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Management Strategies Evaluation for the Jack Mackerel Fishery

Chile

Working Paper

Management Strategies Evaluation for the Jack Mackerel Fishery

By

Cristian M. Canales[1], Ignacio Payá[2], Fernando Espíndola[2], José Zenteno[2], Nazareth Sánchez[1], Juan Carlos Quiroz[1], Robyn Forrest[3], Roberto Licandeo[4].

(1) Pontificia Universidad Católica de Valparaíso - PUCV, Chile
(2) Instituto de Fomento Pesquero – IFOP, Chile
(3) Fisheries and Oceans Canada – DFO/MPO, Canada
(4) Independent consultant, Canada

1. Introduction

The South Pacific Regional Fisheries Management Organization (SPRFMO) has managed the jack mackerel fishery based on a fishing mortality reference measure (FMSY) within a population status-dependent management procedure. This procedure has been complemented by a landing stability band and other details that have refined the catch decision-making process over time. In addition to the above, and as a consequence of the significant fluctuations in the stock of this resource, the SPRFMO has requested the Scientific Committee (SC) to assess the robustness of this management procedure and other alternative procedures using the Management Strategy Evaluation (MSE) technique. This task has been hampered, among other factors, by the characteristics and complexity of the current stock assessment model.

This document summarizes the results of a project carried out in Chile 2025-2026 (FIPA2024-27) whose main objective was to develop a MSE analysis for this fishery, using the OpenMSE platform as a reference, based on several uncertainty axes (Operating Models) and alternative management procedures. The management procedures and performance variables were defined through consultation with stakeholders. The analyses were performed using a shortcut version, and the results were validated using a full MSE based on a smaller-scale age-structured estimation model. The results provide guidance and perspectives for the future management of this important South Pacific fishery.

2. Methodology

2.1. Stakeholder engagement and prioritization of operational objectives

Within the framework of the MSE, the expertise, priorities, and expectations of key stakeholders were taken into account. This fosters consensus on operational objectives and management preferences, and ensures that the simulation models and management procedures (MPs) are aligned with the jack mackerel fishery. The engagement process utilized a combination of quantitative and qualitative tools conducted throughout 2025:

- **Semi-structured Surveys:** Conducted via Google Forms and distributed to 40 representatives from the artisanal and industrial sectors, the Management Committee (CM), the Scientific Technical Committee (CCT-J), and government administrators.
- **Theoretical-Practical Workshops:** Three sessions were held to facilitate direct dialogue and consensus-building: operational objectives and performance variables, management Procedures and Harvest Control Rules (HCR), and uncertainty source in the biological-fishery system.
- **Focus Groups:** Used during workshops to visualize points of agreement and dissent through individual cards and moderated plenary discussions.

Participants were asked to prioritize their preferences regarding: maximizing catches, avoiding large year-to-year changes in catches, avoiding overfishing, avoiding overexploitation (biomass below target), maximizing population biomass, achieving rapid resource recovery in the event of overexploitation, ensuring catches consist primarily of larger specimens, and fulfilling the catch quota. They were also asked for their opinions on the percentage of catch variation between years, desirable catch ranges, the decision to fish in the event of a collapse, sources of uncertainty for the fishery, and other factors (**Table 1**).

Figure 1. Photographic record of the three workshops held with the members of the Jack Mackerel Management Committee.

Table 1. Aspects consulted and alternative responses for the design of management procedures during the participatory process.

Stock status	Aspect consulted	Response options
Fully exploited	Stability band: Maximum allowable interannual variation (increase and decrease)	i. Variation determined by stock status. ii. Between 10% and 30% iii. Other alternative
	Banking & Borrowing (B&B): Implementation of the mechanism and acceptable quota percentage that can be transferred between years	i. Yes or No. ii. Banking only iii. Borrowing only Transfer percentage (10%, 20%, or another value).
Collapsed/Depleted	Management action: Catch measure to be applied and, where appropriate, definition of the stability band or minimum quota.	i. Catch determined by stock status. ii. Maintain a stability band. iii Zero quota. iv. Minimum quota
Underexploited	Management action: Catch measure to be applied and, where appropriate, definition of the stability band or maximum quota.	i. Catch determined by stock status ii. Maintain a stability band iii. Maximum quota

2.2. OpenMSE implementation workshop

The OpenMSE implementation was supported by Dr. Robyn Forrest (Fisheries and Oceans, Canada) in a technical workshop. This specific focused on coding and verifying the OpenMSE components. During the workshop, the Rapid Conditioning Model (RCM) exhibited implementation challenges due to the complexities of the current estimation model. The OM conditioning considered the results of the most recent stock assessment and its verification showed that the OMs closely reproduced the age-abundance and spawning biomass trajectories estimated by the original SPRFMO assessments.

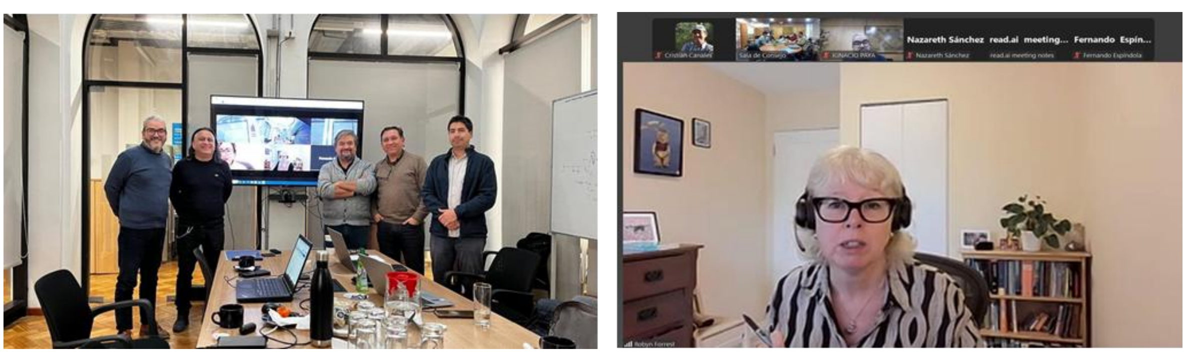


Figure 2. Workshop of OpenMSE implementation.

