SCRS/2022/149 Collect. Vol. Sci. Pap. ICCAT, 79(2): 770-781 (2022)

SUMMARY OF OPERATING MODEL DIAGNOSTICS AND EVALUATION OF THE UNCERTAINTY AXES BASED ON THE 2022 STOCK ASSESSMENT OF NORTH ATLANTIC SWORDFISH

Adrian Hordyk[1], Michael Schirripa[2], and Kyle Gillespie[3]

SUMMARY

A new stock assessment of the North Atlantic Swordfish fishery was conducted in 2022. The operating models (OMs) used for the management strategy evaluation (MSE) of the swordfish fishery have been updated based on this new assessment. The OM uncertainty grid was revised based on analyses of the new models, and the operating models classified in groups spanning the key assumptions and uncertainties in the system. This paper reports the process for revising the uncertainty grid, re-conditioning the new OMs, validating the models, and summarizes the predicted stock dynamics across the OMs. The results reveal that the three levels of natural mortality (M) and three levels of steepness (h) have the largest impact on the predicted stock dynamics. Therefore, the nine OMs spanning these uncertainties are considered the Reference OMs. Additional Robustness OMs were developed to span additional uncertainties, including increased recruitment variability, removing the length composition data from the model, and assuming a 1% average annual increase in historical catchability for the indices of abundance. These OMs will be used to evaluate the performance of candidate management procedures.

RÉSUMÉ

Une nouvelle évaluation de la pêcherie d'espadon de l'Atlantique Nord a été réalisée en 2022. Les modèles opérationnels (OM) utilisés pour l'évaluation de la stratégie de gestion (MSE) de la pêcherie d'espadon ont été actualisés sur la base de cette nouvelle évaluation. La grille d'incertitude des OM a été révisée d'après les analyses des nouveaux modèles et les modèles opérationnels ont été classés en groupes couvrant les principales hypothèses et incertitudes du système. Ce document fait état du processus de révision de la grille d'incertitude, de reconditionnement des nouveaux OM, de la validation des modèles et résume la dynamique du stock prédite dans les OM. Les résultats révèlent que les trois niveaux de mortalité naturelle (M) et les trois niveaux de pente (h) ont le plus fort impact sur la dynamique du stock prédite. Par conséquent, les neuf OM couvrant ces incertitudes sont considérés comme les OM de référence. Des OM de robustesse additionnels ont été développés pour couvrir des incertitudes supplémentaires, incluant l'augmentation de la variabilité du recrutement, en supprimant les données de composition par taille du modèle et en postulant une augmentation annuelle moyenne de 1% de la capturabilité historique pour les indices d'abondance. Ces OM seront utilisés pour évaluer la performance des procédures de gestion potentielles.

RESUMEN

En 2022 se realizó una nueva evaluación de la pesquería de pez espada del Atlántico norte. Los modelos operativos (OM) utilizados para la evaluación de estrategias de ordenación (MSE) de la pesquería de pez espada se han actualizado sobre la base de esta nueva evaluación. La matriz de incertidumbres de los OM se revisó a partir de los análisis de los nuevos modelos, y los modelos operativos se clasificaron en grupos que abarcaban los principales supuestos e incertidumbres del sistema. Este documento informa sobre el proceso de revisión de la matriz de incertidumbre, el recondicionamiento de los nuevos OM, la validación de los modelos y el resumen de la dinámica prevista del stock en los OM. Los resultados revelan que los tres niveles de mortalidad natural (M) y los tres niveles de inclinación (h) son los que más influyen en la

[1] Blue Matter Science Ltd, 2150 Bridgman Avenue, North Vancouver, BC, CANADA, V7P2T9 adrian@bluematterscience.com

[2] NOAA Fisheries, Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL, 33149 USA. Michael.schirripa@noaa.gov

[3] Fisheries and Oceans Canada, 125 Marine Science Drive, St. Andrews, NB, CANADA, E5B 0E4. Kyle.Gillespie@dfo-mpo.gc.ca

dinámica prevista del stock. Por lo tanto, los nueve OM que abarcan estas incertidumbres se consideran los OM de referencia. Se desarrollaron OM de robustez adicionales para abarcar incertidumbres adicionales, incluyendo el aumento de la variabilidad del reclutamiento, la eliminación de los datos de composición por tallas del modelo y el supuesto de un aumento medio anual del 1 % en la capturabilidad histórica para los índices de abundancia. Estos OM se utilizarán para evaluar el desempeño de los procedimientos de ordenación candidatos.

