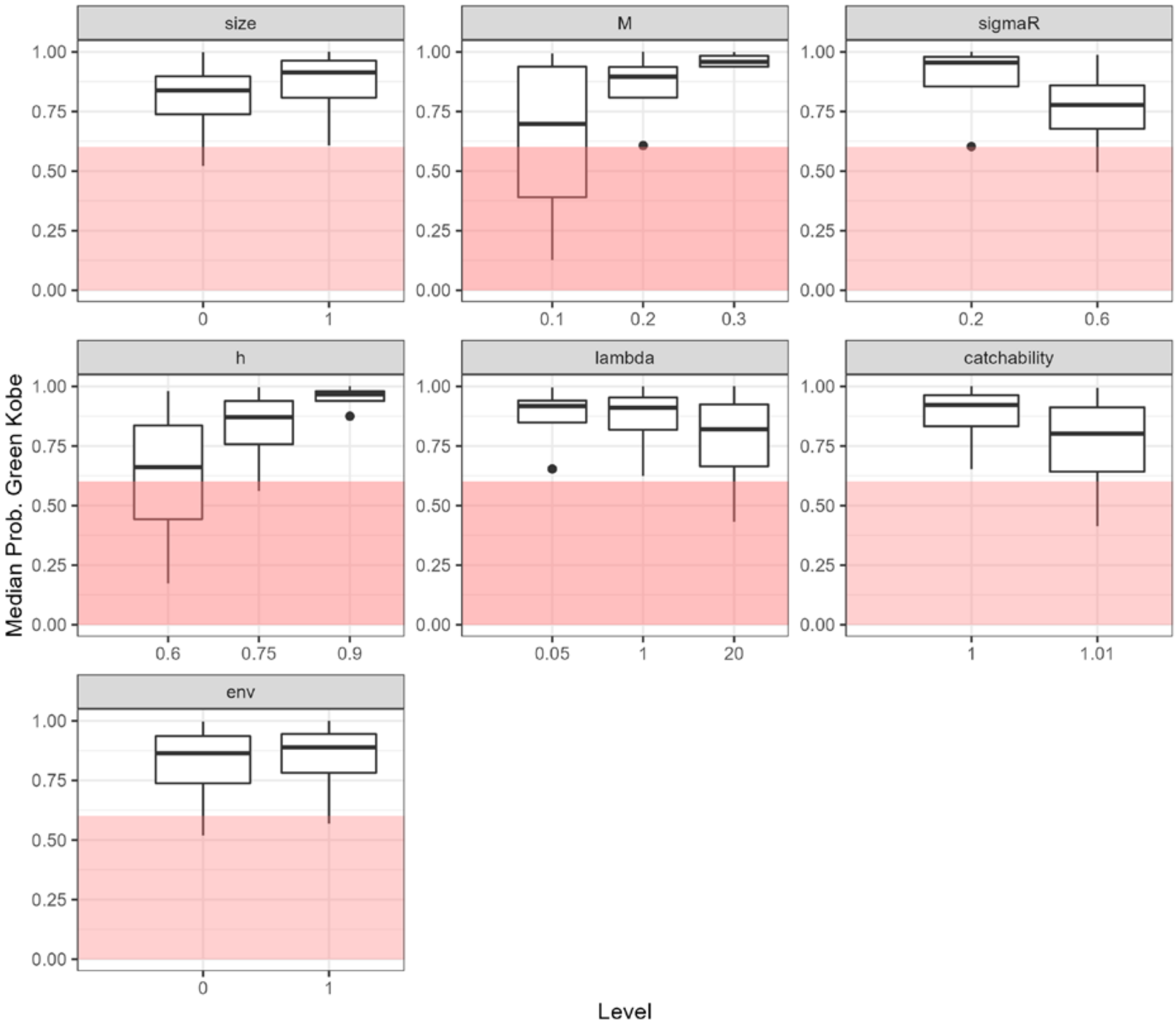

Figure 3. Median value of the Status performance metric (Medium time-span) across the levels for the 7 axes of uncertainty: size – the two versions of the size composition data (0=original, 1=adjusted); M – three levels of natural mortality; sigmaR – two levels of recruitment variance; h – three level of steepness; lamba - the three levels of the relative weighting for the CPUE data; catchability – two levels related to the assumption of catchability in the historical period (1=no increase, 1.01=1% annual increase in catchability); and env – two levels of including the Atlantic multidecadal oscillation (AMO) in the OM conditioning (0=not included, 1=included). The red shading indicates the region where the probability is considered unacceptably low (<60%).