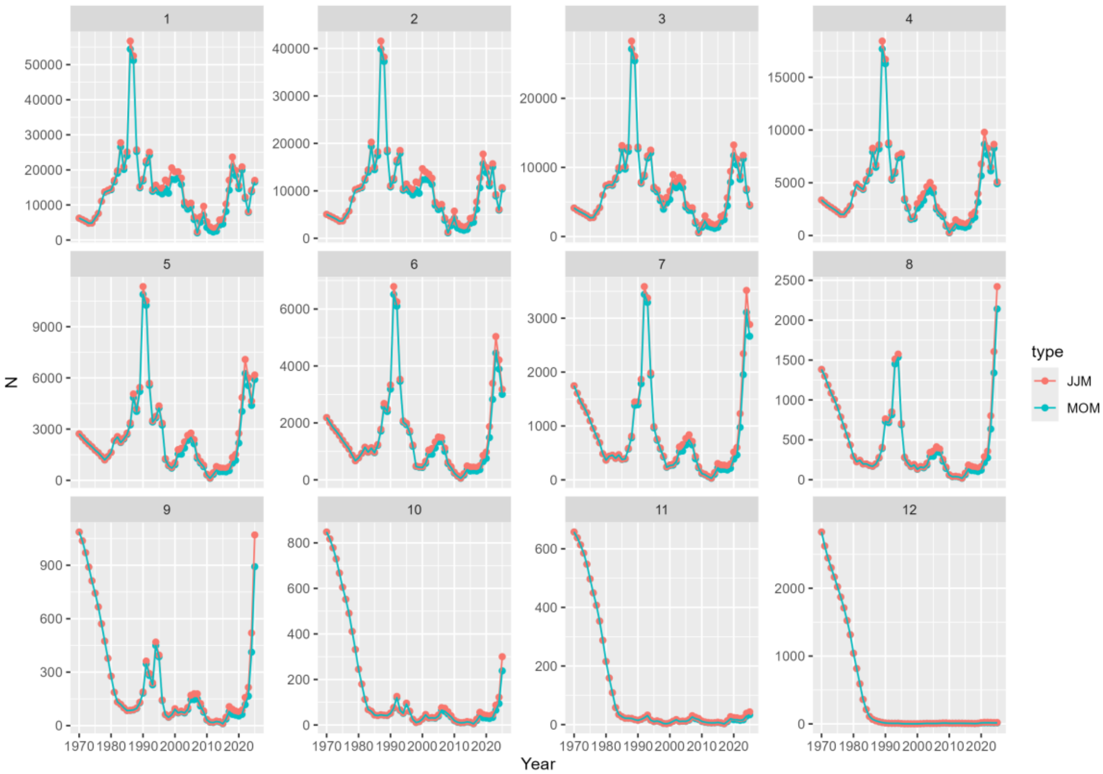


Figure 3. Number by year and at age (panels) estimated by JJM and the OM.

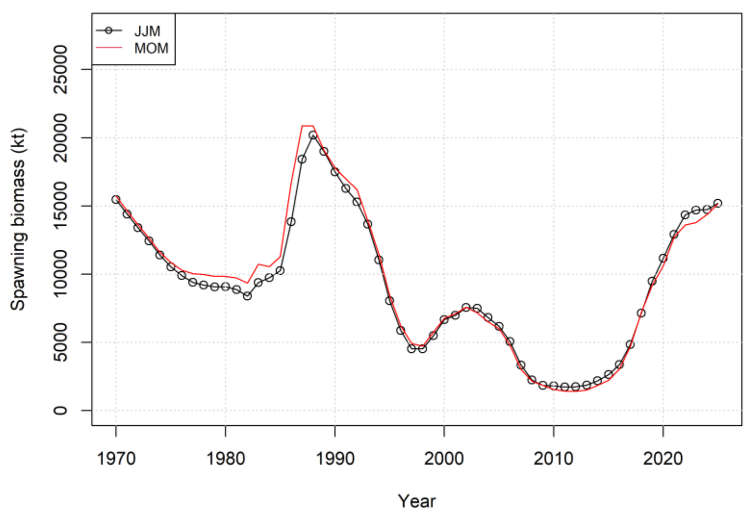


Figure 4. Spawning biomass by year estimated by JJM and the OM.

Three primary operating models (OM) based on different future recruitment levels to test the resilience of management strategies under varying productivity scenarios were proposed (**Figure 5**).

Table 2. Operating Models based on different future recruitment levels of jack mackerel

Model	Productivity Level	Multiplier on R0	Assumption
OM1	Low	0.5	Reduced productivity
OM2	Medium	1.0	Baseline productivity (historical average)
OM3	High	1.5	Increased productivity

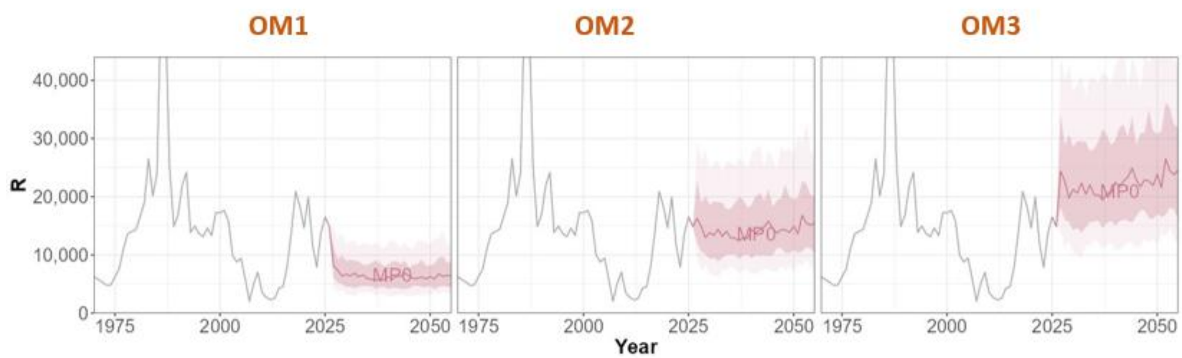


Figure 5. Historical and three future recruitment scenarios.

To perform the MSE analysis, the "Shortcut" function of the SAMtool package was used. This function emulates stock assessment by sampling the biomass of the OM instead of fitting a stock assessment model. The estimated biomass considered an estimation error of σ = 0.15 and an autocorrelation of ρ = 0.77, with no bias.

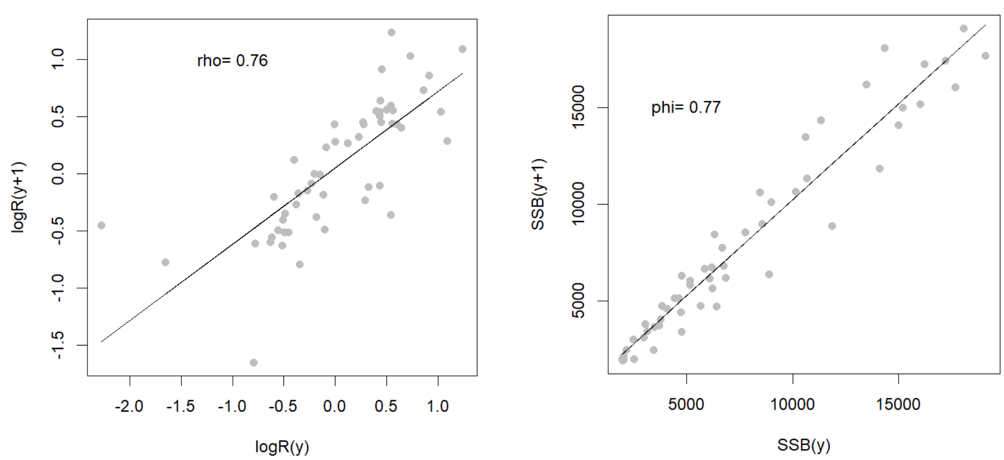


Figure 6. Partial correlation of jack mackerel recruitment log deviates (a) and spawning biomass (b) with a one-year lag

Variability sources

The models assumed a constant natural mortality (M=0.28) and utilized maturity ogives and weight-at-age data directly from the base assessment model. The main sources of variability in the simulations were the process error of the annual recruitment and fleet selectivity. Annual recruitment follows a Beverton-Holt relationship between stock and recruitment, with a slope parameter h = 0.8. Recruitment variability incorporates both the process error (sampling of historical deviations) and the temporal autocorrelation (ρ = 0.77), both estimated in last stock assessment. Selectivity variability was implemented using bootstrap sampling of selectivity vectors recorded over the last 16 years of the fishery.

