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JM11 Conditioning of Operating Models and development of Management Procedures for the SPRFMO JM stock

Jack Mackerel Working Group – MSE

Conditioning of Operating Models and development of Management Procedures for the SPRFMO jack mackerel stock

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Operating models for the South Pacific Chilean jack mackerel (*Trachurus murphyi*) stock have been developed to be used as a basis for the evaluation of alternative management procedures for the stock. The main axis of uncertainty incorporated in the OMs are stock structure, the steepness of the stock-recruitment relationship, and future recruitment regimes. Parameter uncertainty has been quantified through Markov chain Monte Carlo (McMC). A number of candidate MPs have been defined and tested. Work is strating on carrying out the full simulation design for tuning and evaluating the performance of those procedures under different scenarios.

1 Introduction

An important objective in the current Multi-annual workplan of the Scientific Committee (SC) of the South Pacific Regional Fisheries Management Organization (SPRFMO) is the *MSE development to design alternative harvest control rule*. The objective is for this work to lead to the adoption of a management procedure to replace the current rebuilding plan which is currently used to provide catch advice on Chilean jack mackerel (CJM). The stock is considered to have recovered from the time-series low around 2010, as intended by the rebuilding plan, and is now around the proxy biomass reference levels. Management procedures should thus be explored and evaluated that focus on the long-term exploitation of the stock.

Management Strategy Evaluation (MSE) is considered here as the analysis by which a management procedure is simulation-tested. Simulations are to be carried out on a model that represents our best knowledge of the stock and fisheries past and future dynamics, but also recognizes and quantifies the uncertainties in that knowledge. Operating models (OMs) are constructed to incorporate that uncertainty and provide tools for the stochastic evaluation of the performance of candidate management procedures.

The current status of development of the MSE toolset and platform for Chilean jack mackerel is briefly presented here. A final design for both the OM grid and the set of simulations to be carried out has been put together under the guidance of the SPRFMO Chilean jack mackerel Working Group MSE taskforce. Final development for the complete

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implementation of this design are taking place and simulation runs that will provide a first complete set of results will be carried out shortly.

1.1 Development

The analysis is being carried out using the tools available in the https://flr-project.org (Kell et al. 2007). The work builds of previous developments (Mosqueira and Tien 2022), but most of the codebase has been reorganized and streamlined.

Development work for this analysis is being carried out using source code repositories hosted at the SPRFMO github space. Operating model conditioning can be found at the jmOM repository and the application of MSE at jmMSE. Code is set up there following the conventions of the Transparent Assessment Framework (TAF) system, developed by the International Council for the Exploration of the Sea (ICES) but also used by other scientific bodies (e.g. IOTC and WCPFC). A third repository hosts the code for the *FLjjm* R package, which contains functions to bridge inputs and outputs of the JJM model to FLR and viceversa.

Use is also being made of the development infrastructure available for R that simplifies the compilation and installation of packages for a given project. The latest version of the necessary packages are available from the SPRFMO R-universe page and can be easily installed from an R session.

2 Operating Model conditioning

Operating models (OM) are quantitative representations of the past and future dynamics of a stock, or set of stocks, and the fisheries operating on them. Although commonly based on the existing stock assessment model (Sharma et al. 2020), the emphasis is on characterizing the productivity and time series dynamics of the population, together with the uncertainty in our knowledge about them, rather than the values of past and current stock status.

2.1 Joint Jack mackerel (JJM) stock assessment model

The fishery and population model in the OM is that of the Joint Jack mackerel (JJM) stock assessment model that is currently in use at SPRFMO (SPRFMO 2022).

2.1.1 Stock structure

The *jjms* model can be fitted to data with two different configurations on stock structure. A single stock, covering the whole area of distribution, or two sub-stocks (North and

Southern), with no exchange of biomass between them (see Figure 2.1).