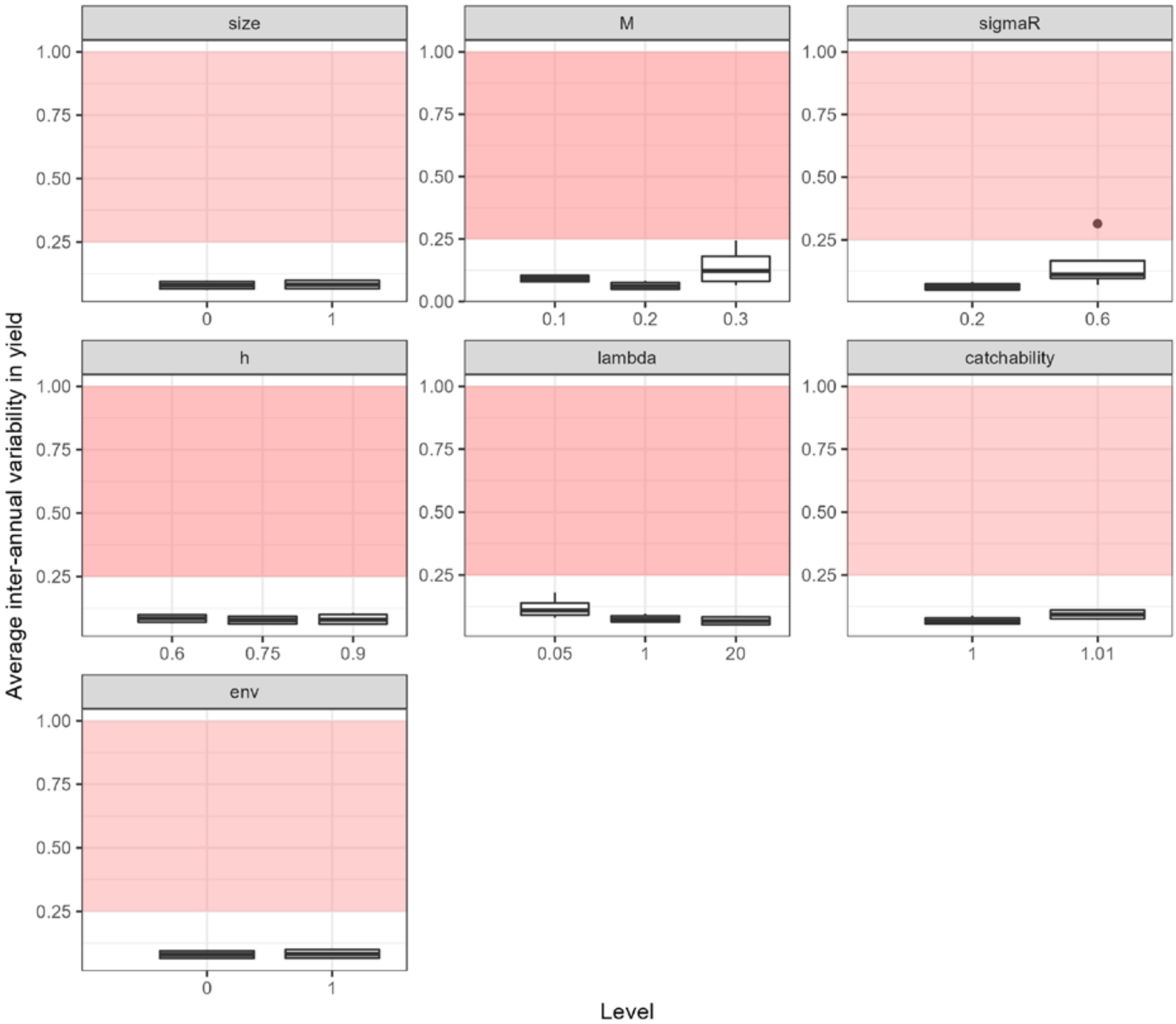

Figure 4. Median value of the Stability performance metric across the levels for the 7 axes of uncertainty: size – the two versions of the size composition data (0=original, 1=adjusted); M – three levels of natural mortality; sigmaR – two levels of recruitment variance; h – three level of steepness; lamba - the three levels of the relative weighting for the CPUE data; catchability – two levels related to the assumption of catchability in the historical period (1=no increase, 