KEYWORDS

Management Strategy Evaluation, Simulation, Fishery management

1. Introduction

The North Atlantic swordfish (hereafter swordfish) fishery has been undergoing a Management Strategy Evaluation (MSE) process since 2019. The Swordfish Species Working Group (hereafter the Group) developed an operating model (OM) uncertainty grid to span the key uncertainties in the fishery system (**Table 1**). A full factorial design of this uncertainty grid resulted in 216 OMs, which were conditioned with the Stock Synthesis 3 (SS3) assessment software (Methot & Wetzel, 2013) based on the 2017 assessment of the swordfish fishery (Anon., 2017). A new stock assessment was conducted in 2022 (Anon., 2022), using data up to 2020 (**Figure 1**). Subsequently, the operating models in the uncertainty grid were re-conditioned based on this updated assessment.

Based on previous analysis of the uncertainty grid conditioned on the 2017 assessment, and new analyses of the updated models, the OM uncertainty grid was subject to some minor modifications, and the OMs were classified into separate classes representing the key system assumptions and uncertainties (Reference OMs) and OMs spanning additional uncertainties (Robustness OMs).

In this paper, we summarize the work carried out to revise the uncertainty grid and re-condition the operating models based on the 2022 assessment, provide an overview of the model validation process, and report the predicted stock dynamics across the range of operating models considered in the analysis. Additional information, including detailed diagnostic reports for each OM and the Trial Specifications document detailing the assumptions and structure of the MSE framework are available on the North Atlantic Swordfish MSE homepage (https://iccat.github.io/nswo-mse/).

2. Evaluation and Revision of Uncertainty Grid

Analyses of the operating models conditioned on the 2017 assessment, and a repeat of this analyses on the models conditioned on the 2022 assessment, revealed the relative impact of the axes on uncertainty on the predicted stock dynamics and performance of some candidate management procedures (Hordyk, 2021; Hordyk et al., 2021). Based on these results, the OM uncertainty grid (**Table 1)** was revised, and the operating models were classified into groups referred to as Reference and Robustness OMs, which focused on examining the impacts of different assumptions of the fishery system (**Table 2**).

In both the 2017 and 2022 stock assessments, the catchability coefficient (*q*) for the CPUE indices of the Canada, Japan, EU-Portugal, Morocco, and the EU-Spain age-specific survey indices, was made a function of the Atlantic Multidecadal Oscillation (AMO). Including this environmental covariate resulted in a better statistical fit to these indices. The sixth axis of the uncertainty grid examined the impact of not including this environmental covariate in the stock assessment. The analyses revealed that removing the environmental covariate from the assessment model had no detectable influence on either the predicted stock dynamics (Hordyk et al., 2021) or the performance of candidate management procedures (Hordyk, 2021). Therefore, the environmental covariate was included in all models in the OM grid. Further examination of the impact of changing environmental conditions on the performance of the candidate management procedures may be examined in additional robustness tests (see below for more details).

2.1 Reference Set Operating Models

Previous analyses of the OM uncertainty grid based on the 2017 assessment (**Table 1**) revealed that the three levels of natural mortality (*M*) and steepness (*h*) had the largest impact on the predicted stock dynamics and are the most important axes of uncertainty in the OM grid (Hordyk et al., 2021). Therefore, a set of nine operating models spanning the range of assumed *M* and *h* values were identified as the primary uncertainties and are referred to as the Reference OMs (**Table 2**). These OMs share the same assumptions as the 2022 stock assessment, with the exception of systematic changes in the assumed values of *M* and *h.* The eighth operating model in this Reference set has parameters that are very similar to the 2022 assessment (referred to here as the Base Case OM; **Table 2**).

2.2 Robustness Operating Models

2.2.1 R1. Higher sigmaR

The recruitment deviations in the assessment model are estimated via a penalized term in the likelihood function, with an assumed value for the standard deviation of the log-normally distributed deviations (σ_R; sigmaR; **Table 1**). Both the 2017 and 2022 stock assessments assumed $\sigma_R = 0.2$. Previous analyses revealed that the second level of recruitment variability (σ_R=0.6) had a minor impact on the predicted stock dynamics (Hordyk et al., 2021), but did influence the relative performance of candidate management procedures (Hordyk, 2021).

This second level is now treated as a robustness test called R1. Higher sigmaR (**Table 2**). This set of nine operating models had the same structure and assumptions as the Reference Set, with the exception that the recruitment variability was assumed to higher (σ_R=0.6; **Table 2**).