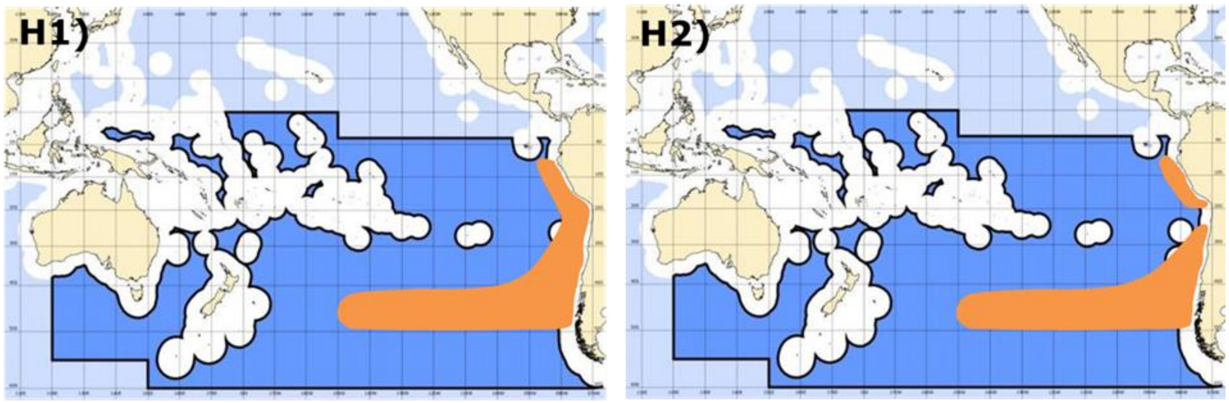

Figure 2.1. Illustration of two stock structure hypotheses currently used for stock assessment purposes within the SPRFMO Scientific Committee.

2.2 Uncertainty

For each of the operating models, a Markov chain Monte Carlo (McMC) sampling procedure was carried out using the latest version of the no-U-turn (NUTS) sampler for ADMB-based models(Monnahan and Kristensen 2018), as implemented in the R package *adnuts*. The sampler was set to run for a total of 12,500 iterations over two chains, with a fifth of those being used as burnin period, and thinning set to one every 10 iterations. A random sample of 500 iterations from each model run was then used to populate the operating model objects in FLR.

3 Operating Models

The operating model set summarised below has been agreed after analysis and consideration of the main sources of uncertainty for this stock. The base case OM has been chosen to be used for tuning the candidate MPs to a number of management objectives. Due to the different number of stocks in H2 and H2m, it is impossible to tune over multiple OMs in the base case. Hence, the performance of the procedures will be evaluated over the reference set, on which it will be required not to degrade significantly. Finally, the robustness set of OMs will be employed to understand the risks of the candidate MPs when confronted to alternative future stock or fishery dynamics. The current set has been assembled after a number of other hypothesis, for example alternative growth or natural mortality values, but were considered of limited interest or showed a limited effect on population dynamics.

- **Base case**
  - H1. Single-stock JJM model 1.07, h=0.65.
- **Reference set**
  - H2. Two stocks JJM model 1.07, h=0.65.
  - H2m. Two sub-stocks JJM model 1.07, movement rates in the future from SEAPODYM fit (Dragon et al. 2017).

- H1h80, Single-stock JJM model 1.07, higher stock-recruitment steepness h=0.80.
- H2h80, Two stocks JJM model 1.07, higher stock-recruitment steepness h=0.80.

- **Robustness set**
  - H1lowrec & H2lowrec, Alternative low future recruitment scenario [@].

The operating models, conditioned for the historical period by applying the McMC procedure detailed above, were loaded as *FLR* objects of class *FLombf* using the custom-written code available in the *FLjjm* package. Alternative formulations and values for future dynamics (e.g., movement, recruitment level) were then formulated to build the complete grid.

3.1 Single-stock (H1)

Figures 3.1 to 3.4 present the single-stock operating model. The time series of population and fishery metrics (Figure 3.1) show the level of uncertainty in past and current status that the OM contains. This is expressed relative to MSY and virgin reference points in Figure 3.2. The OM has as starting point that appears to be well above the desired exploitation levels.