Biological Reference Points (BRPs)

For the estimation of BRPs, the F_{MSY} calculation considered the default OpenMSE configuration, which is based on the average of the data for the last three years (2023-2025), including weights at the age of the commercial catch. The spawning biomass associated with the MSY, dynamically estimated per year, was estimated as an average of B_{MSY} = 10.6 million t. Consistently, the F_{MSY} value was estimated at F = 1.36.

2.3. Full MSE and JJM_simple Estimation Model

For comparative purposes and to validate the results obtained from the shortcut MSE version, a full closed-loop simulation-estimation MSE was implemented. The same OM equations were coded in R (version 4.6.1) and a population model structured by age, called JJM_simple, was formulated and implemented in ADMB. This model has a less complex structure and greater parsimony in the use of data and parameters. The main difference is that it replaces the complexity of modeling four fleets and their abundance indices with only one fleet and high dynamic flexibility of the overall exploitation pattern. The JJM_simple model uses parametric selectivity (double normal) on blocks of years (same as the original jjm model), combined age compositions of the four fleets, and CPUE series from the central-southern region and acoustic biomass from northern Chile, along with their age composition. The model is hosted at https://github.com/criscan/JJM_simple

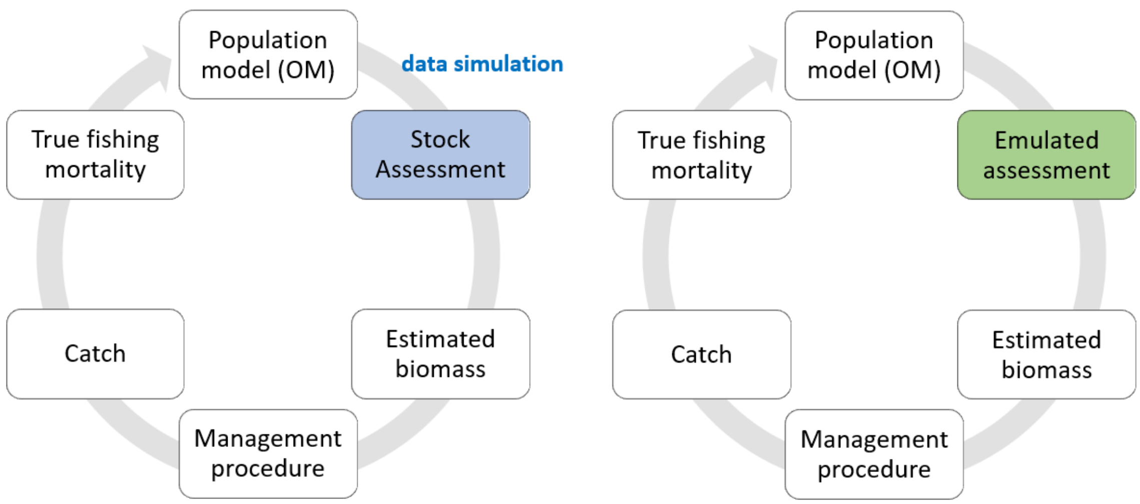


Figure 7. Main steps in MSE implementation. The differences between the shortcut version (left) and the full version (right) are highlighted in color.

2.4. Management Procedures (MP)

As a result of the stakeholder consultations, the management procedures (MPs) were defined based on four catch control rules (**Figure 8**), stabilization bands, reference catches, and the catch saving and lending criterion (**Table 2**). For simplicity and ease of understanding for the users themselves, the Harvest Control Rules (HCR) were defined in terms of catch. HCR1 is the current management procedure defined based on the adjustment of the reference fishing mortality F_{MSY} (https://www.sprfmo.int/assets/Fisheries/Science/HCR_2022.pdf), HCR2 is a ramp HCR with minimum catch of 270 hundred thousand tons, HCR3 is a linear HCR (constant F) with minimum catch, and HCR4 is a double-potential HCR with minimum catch. Based on all of the above, 10 Management Procedures (MPs) were proposed for this fishery (**Table 3**).