2.2.2 R2. Remove CAL

The fourth axis of uncertainty was intended to evaluate the effect of alternative relative weightings of the length composition data and the indices of abundance (CPUE Lambda; **Table 1**). The three levels reflect a complete down-weighting of the indices of abundance (0.05; effectively only fitting the model to the length composition data), leaving the relative weighting of the two data sources unchanged from that used in the assessment (1), and up-weighting the indices of abundance so the model ignores the length composition data (20). This was done because of apparent conflicting signals between the length composition data and some of the indices of abundance, and the high computation demand of conducting the recommended iterative re-weighting procedure across all OMs in the grid (Francis, 2011).

However, this iterative re-weighting procedure has now been conducted for the new operating models based on the 2022 assessment, and therefore this axis of uncertainty has been renamed to Include CAL, and modified to two levels: 1) TRUE: fit the assessment to both length and CPUE data and conduct the iterative re-weighting procedure, and 2) FALSE: only fit the model to the CPUE data. This second level is now treated as a robustness test named R2. Remove CAL, where the nine operating models share the same assumptions as the Reference Set, except that the fits to the length composition data are not included in the total likelihood function (Include CAL = FALSE; **Table 2**).

2.2.3 R3. Increasing q

The fifth axis of uncertainty (Increasing q; **Table 1**) with the assumed average annual 1% increase in catchability (*q*) for the indices of abundance had a relatively minor influence on both the predicted stock dynamics (Hordyk et al., 2021) and the performance of candidate management procedures (Hordyk, 2021). This second level is now treated as a robustness test called R3. Increasing q, where the nine operating models share the same assumptions as the Reference Set, except that the CPUE indices were modified to assume an average annual 1% increase in catchability over the historical period (**Table 2**).

2.2.4 Additional Robustness OMs

The Group has discussed additional robustness tests, such as investigating the impact of alternative size limits and examining the potential impact of changing environmental conditions due to climate change. These will be discussed in more detail at the 2022 Species Group Meeting, and the additional

3. Conditioning New Operating Models

The 36 OMs from the Reference and Robustness were re-conditioned based on the 2022 stock assessment (Base Case; **Table 2**). Diagnostic reports were generated for each operating model and the Base Case OM. These reports are available on the North Atlantic Swordfish MSE homepage (https://iccat.github.io/nswo-mse/). An OM Summary Report, also available on the MSE homepage, was generated to summarize the model diagnostic checks and provide an overview of the predicted stock dynamics across the Reference and Robustness OMs.

This section provides a summary of these results. More details, including interactive tables and additional summary plots, are available in the OM Summary Report (https://iccat.github.io/nswo-mse/Reports/OM_Summary/2022/OM_Summary_Report.html).

3.1 Model Diagnostic Checks

Three diagnostic checks were conducted to validate the operating model conditioning process.

First, the models were checked for any estimated parameters that were within 1% of the pre-specified bounds.

Next, the models were checked for successful convergence and a sufficiently low final gradient of the objective function value. Successful convergence was identified by confirming that the Hessian matrix was invertible.

Parameters where the final gradient was greater than 0.0001 were reported and further discussion with the Group. Finally, the models were checked for high correlations (>0.95) between pairs of estimated parameters.

3.1.1 Check for Parameters Close to Bounds

Four parameters, all related to the selectivity parameters of the Canada and EU-Spain fleets, in 18 OMs were estimated within 1% of the pre-specified bounds (**Table 3**). Of these, five OMs were from the R2 set, where the length composition data was not included in the likelihood and therefore there was little information to inform the selectivity-at-length curves. Of the remaining, all except one parameter were related to the selectivity curve in the early period of the historical data, prior to the implementation of the size limit in 1993 (**Table 3**).

3.1.2 Check for Model Convergence

All 36 OMs had an invertible Hessian matrix. Twenty-four OMs had maximum absolute final gradient for at least one estimated parameter above the default SS3 warning flag of 0.0001. The maximum absolute final gradient in the estimated parameters across the OMs was 0.30, and this was for the estimated unfished recruitment (R_0) in the R3 set (OM 194). The next highest gradient was 0.028 for the estimated selectivity parameters in R2. The remainder of the gradients were below 0.018 and are unlikely to indicate a serious issue with model convergence. The full table of gradient values is available in the online OM Summary Report.

3.1.3 Check for High Correlations

Sixteen OMs had a least one parameter that was highly correlated with another estimated parameter (**Table 4**). Of these, the majority of the correlations were between selectivity-at-length parameters within a fleet, and between the catchability coefficient (q) and the estimated unfished recruitment (R_0), particularly for R2 (**Table 4**).