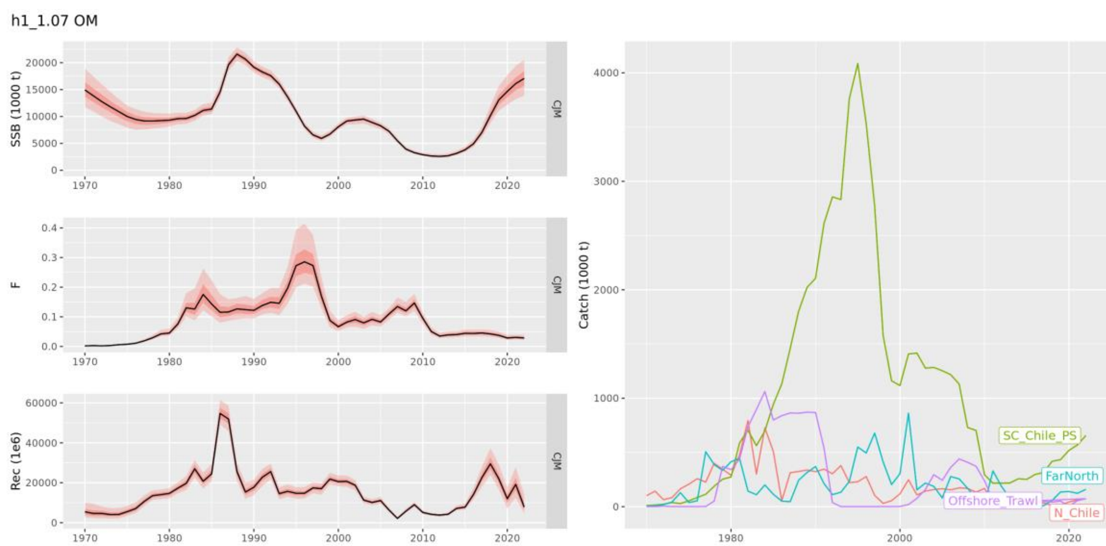

Figure 3.1: Time series for the biological population (SSB, F and recruitment on the left) and the catch per fishery (right) over the historical conditioning period (1970-2023) for the single-stock OM. Ribbons show the 50 and 90% credibility intervals and black line the median.

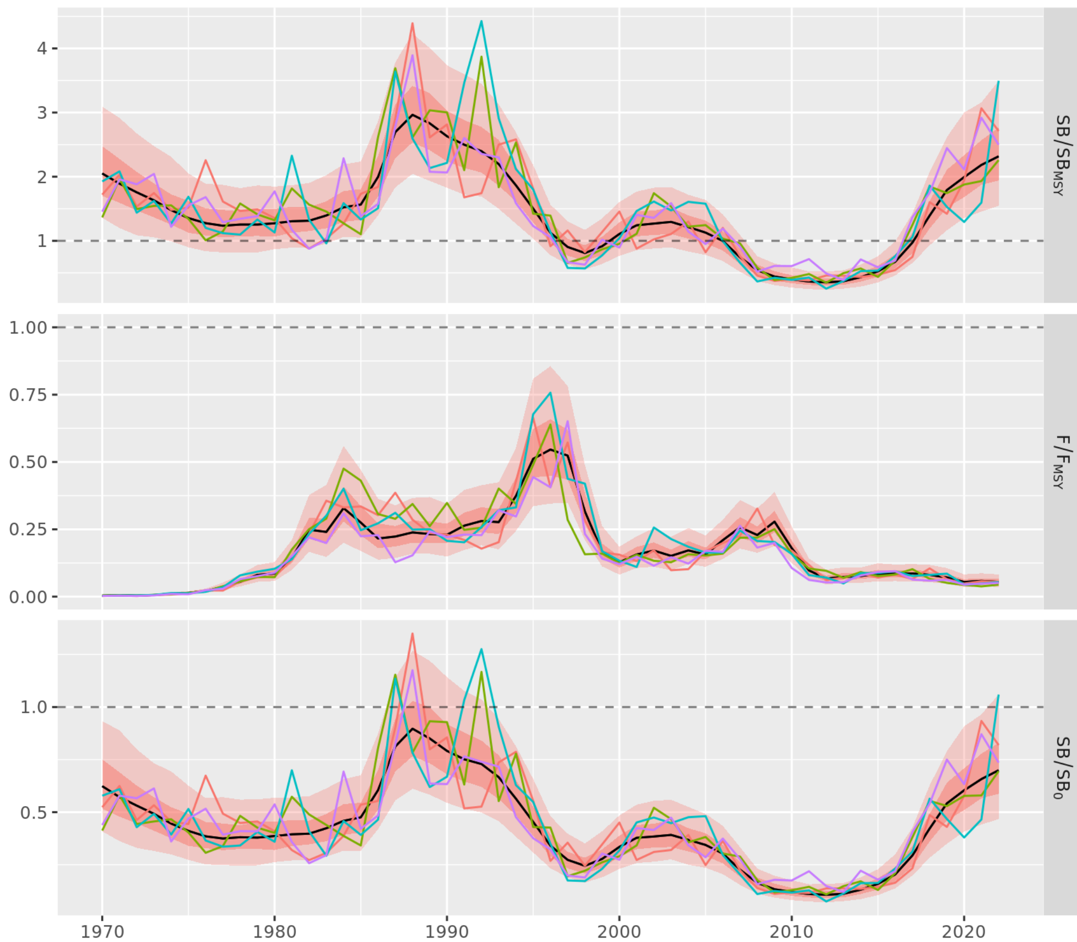

Figure 3.2: Time series of stock status indicators (SB/SB_{MSY}, F/F_{MSY} and SB/SB_0) over the historical conditioning period (1970-2023) for the single-stock OM. Ribbons show the 50 and 90% credibility intervals, black line the median, and coloured lines a number of individual trajectories.