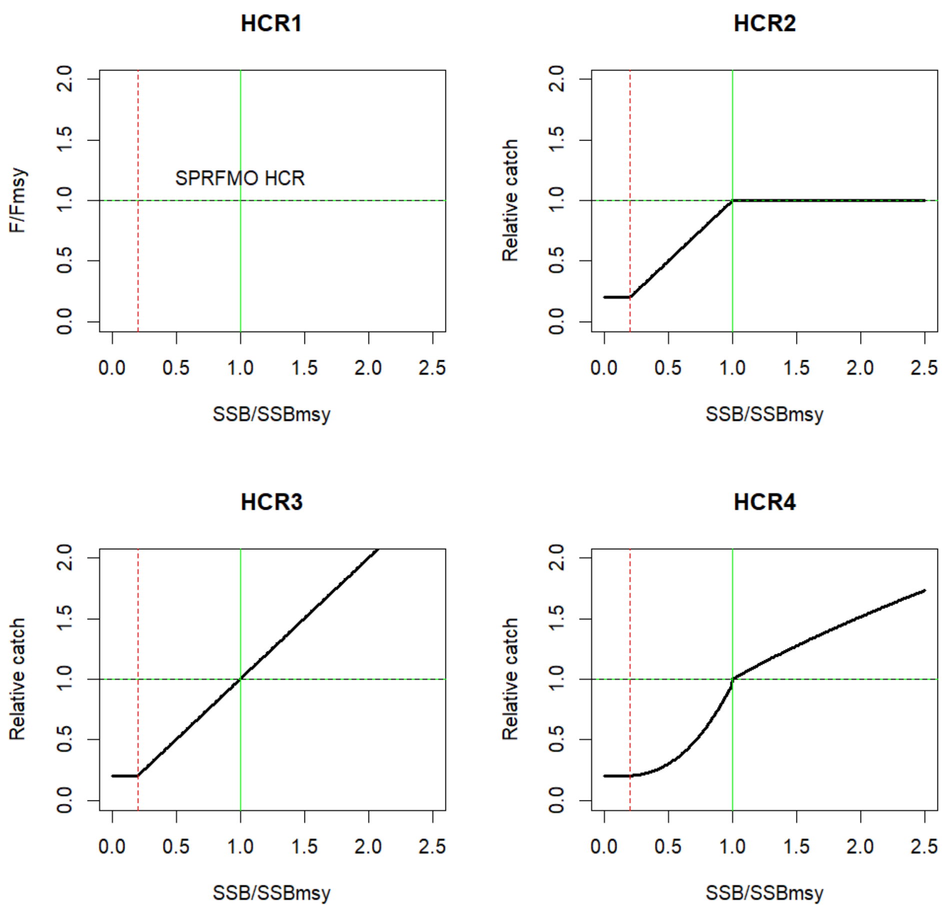


Figure 8. Harvest Control Rules proposed for the Jack mackerel fishery

Table 3. Management Procedures (MPs) proposed for the jack mackerel fishery

Management Procedure	HCR	Stabilizer (%) (Increase–Decrease)	Target Catch (thousand t) (ABCref)	B&B	Description
MP1	HCR1	25–15	–	No	MP2 with a modified stabilizer.
MP2	HCR1	15–15	–	No	Current management procedure with a minimum catch of **270 thousand t**.
MP3	HCR1	15–15	–	10%	MP2 including the B&B effect when SSB>SSBmsy
MP4	HCR2	20–15	1,500	No	Modified HCR and ABCref.
MP5	HCR2	20–15	2,000	No	MP4 with a revised ABCref.
MP6	HCR3	20–15	1,500	No	Modified HCR and ABCref.
MP7	HCR3	20–15	2,000	No	MP6 with a revised ABCref.
MP8	HCR4	20–15	1,500	No	Modified HCR and ABCref.
MP9	HCR4	20–15	2,000	No	MP8 with a revised ABCref.
MP10	–	–	1,500	No	Constant catch.

Alternatively, the design of an empirical HCR was explored. The acoustic biomass of northern Chile was considered as an abundance indicator because it shows the strongest correlation with spawning biomass. The reference acoustic biomass was calculated to be 1.27 million t, which is equivalent to SSB_{MSY} on the spawning biomass axis.

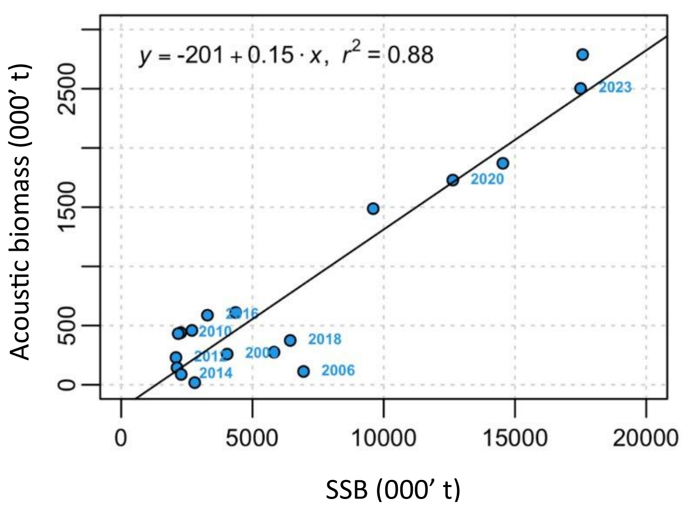


Figure 9. Relationship between biomass estimated by acoustic in central-north of Chile and Spawning biomass estimated by JJM

2.5. Performance metrics

Twelve performance indicators were defined to evaluate the effectiveness of management procedures over short-term (1-5 years) and long-term (20-30 years) time horizons. These performance indicators are aligned with the preferences identified through workshops and surveys, demonstrating a prioritization of objectives related to resource conservation, along with the level and stability of catches (**Table 4**).

Table 4. Proposed performance metrics for the jack mackerel fishery

Num	Code	Indicator	Time Horizon	Description
1	NSP_CP	No overfishing	Short term	Probability that **F < Fmsy**
2	NSP_LP	No overfishing	Long term	Probability that **F < Fmsy**
3	NZR_CP	Outside the red zone	Short term	Probability that **B>0.5Bmsy**
4	NZR_LP	Outside the red zone	Long term	Probability that **B>0.5Bmsy**
5	ZV_CP	Green zone	Short term	Probability that **B>Bmsy and F<Fmsy**
6	ZV_LP	Green zone	Long term	Probability that **B > Bmsy**
7	CBAprom_CP	Catch	Short term	Mean ABC
8	CBAprom_LP	Catch	Long term	Mean ABC
9	CBA_5y	Catch	Years 5–6	Mean ABC
10	C10_CP	Catch exceeding 1.0 million t	Short term	Probability that **ABC > 1.0 million t**
11	C10_LP	Catch exceeding 1.0 million t	Long term	Probability that **ABC > 1.0 million t**
12	CBAv	Catch variability	Years 1–30	Probability that **ABC variability < 10%**

3. Results

3.1. Performance of alternative stock assessment model (jjm_simple)

To improve computational efficiency and stability for MSE purposes, a simplified version of the assessment model was developed (jjm_simple). The model adequately reproduced the trends in the historical data for this fishery (**Figure 10**), which is partly explained by the annual variability of the fleet's dome-shape exploitation pattern in 19 blocks of years and the acoustic over 6 blocks (**Figure 11**). This model successfully reproduced historical stock dynamics while reducing computation time to approximately 6 seconds per run for 188 estimated parameters (original jjm model take 1.5 minute for 1825 estimated parameters). It maintained a high correlation (>90%) with the original jjm model regarding spawning biomass and recruitment estimates (**Figure 12**). Its parsimonious structure makes it an ideal tool for "Full MSE" applications where the assessment model must be re-fitted in every year of the projection. The projection analysis, a 30-year population simulation, shows the inaccuracy of the estimation model with respect to the true biomass (**Figure 13**). The simulation-estimation relationship indicates jjm_simple has a correlation of 86% with true biomass, an inaccuracy level of cv = 0.2 and 4% of biased (median relative error, MRE) based on 100 repetitions x 30 years future (**Figure 14**).