4. Summary of Predicted Stock Dynamics

The predicted stock dynamics are summarized here with plots of the estimated total spawning biomass, and the spawning biomass relative to the equilibrium biomass corresponding with maximum sustainable yield (SB_{MSY}). These were chosen as they are the two metrics that are most likely to impact the performance of candidate management procedures in the closed-loop projections: absolute abundance will impact the absolute level of catch, and relative stock biomass will impact the status of the OMs at the beginning of the projection period. Additional plots, including spawning biomass relative to equilibrium unfished levels, and absolute and relative fishing mortality are available in the online OM Summary Report.

The estimated spawning biomass followed a similar trend across the three levels of *M* and *h* for all operating models, with estimates of absolute biomass decreasing the increasing levels of *M* and increasing levels of *h* (**Figure 2**). Within each pair of *M* and *h* values, the Reference OMs and those from R1 had similar estimates of absolute spawning biomass, particularly towards the latter period of the assessment period (**Figure 2**). The OMs in R2 had consistently higher estimates of spawning biomass, with the exception of the OMs with the highest level of *M*, where the estimates of spawning biomass, particularly in the final years of the assessment period, were very similar (**Figure 2**). The OMs in R3 consistently had lower estimates of absolute spawning abundance throughout the time-series, particularly for the OMs where M was in the lowest level (**Figure 2**).

The spawning biomass relative SB_{MSY} in the terminal year (2020) range from 1.01 – 2.25 in Reference OMs, with most OMs between 1 and 1.3 (**Figure 3**). The estimate SB/SB_{MSY} for the OMs in R2 were very similar to those from the corresponding OMs in the Reference OMs, ranging from 0.99 – 2.05 (**Figure 3**). The OMs from R2 had a considerable higher estimate of stock status, with estimates of SB/ SB_{MSY} ranging from 1.35 – 2.31, with the highest values in the OM with highest *M* and *h* values (**Figure 3**). The estimated stock status was the lowest for the OMs in R3, ranging from 0.88 – 1.7 SB_{MSY}.

5. Discussion

The primary uncertainties in the North Atlantic Swordfish MSE are the three levels of natural mortality and steepness, affecting estimates of both absolute and relative spawning biomass. Across the 36 OMs considered in this paper, the estimated stock status in the terminal year ranged from 0.88 to 2.31 SB_{MSY}. The estimates of *F* relative to F_{MSY} in the terminal year were less than 1 across all OMs, except those in R3, where *F* in the terminal year ranged from 0.55 – 1.24 F_{MSY}.

Modifying the assumption of the Reference Set of OMs by increasing the assumed recruitment variability did not have a significant impact on the predicted stock dynamics, either in absolute or relative terms, but may influence the performance on candidate management procedures in the projection years due to increased recruitment variability in that period.

Removing the catch-at-length data generally resulted in more optimistic predictions, both in terms of absolute and relative biomass and fishing mortality, especially for the OMs where natural mortality was in the lower levels and steepness in the higher levels.

Assuming a 1% average annual increase in catchability resulted in more pessimistic predictions, both in terms of absolute and relative biomass and fishing mortality.

These analyses will be continued to be applied to additional robustness tests as they are developed, and candidate management procedures will be evaluated against the Reference and Robustness OMs to determine the management procedure that is most robust to uncertainty, and most closely meets the management objectives for this fishery.

6. Acknowledgements

We thank the Swordfish Species for their input and feedback on 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**	**Increasing q**	**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 axes of uncertainty for the 36 Reference and Robustness OMs in the revised operating model uncertainty grid for the North Atlantic Swordfish MSE.