Another view of the uncertainty in stock dynamics and scale is provided by the distributions of various reference points in Figure 3.3.

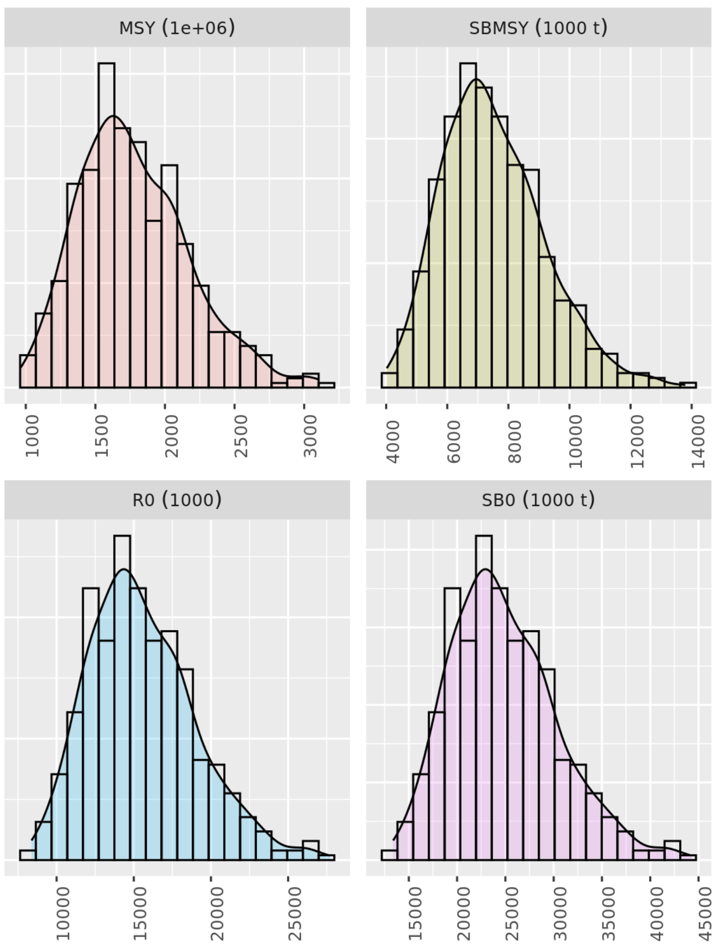

Figure 3.3: Distributions of the reference points (MSY, SB_{MSY}, F_{MSY}, R_0 and SB_0) returned by the McMC run for the single-stock OM.

Finally, the standard set of future recruitment deviances can be compared with those estimated by the OM conditioning (Figure 3.4). These are lognormal deviances, generated from the individual values of variance (σ) and lag 1 autocorrelation (rho) in each McMC sample. Robustness tests will be carried out employing alternative levels of mean recruitment, following the perceived dynamics of the stock that appears to oscillate between periods of higher or lower recruitment due to environmental factors.