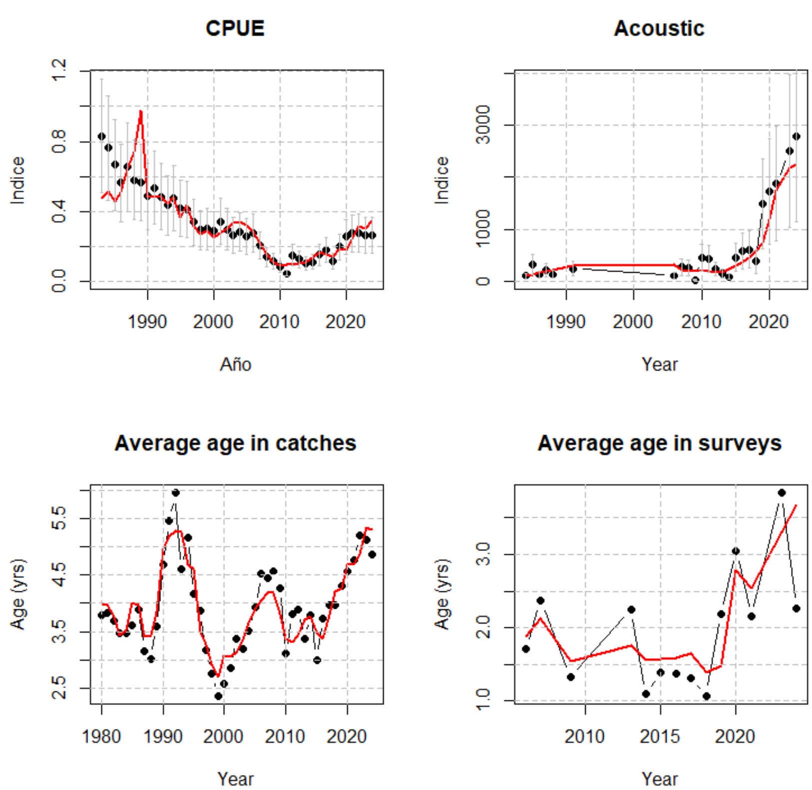


Figure 10. Model "jjm_simple" fitted to Jack mackerel data fishery

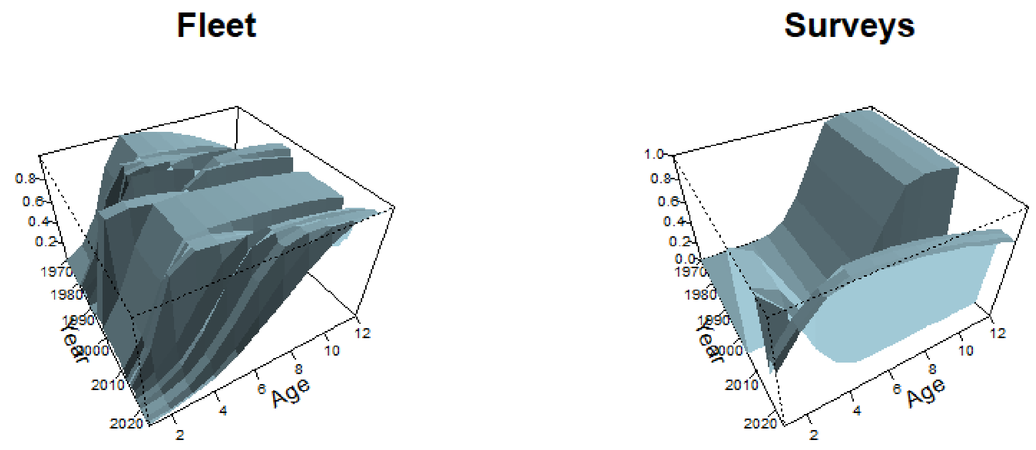


Figure 11. Blocks of years of selectivity of the fishing fleet and acoustic surveys

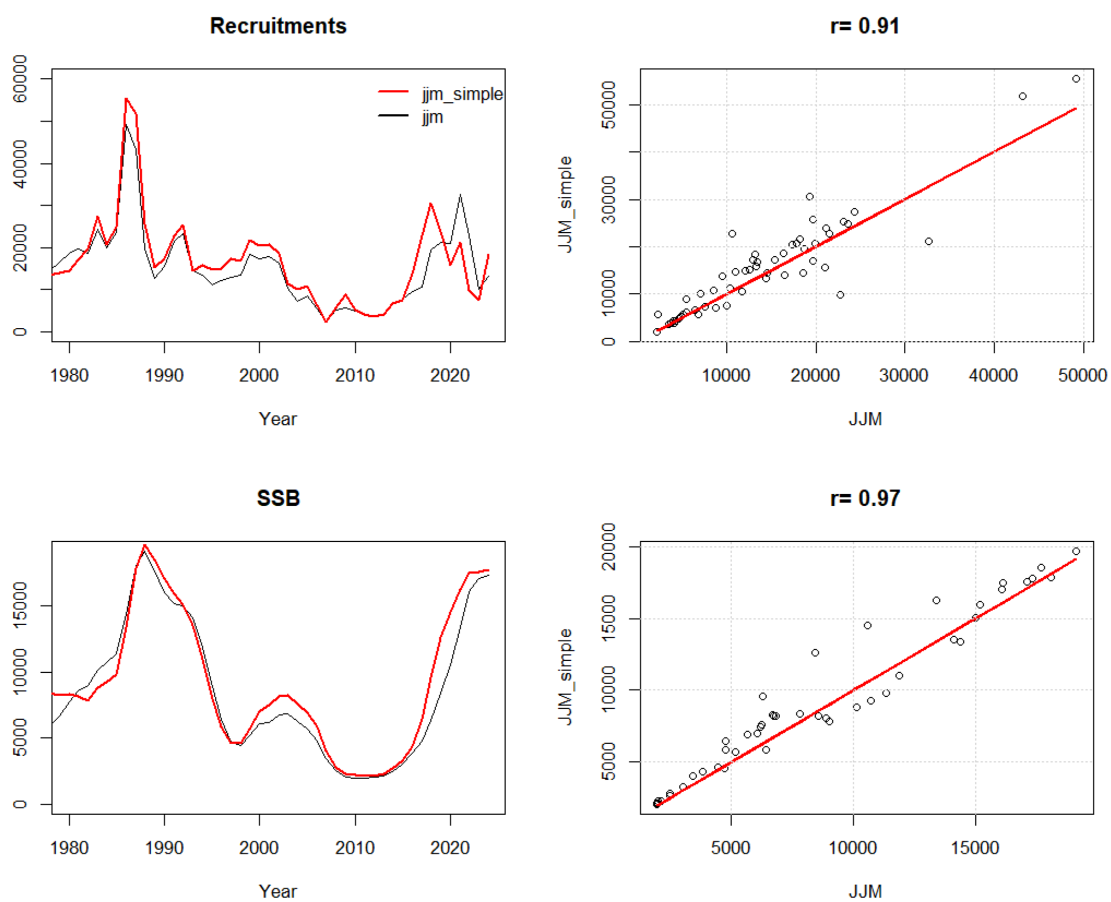


Figure 12. Recruitments, spawning biomass and correlations between original model jjm and alternative jack mackerel model jjm_simple.