Class	**OM #**	**M**	**sigmaR**	**h**	**Include CAL**	**Increasing q**
Base Case	000	0.2	0.2	0.88	TRUE	FALSE
Reference	127	0.1	0.2	0.6	TRUE	FALSE
	128	0.2	0.2	0.6	TRUE	FALSE
	129	0.3	0.2	0.6	TRUE	FALSE
	133	0.1	0.2	0.75	TRUE	FALSE
	134	0.2	0.2	0.75	TRUE	FALSE
	135	0.3	0.2	0.75	TRUE	FALSE
	139	0.1	0.2	0.9	TRUE	FALSE
	140	0.2	0.2	0.9	TRUE	FALSE
	141	0.3	0.2	0.9	TRUE	FALSE
R1. Higher sigmaR	130	0.1	0.6	0.6	TRUE	FALSE
	131	0.2	0.6	0.6	TRUE	FALSE
	132	0.3	0.6	0.6	TRUE	FALSE
	136	0.1	0.6	0.75	TRUE	FALSE
	137	0.2	0.6	0.75	TRUE	FALSE
	138	0.3	0.6	0.75	TRUE	FALSE
	142	0.1	0.6	0.9	TRUE	FALSE
	143	0.2	0.6	0.9	TRUE	FALSE
	144	0.3	0.6	0.9	TRUE	FALSE
R2. Remove CAL	145	0.1	0.2	0.6	FALSE	FALSE
	146	0.2	0.2	0.6	FALSE	FALSE
	147	0.3	0.2	0.6	FALSE	FALSE
	151	0.1	0.2	0.75	FALSE	FALSE
	152	0.2	0.2	0.75	FALSE	FALSE
	153	0.3	0.2	0.75	FALSE	FALSE
	157	0.1	0.2	0.9	FALSE	FALSE
	158	0.2	0.2	0.9	FALSE	FALSE
	159	0.3	0.2	0.9	FALSE	FALSE
R3. Increasing q	181	0.1	0.2	0.6	TRUE	TRUE
	182	0.2	0.2	0.6	TRUE	TRUE
	183	0.3	0.2	0.6	TRUE	TRUE
	187	0.1	0.2	0.75	TRUE	TRUE
	188	0.2	0.2	0.75	TRUE	TRUE
	189	0.3	0.2	0.75	TRUE	TRUE
	193	0.1	0.2	0.9	TRUE	TRUE
	194	0.2	0.2	0.9	TRUE	TRUE
	195	0.3	0.2	0.9	TRUE	TRUE

Table 3. The details of the 18 operating models that had an estimated selectivity parameter close to a pre-specified bound.

OM #	Class	Parameter	Min	Max	Value
127	Reference	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.995
133	Reference	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9937
139	Reference	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9908
141	Reference	Size_DblN_peak_CAN_3(3)_BLK1repl_1993	100	200	199.98
130	R1. Higher sigmaR	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9949
136	R1. Higher sigmaR	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9935
142	R1. Higher sigmaR	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9907
146	R2. Remove CAL	Size_DblN_ascend_se_SPN_1(1)_BLK1repl_1950	-5	7	6.99845
151	R2. Remove CAL	Size_DblN_ascend_se_SPN_1(1)_BLK1repl_1950	-5	7	6.99081
152	R2. Remove CAL	Size_DblN_ascend_se_SPN_1(1)_BLK1repl_1950	-5	7	6.99923
157	R2. Remove CAL	Size_DblN_ascend_se_SPN_1(1)_BLK1repl_1993	-5	7	-4.93872
158	R2. Remove CAL	Size_DblN_ascend_se_SPN_1(1)_BLK1repl_1950	-5	7	6.99857
181	R3. increase q	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9957
182	R3. increase q	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.8518
187	R3. increase q	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9945
189	R3. increase q	Size_DblN_peak_CAN_3(3)_BLK1repl_1993	100	200	199.977
193	R3. increase q	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1950	0	15	14.9924
195	R3. increase q	Size_DblN_peak_CAN_3(3)_BLK1repl_1993	100	200	199.994

Table 4. The details of the 16 operating models where at least one estimated parameter was highly correlated with another parameter.