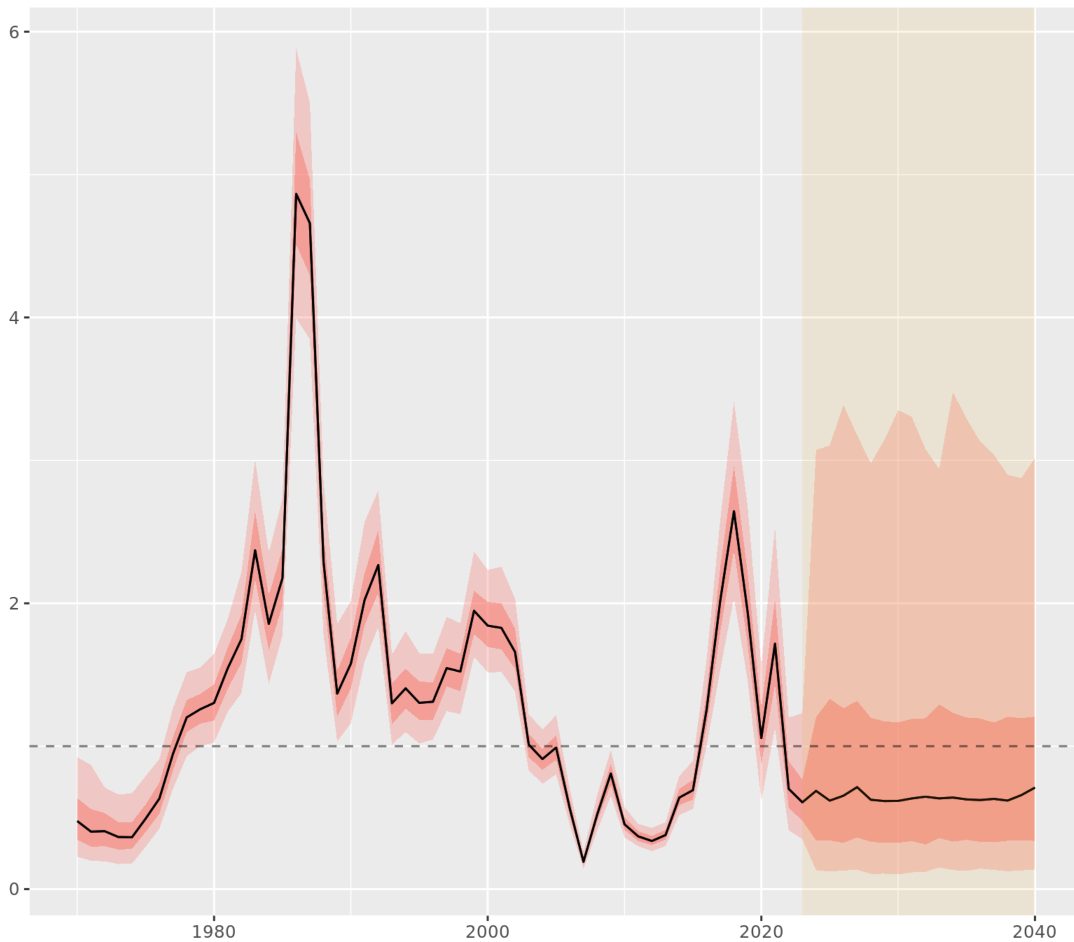

Figure 3.4: Past and future log-scale deviances in recruitment for the single-stock OM. Values from 2023 show those used in the base case OM.

3.2 Two stocks (H2)

The same set of figures, but corresponding to the two stock OM (H2) are presented in Figures 3.5 to 3.8.

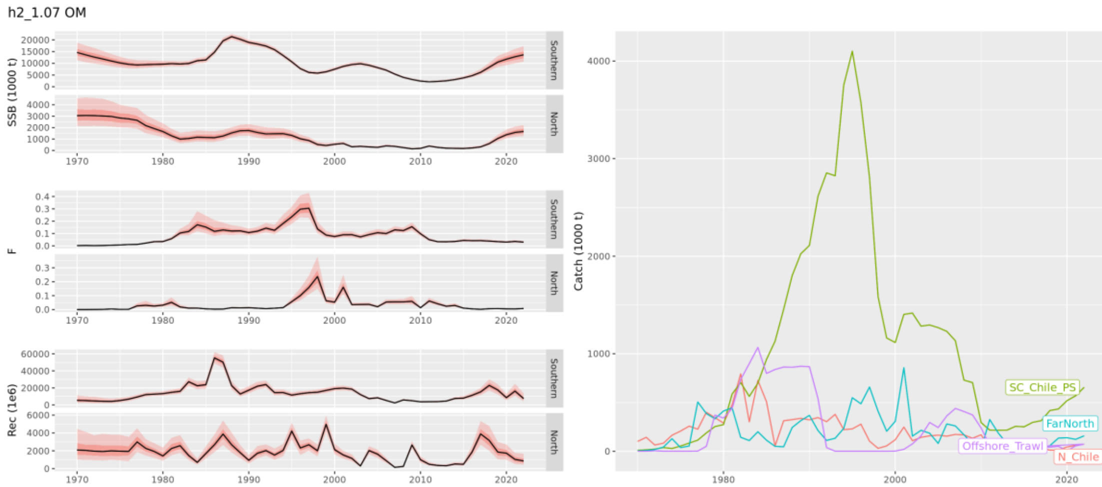

Figure 3.5: Time series for the biological population (SSB, F and recruitment on the left) and the catch per fishery (right) over the historical conditioning period (1970-2023) for the two stocks OM. Ribbons show the 50 and 90% credibility intervals and black line the median.