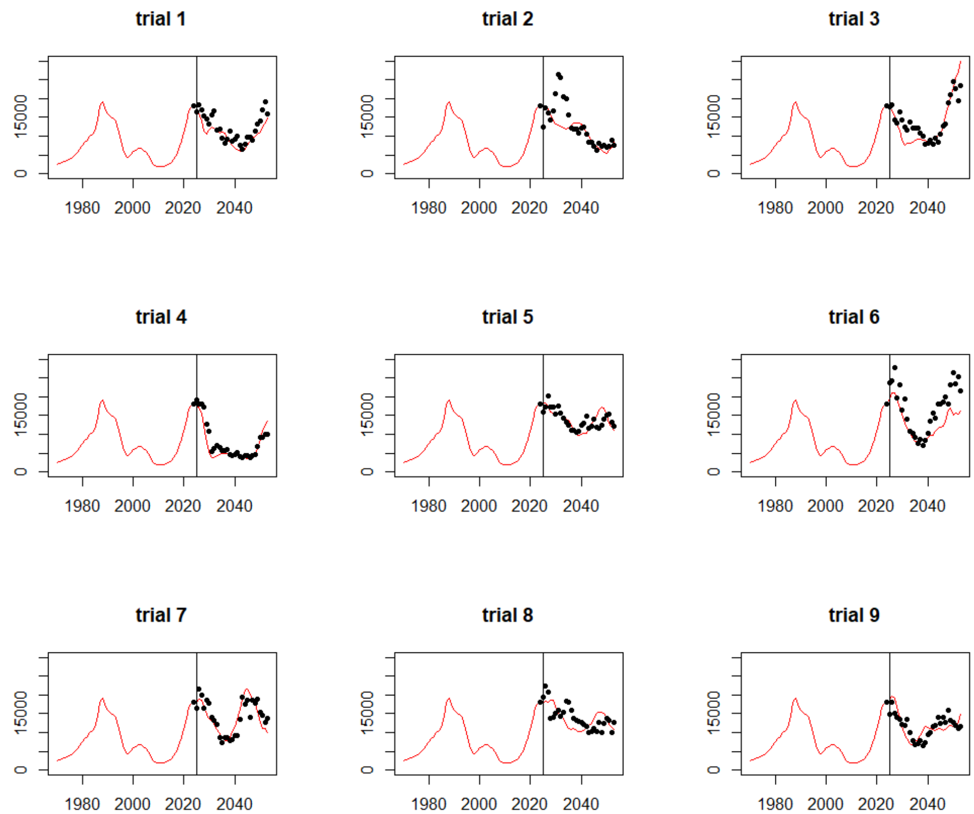


Figure 13. Example of spawning biomass simulated by OM (red line) and estimations of alternative jack mackerel model jjm_simple (black dots) in nine trials for MP3. Vertical line indicates the start of simulations.

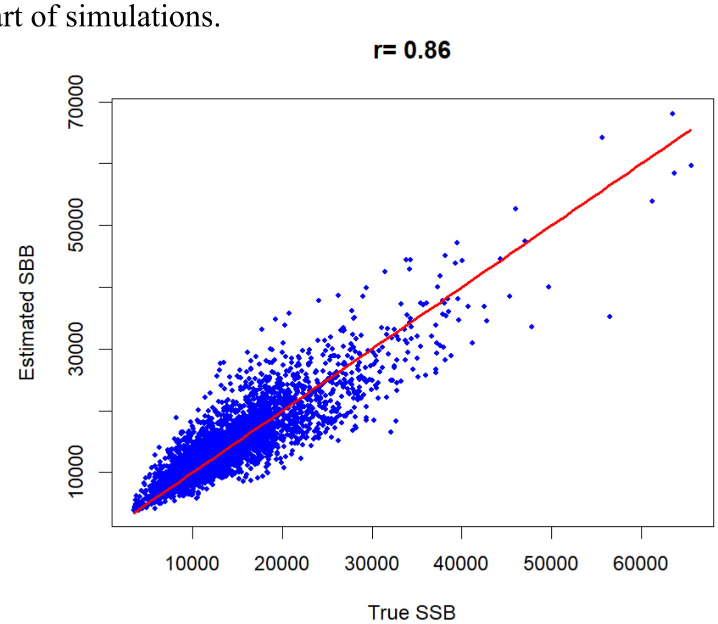


Figure 14. Scatter plot and correlation level between spawning biomass simulated and estimations of alternative jack mackerel model jjm_simple (100 simulations x 30 years future).

3.2. Full vs shortcut MSE versions

A full MSE was implemented based on 100 simulations for 9 MPs, and its overall performance was compared to the abbreviated version. The process time was 45 hours. Generally, no major differences were observed in the average values of the population variables (**Figure 15**). Greater variability was noted in the estimates with the full MSE, particularly in catch and fishing mortality for MP 8 and MP 9 related to HCR4 (double-power HCR) (**Figure 16**).