OM #	Class	Parameter i	Parameter j	Correlation
133	Reference	Size_DblN_ascend_se_US_2(2)_BLK1repl_1950	Size_DblN_peak_US_2(2)_BLK1repl_1950	0.99
134	Reference	Size_DblN_ascend_se_CHT_EARLY_7(7)_BLK1repl_1950	Size_DblN_peak_CHT_EARLY_7(7)_BLK1repl_1950	0.96
135	Reference	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1993	Size_DblN_peak_CAN_3(3)_BLK1repl_1993	0.95
141	Reference	Size_DblN_ascend_se_JPN_ERLY_4(4)_BLK1repl_1993	Size_DblN_peak_JPN_ERLY_4(4)_BLK1repl_1993	0.95
132	R1. Higher sigmaR	Size_DblN_ascend_se_JPN_ERLY_4(4)_BLK1repl_1950	Size_DblN_peak_JPN_ERLY_4(4)_BLK1repl_1950	0.95
144	R1. Higher sigmaR	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1993	Size_DblN_peak_CAN_3(3)_BLK1repl_1993	0.95
145	R2. Remove CAL	LnQ_base_Age-3(16)	SR_LN(R0)	-0.95
145	R2. Remove CAL	LnQ_base_Age-4(17)	LnQ_base_Age-3(16)	0.95
145	R2. Remove CAL	LnQ_base_Age-5+(18)	SR_LN(R0)	-0.96
145	R2. Remove CAL	LnQ_base_Age-5+(18)	LnQ_base_Age-2(15)	0.95
145	R2. Remove CAL	LnQ_base_Age-5+(18)	LnQ_base_Age-3(16)	0.96
145	R2. Remove CAL	LnQ_base_Age-5+(18)	LnQ_base_Age-4(17)	0.95
147	R2. Remove CAL	Size_DblN_ascend_se_JPN_ERLY_4(4)_BLK1repl_1950	Size_DblN_peak_JPN_ERLY_4(4)_BLK1repl_1950	0.95
151	R2. Remove CAL	LnQ_base_Age-5+(18)	SR_LN(R0)	-0.96
151	R2. Remove CAL	LnQ_base_Age-5+(18)	LnQ_base_Age-3(16)	0.95
151	R2. Remove CAL	LnQ_base_Age-5+(18)	LnQ_base_Age-4(17)	0.95
153	R2. Remove CAL	Size_DblN_ascend_se_JPN_ERLY_4(4)_BLK1repl_1950	Size_DblN_peak_JPN_ERLY_4(4)_BLK1repl_1950	0.96
157	R2. Remove CAL	LnQ_base_Age-5+(18)	SR_LN(R0)	-0.96
157	R2. Remove CAL	LnQ_base_Age-5+(18)	LnQ_base_Age-3(16)	0.95
157	R2. Remove CAL	LnQ_base_Age-5+(18)	LnQ_base_Age-4(17)	0.95
159	R2. Remove CAL	Size_DblN_ascend_se_JPN_ERLY_4(4)_BLK1repl_1950	Size_DblN_peak_JPN_ERLY_4(4)_BLK1repl_1950	0.96
181	R3. increase q	Size_DblN_ascend_se_CHT_EARLY_7(7)_BLK1repl_1993	Size_DblN_peak_CHT_EARLY_7(7)_BLK1repl_1993	0.95
183	R3. increase q	Size_DblN_ascend_se_CAN_3(3)_BLK1repl_1993	Size_DblN_peak_CAN_3(3)_BLK1repl_1993	0.95
189	R3. increase q	Size_DblN_ascend_se_JPN_ERLY_4(4)_BLK1repl_1993	Size_DblN_peak_JPN_ERLY_4(4)_BLK1repl_1993	0.95
195	R3. increase q	Size_DblN_ascend_se_JPN_ERLY_4(4)_BLK1repl_1993	Size_DblN_peak_JPN_ERLY_4(4)_BLK1repl_1993	0.97