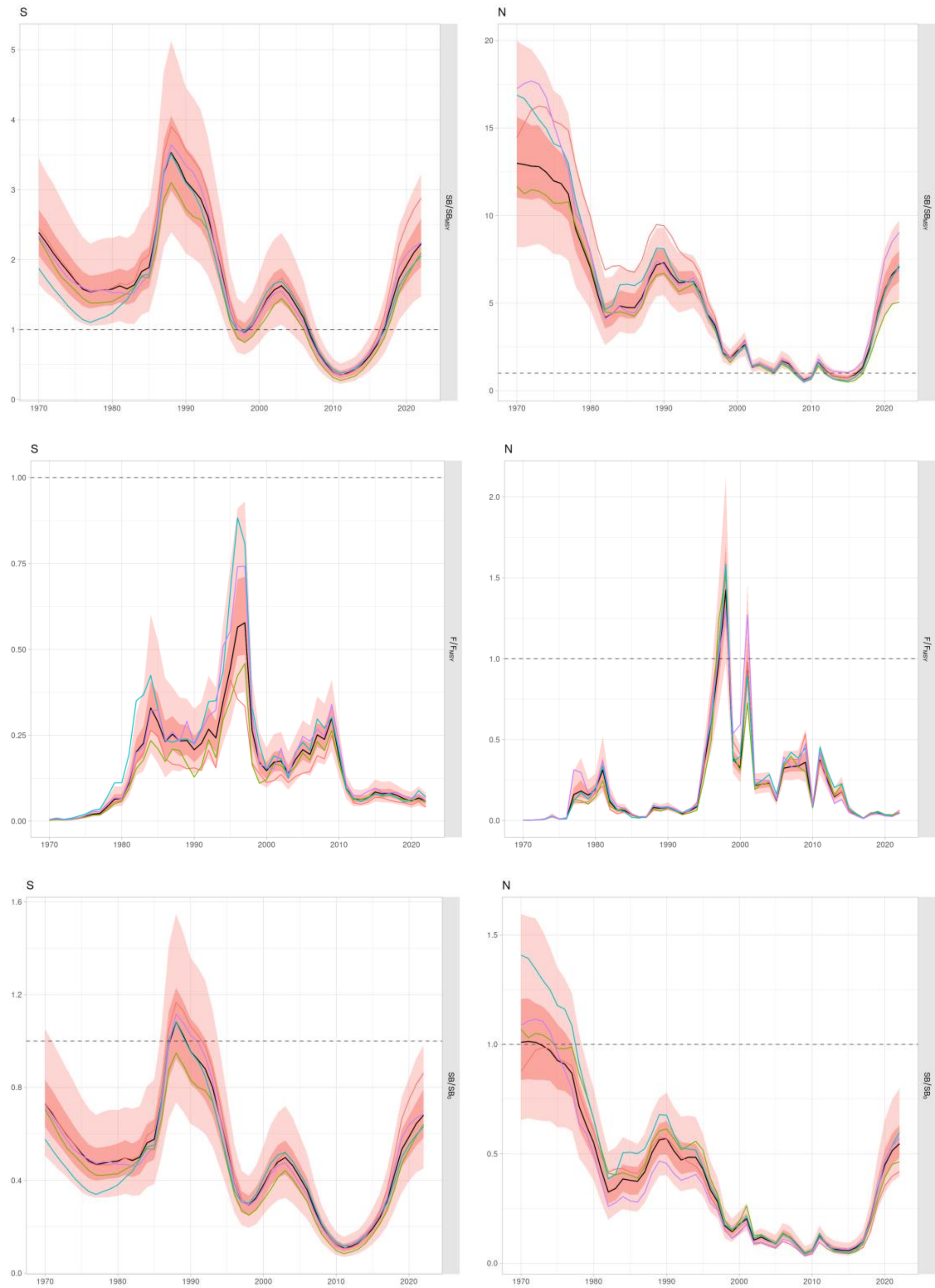

Figure 3.6: Time series of stock status indicators (SB/SB_{MSY}, F/F_{MSY} and SB/SB_0) over the historical conditioning period (1970-2023) for the two-stock OM. Ribbons show the 50 and 90% credibility intervals, black line the median, and coloured lines a number of individual trajectories.