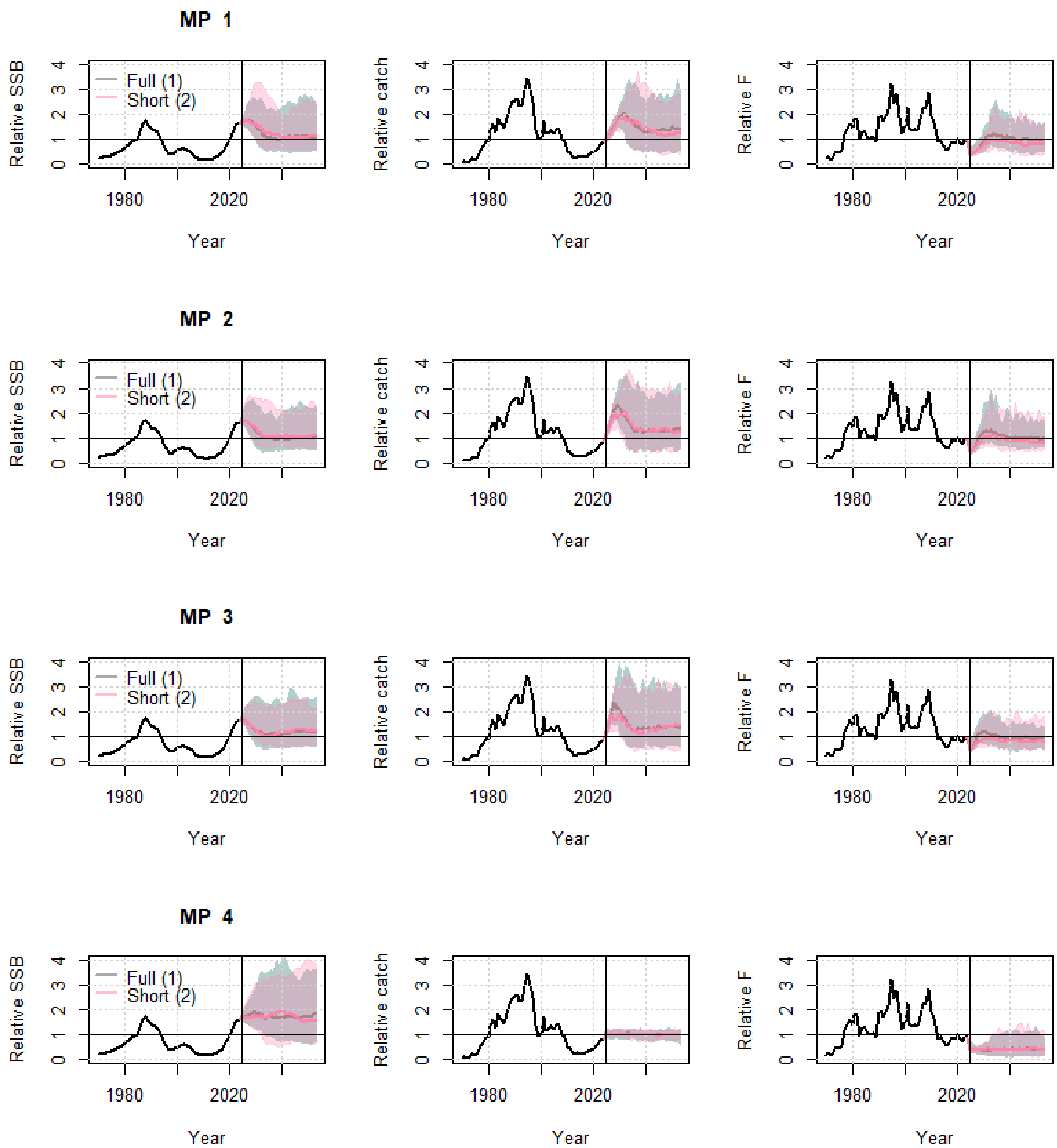


Figure 15. Example of relative biomass, catches, and fishing mortality of jack mackerel projected by 30 years by management procedures and two MSE approximations: full and shortcut.

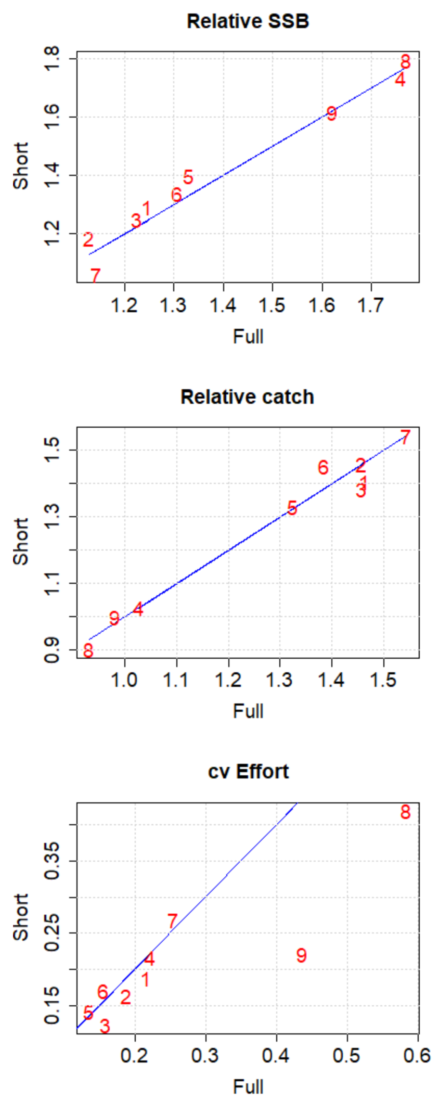
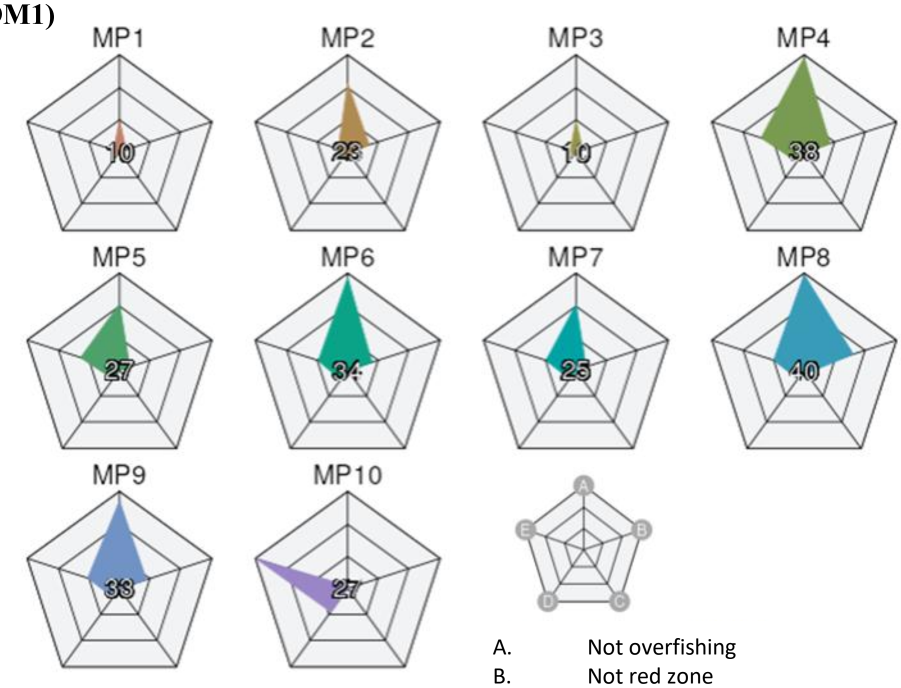


Figure 16. Scatter plot of average performance indicators for different management procedures (MPs) and two MSE methods (full and shortcut). The numbers in red indicate the MP. The blue line indicates the full MSE procedure.

3.3. PM performance for different OM

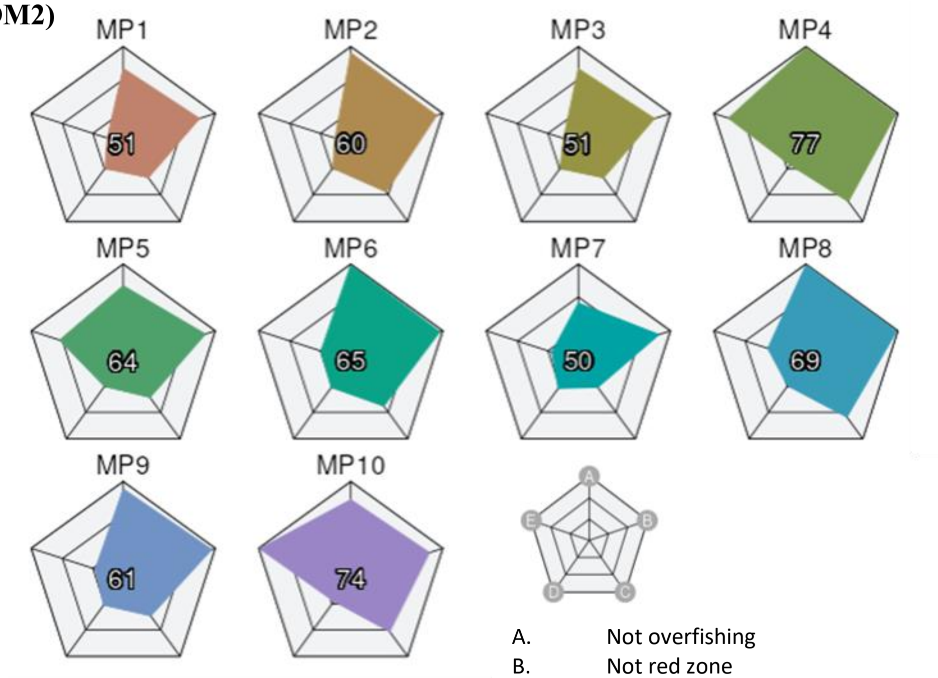
The analyses show that under low productivity conditions, MP4 and MP8 perform best, while under historical productivity conditions, MP4 and MP10 have the best overall score (**Figure 17**). Under low productivity conditions (OM1), and in long term, MP 1 (current), MP3, and MP10 have a high risk of not achieving fisheries management objectives. Under historical recruitment conditions (OM2), the long-term catch (ABC) fluctuates between 1.4 and 1.7 million t, with the lowest catch variability recorded in MP4, MP5, and MP10 (constant catch). Similarly, the lowest risks to the population are present in MP2, MP4, MP6, and MP8 (**Table 5**).