1.01=1% annual increase in catchability); and env – two levels of including the Atlantic multidecadal oscillation (AMO) in the OM conditioning (0=not included, 1=included). The red shading indicates the region where the probability is considered unacceptably low (>25%).

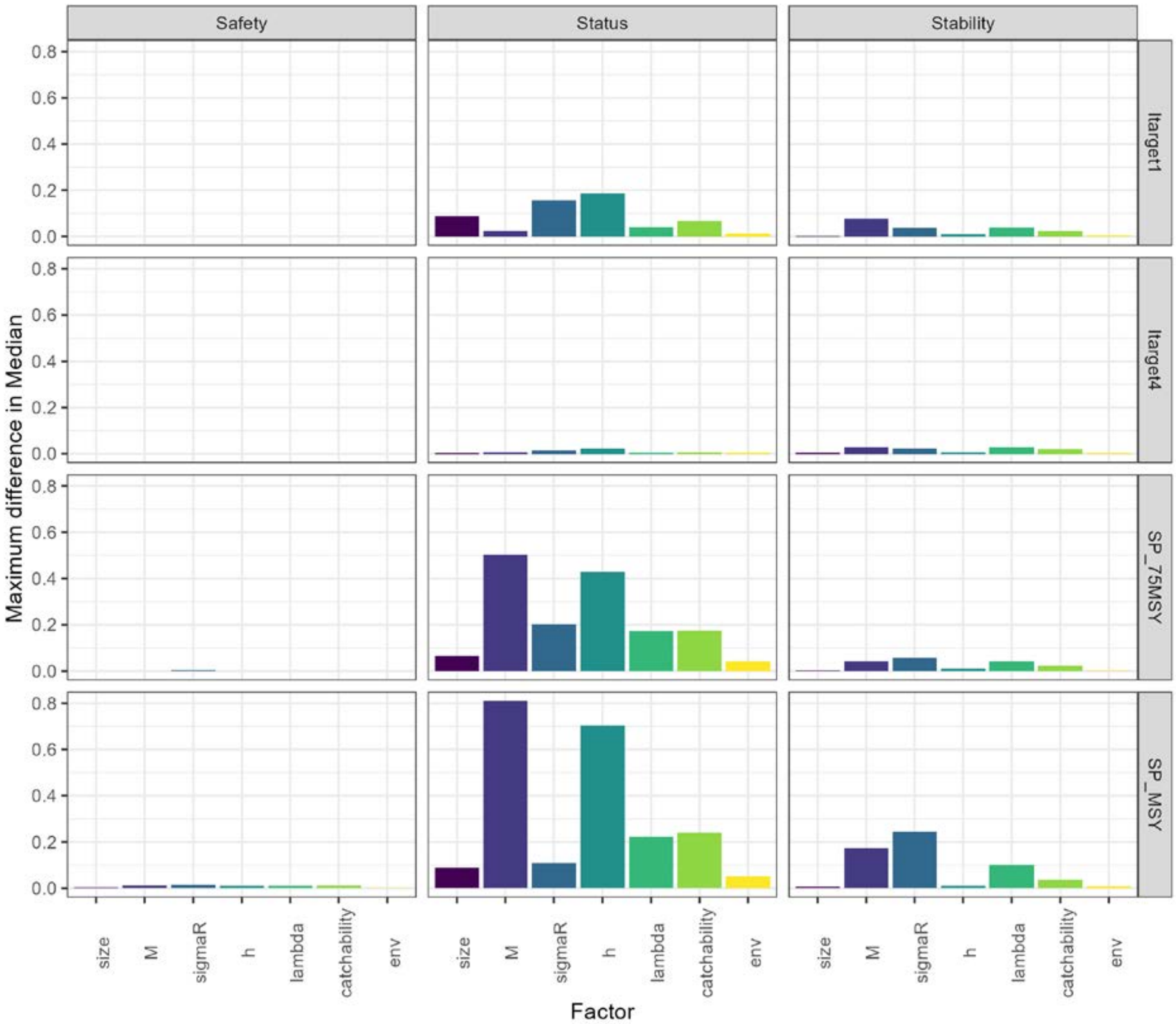

Figure 5. The maximum difference in the median values (y-axis) of the three performance metrics (columns) for the four candidate management procedures (rows) and the seven axes of uncertainty (x-axis).