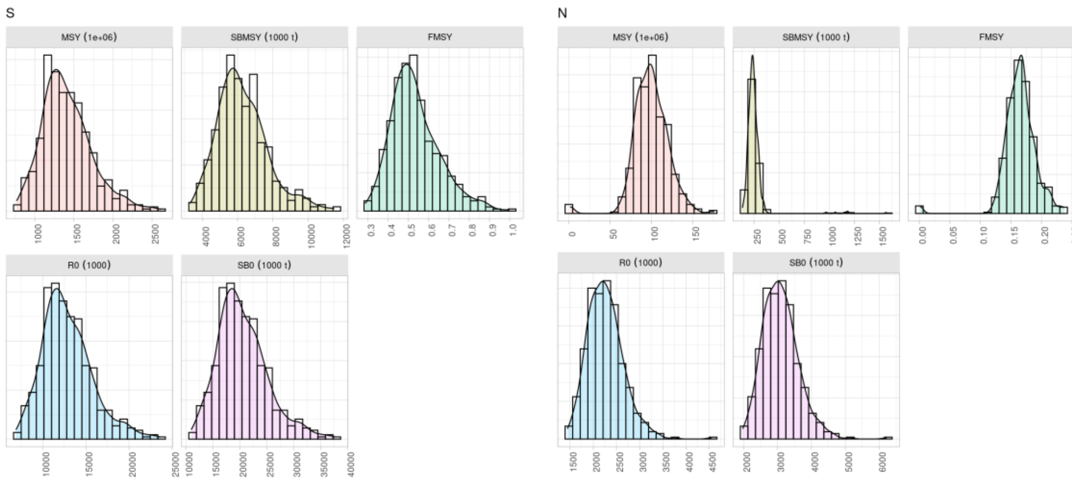

Figure 3.7: Distributions of the reference points (MSY, SB_{MSY}, F_{MSY}, R_0 and SB_0) returned by the McMC run for the two stocks OM.

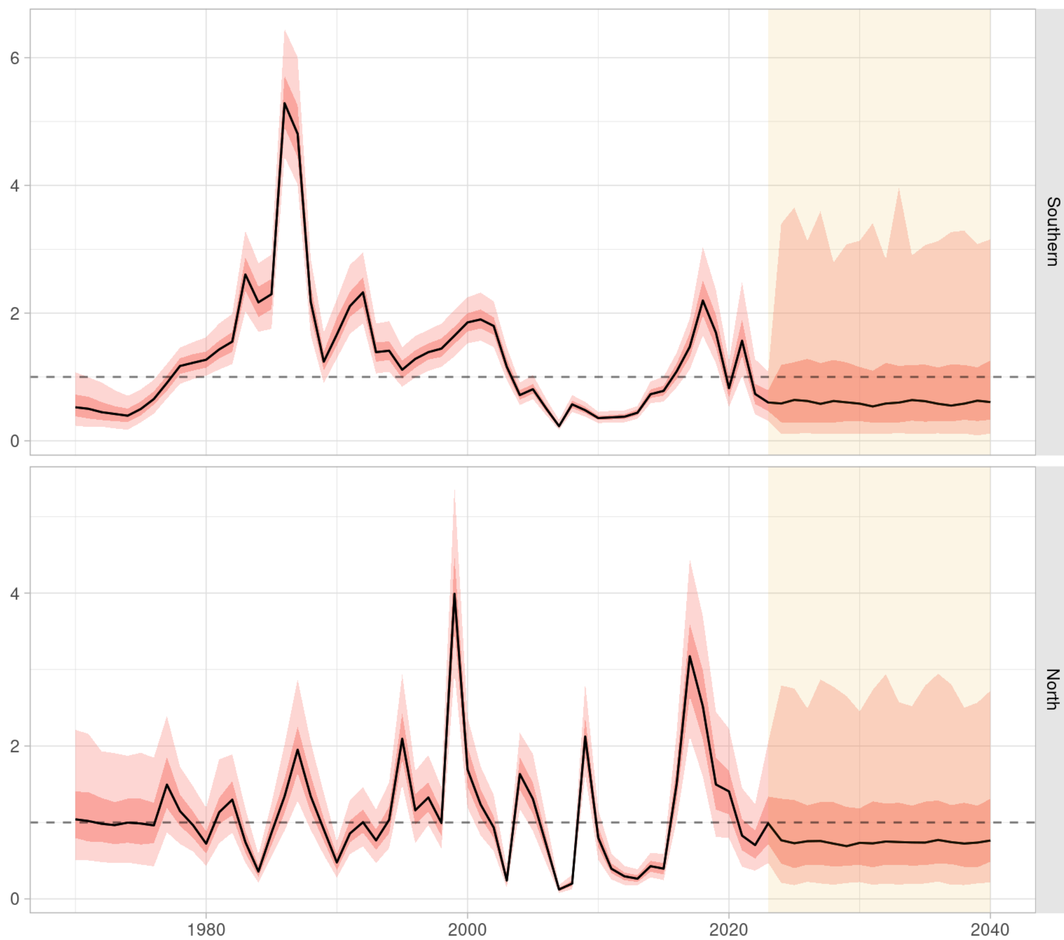

Figure 3.8: Past and future log-scale deviances in recruitment for the two stocks OM. Values from 2023 onwards are those used in the base case OM.