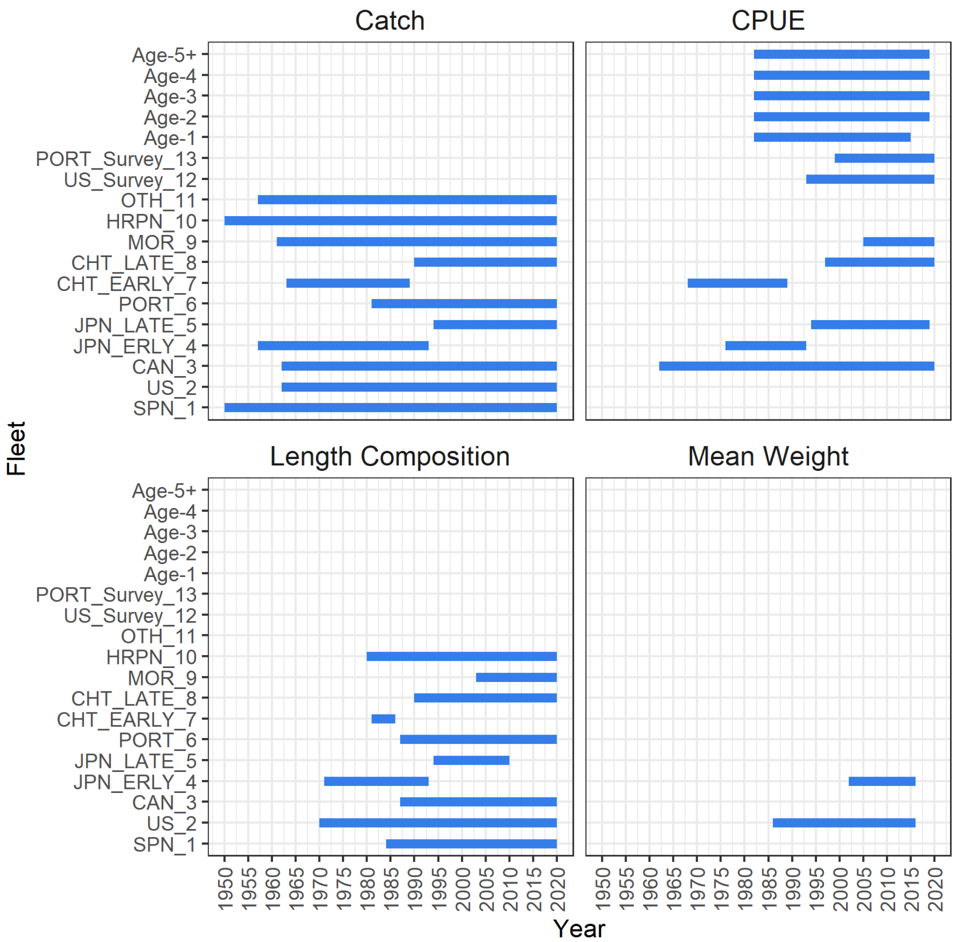

Figure 1. A summary of the data used in the 2022 stock assessment of the North Atlantic swordfish fishery.

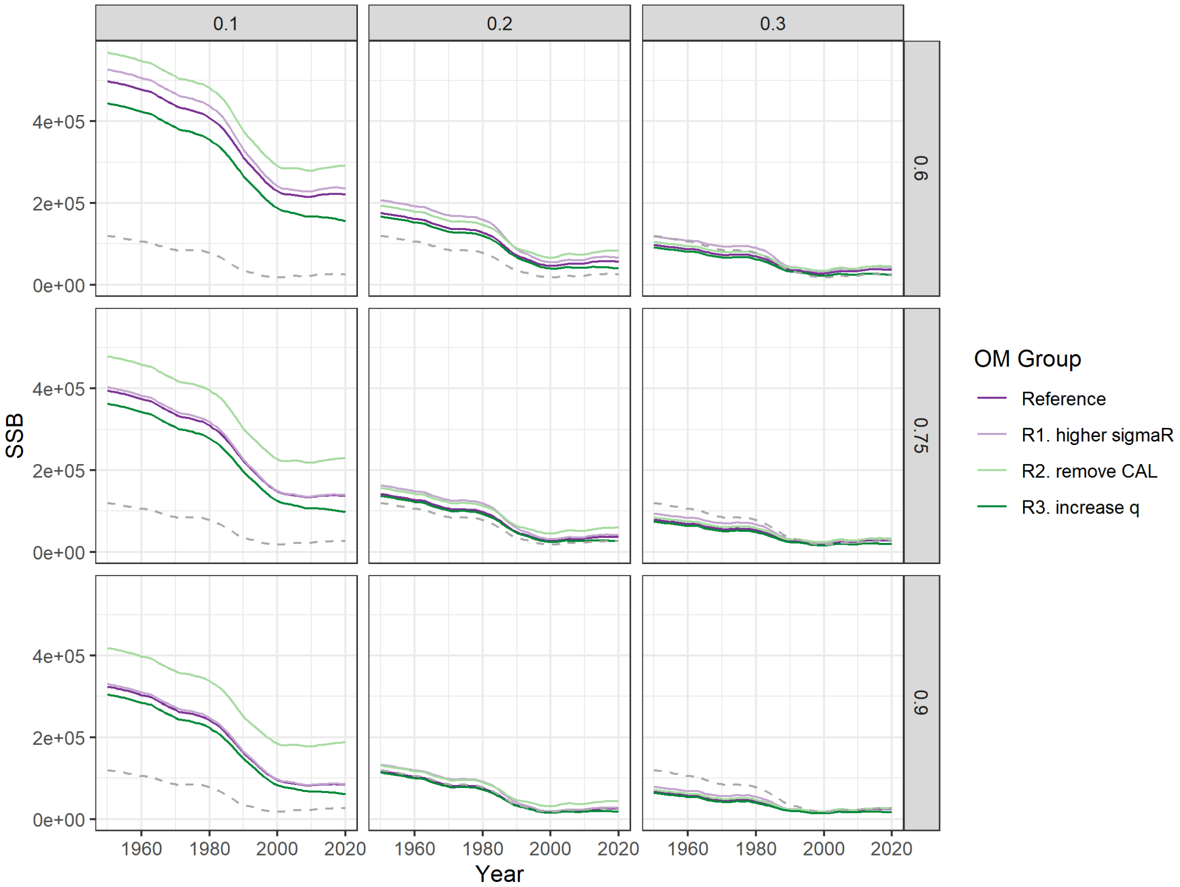

Figure 2. The predicted time-series of spawning stock biomass (SSB; ton) with the three levels of natural mortality (*M*; columns) and three levels of steepness (*h*; rows) and the Reference and Robustness operating model (OM) groups (colors). The Base Case model (2022 assessment) is shown as a gray dashed line.