Low productivity (OM1)



A. Not overfishing
B. Not red zone
C. Green zone
D. Catch
E. Variability ABC <10%

Historic productivity (OM2)



A. Not overfishing
B. Not red zone
C. Green zone
D. Catch
E. Variability ABC <10%

Figure 17. Relative performance of MPs based on long-term indicators. Overall scores correspond to the average of 5 performance indicators for the low and historic productivity scenarios.

Table 5. Performance indicators by MP and two operating models. The color indicates the minimum (least intense) to maximum (most intense) range for each performance indicator.

OM1	NSP_LP	NZR_LP	ZV_CP	ZV_LP	CBA_CP	CBA_LP	CBA_5y	C10_LP	CBAv
MP1	0.32	0.07	0.74	0.00	2100	290	2700	0.04	0.06
MP2	0.71	0.23	0.84	0.02	1750	432	2000	0.07	0.10
MP3	0.32	0.07	0.74	0.00	2110	290	2710	0.04	0.06
MP4	0.98	0.28	0.92	0.02	1490	634	1460	0.11	0.47
MP5	0.69	0.11	0.74	0.00	1970	571	1850	0.10	0.42
MP6	0.96	0.27	0.81	0.01	1810	619	1640	0.10	0.32
MP7	0.68	0.11	0.71	0.00	2080	561	2030	0.09	0.33
MP8	0.99	0.54	0.85	0.04	1700	563	1540	0.08	0.33
MP9	0.91	0.29	0.73	0.01	2020	565	1910	0.07	0.35
MP10	0.03	0.03	0.92	0.00	1500	1500	1500	1.00	1.00

OM2	NSP_LP	NZR_LP	ZV_CP	ZV_LP	CBA_CP	CBA_LP	CBA_5y	C10_LP	CBAv
MP1	0.78	0.84	0.95	0.45	2110	1630	2800	0.74	0.18
MP2	0.94	0.94	0.97	0.63	1760	1610	2060	0.77	0.17
MP3	0.78	0.84	0.95	0.45	2110	1630	2800	0.74	0.16
MP4	1.00	0.99	1.00	0.76	1500	1400	1490	0.91	0.85
MP5	0.78	0.90	0.96	0.48	1990	1660	1970	0.89	0.70
MP6	1.00	0.98	0.98	0.59	1950	1730	2050	0.88	0.33
MP7	0.60	0.89	0.94	0.35	2230	1780	2550	0.86	0.29
MP8	1.00	1.00	0.99	0.73	1800	1620	1830	0.85	0.42
MP9	0.93	0.97	0.95	0.49	2140	1740	2320	0.83	0.31
MP10	0.82	0.86	0.99	0.69	1500	1500	1500	1.00	1.00

Overall, when integrating the data across the three operating models, MP4 stands out as having the best overall performance, slightly better in the conservation dimension. Similarly, MP10 stands out as the second-best management procedure, with better performance in the fisheries dimension. However, it is not sustainable in low-productivity scenarios. MP8 performs similarly to MP4, with better performance for population indexes but lower levels for the fishery dimension. By the other hands, MP1 (the current procedure) is among the lowest performers, along with MP3 and MP7 (**Table 6**). By adjusting the weighting of population indicators, we see that MP8 loses relevance with weights lower than 0.5, while MP5 gains relatively greater importance. However, MP4 remains among the best performers, along with MP10 (not feasible in low-productivity scenarios) (**Table 7**).

Table 6. Average long-term relative performance indicators by MP. The color indicates the range from minimum (least intense) to maximum (most intense) for each performance indicator.

	NSP_LP	NZR_LP	ZV_LP	CBA_LP	C10_LP	CBAv	Avg
MP1	0.78	0.84	0.45	0.92	0.74	0.18	0.65
MP2	0.94	0.94	0.63	0.90	0.77	0.17	0.73
MP3	0.78	0.84	0.45	0.92	0.74	0.16	0.65
MP4	1.00	0.99	0.76	0.79	0.91	0.85	0.88
MP5	0.78	0.90	0.48	0.93	0.89	0.70	0.78
MP6	1.00	0.98	0.59	0.97	0.88	0.33	0.79
MP7	0.60	0.89	0.35	1.00	0.86	0.29	0.66
MP8	1.00	1.00	0.73	0.91	0.85	0.42	0.82
MP9	0.93	0.97	0.49	0.98	0.83	0.31	0.75
MP10	0.82	0.86	0.69	0.84	1.00	1.00	0.87

Table 7. Weighted long-term return. The weighting factor assigns importance to population variables.

	Weighting factor			
	0.2	0.4	0.6	0.8
MP1	0.625	0.641	0.657	0.672
MP2	0.660	0.705	0.749	0.794
MP3	0.623	0.639	0.655	0.671
MP4	0.862	0.875	0.888	0.901
MP5	0.816	0.792	0.768	0.744
MP6	0.753	0.778	0.803	0.828
MP7	0.696	0.675	0.654	0.632
MP8	0.762	0.798	0.835	0.871
MP9	0.723	0.742	0.760	0.779
MP10	0.916	0.885	0.854	0.823

4. Conclusions

The main conclusions of the project are summarized as follows:

- The jjm_simple model is a suitable alternative for use within a full MSE framework for jack mackerel. This is supported by its high correlation (r>0.9) with the population history generated by the jjm_original model, and its efficiency in terms of reducing the number of parameters by 89% and the convergence time by 94%.
- While the performance of the abbreviated MSE version was similar to the full version, the latter exhibited slightly greater variability in catch, fishing mortality, and lower long-term fishery stability.
- The biggest difference between the reduced and full versions of the MSE is generated in the use of HCR4 (double-potential).
- Two alternative MPs showed the best relative performance (MP4 and MP8) in medium and long time, both defined by a minimum catch of 270,000 tons and a maximum reference CBA of 1.5 million tons.
- The MP4 (ramp-type RCC) showed the best balance between biological protection and fisheries stability, while MP8 (double-potential RCC) prioritized stock conservation and higher long-term catches.
- The MP4 (ramp-type RCC) proved to be the most robust against different weightings of population variables.
- The current management procedure MP1 was among the worst performing overall.