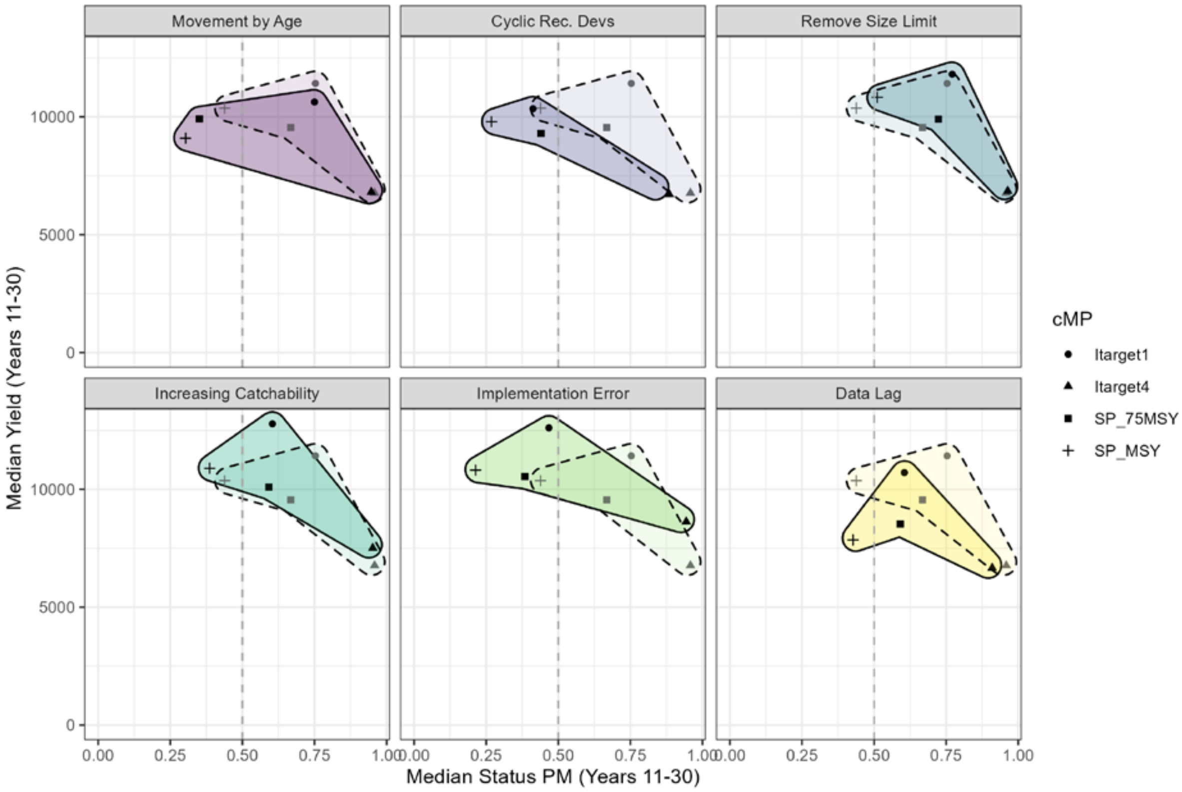

Figure 6. Trade-off plot of the median values over all nine operating models of the Status (x-axis) and Yield (y-axis) performance metrics for the four candidate management procedures (shapes) and the 6 additional uncertainty scenarios. The grey points show the results from the baseline OMs. The colored polygons are used to compare the difference in performance between the uncertainty OMs and the baseline OMs. Points (of the same shape) and polygons that are closer together indicate similar performance and less of an impact of the uncertainty scenario on the performance of the candidate management procedures.