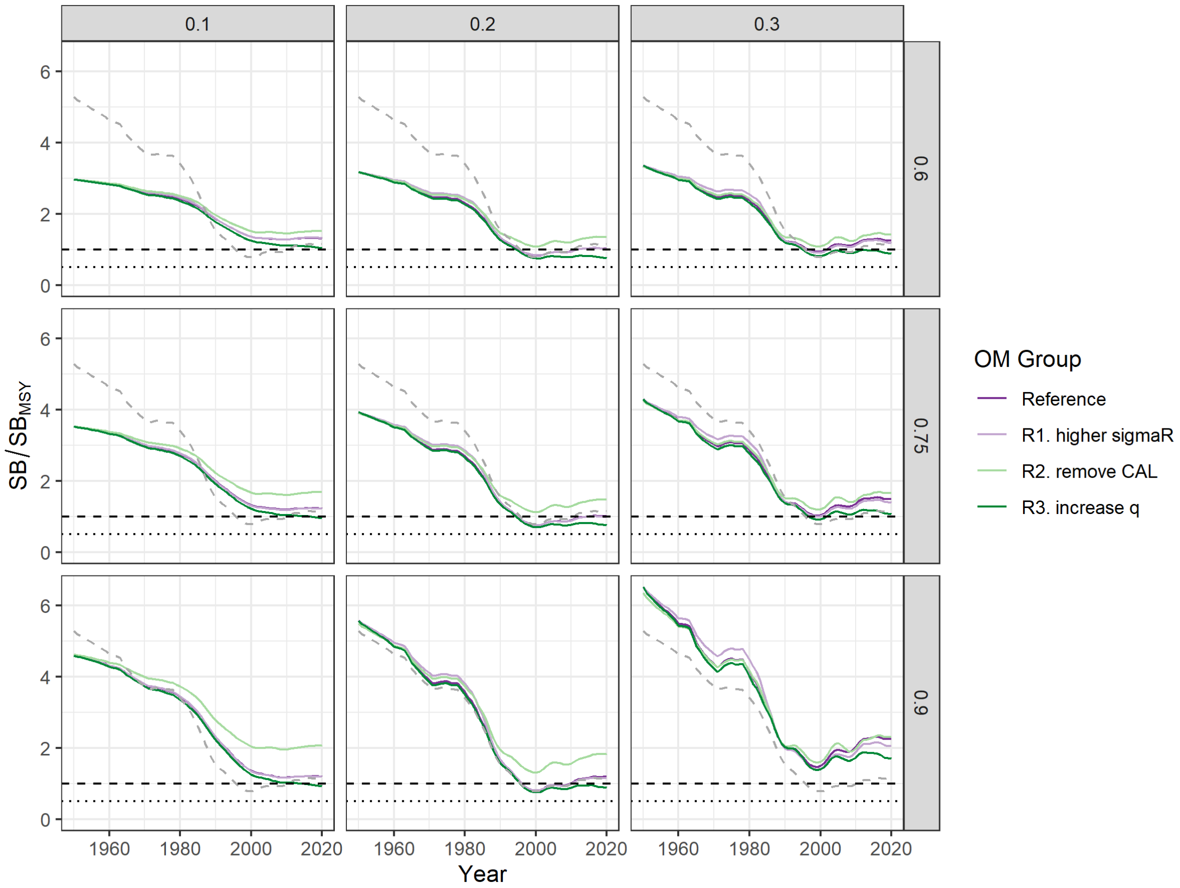

Figure 3. The predicted time-series of spawning biomass relative to the equilibrium spawning biomass corresponding to maximum sustainable yield (SB_{MSY}) with the three levels of natural mortality (*M*; columns) and three levels of steepness (*h*; rows) and the Reference and Robustness operating model (OM) groups (colors). The Base Case model (2022 assessment) is shown as a gray dashed line.