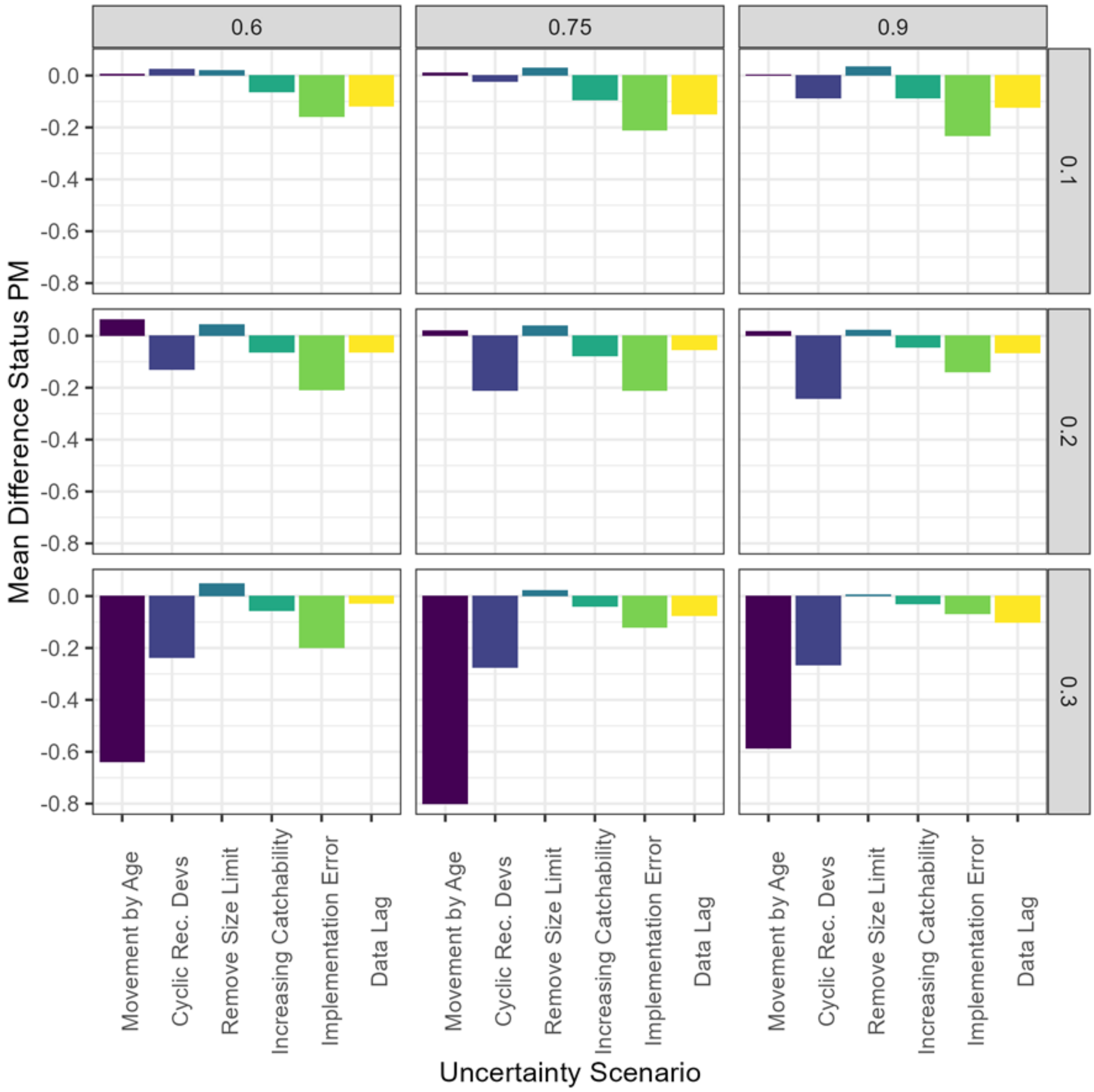

Figure 7. The mean difference in the Status performance metric (y-axis) for the six uncertainty scenarios (x-axis) faceted by the three levels of steepness (columns) and three levels of natural mortality (rows).