4 Validation of Operating Models

A series of projections were conducted to assess the behaviour of the various operating modes, carried out at different levels of fishing mortality ($F = F_{MSY}$, $F = F_{2022}$, and $F = 0$) and catch (0.75, 1 and 1.25 Mt). Time series of the resulting runs are presented in Figures 4.1 to 4.6.

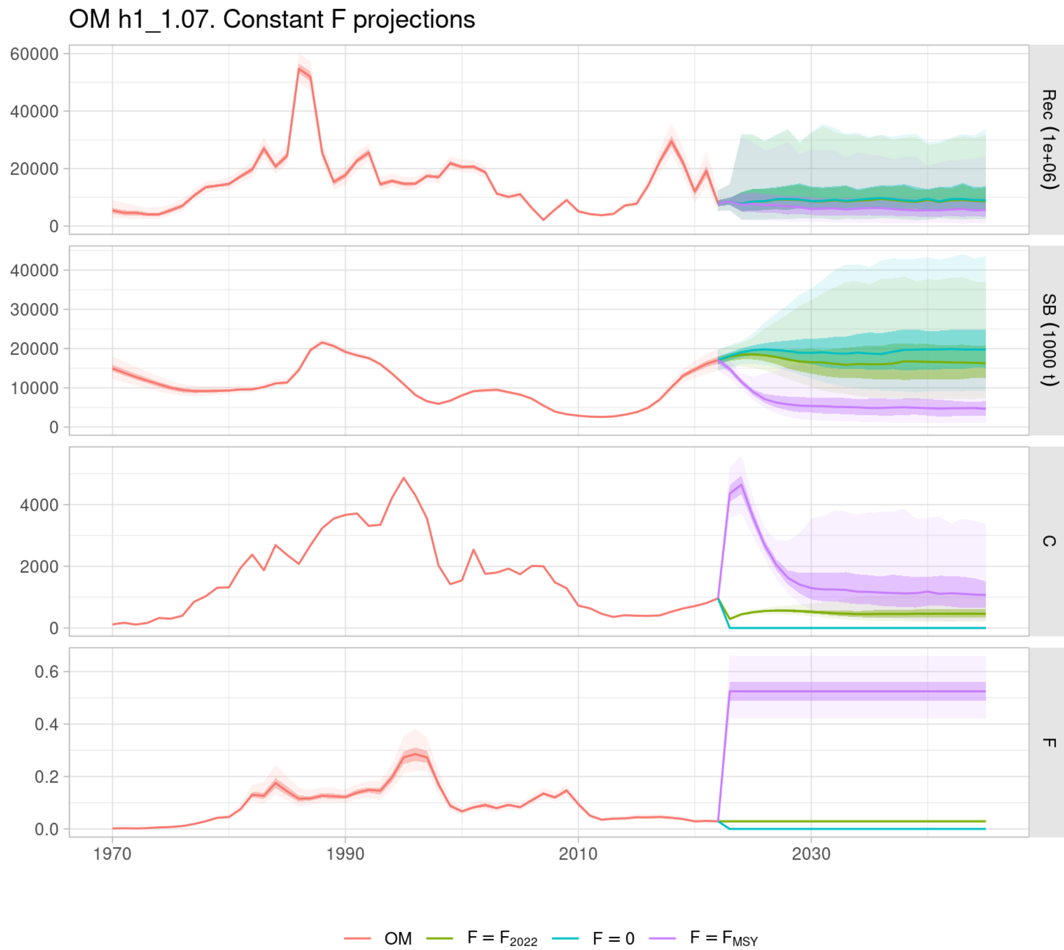

Figure 4.1: Forward projections of the single-stock OM over different levels of constant fishing mortality: F at the 2022 level (F_{2022}), no fishing mortality ($F = 0$), and at the F_{MSY} levels. Ribbons show the 50 and 90% credibility intervals and black line the median.

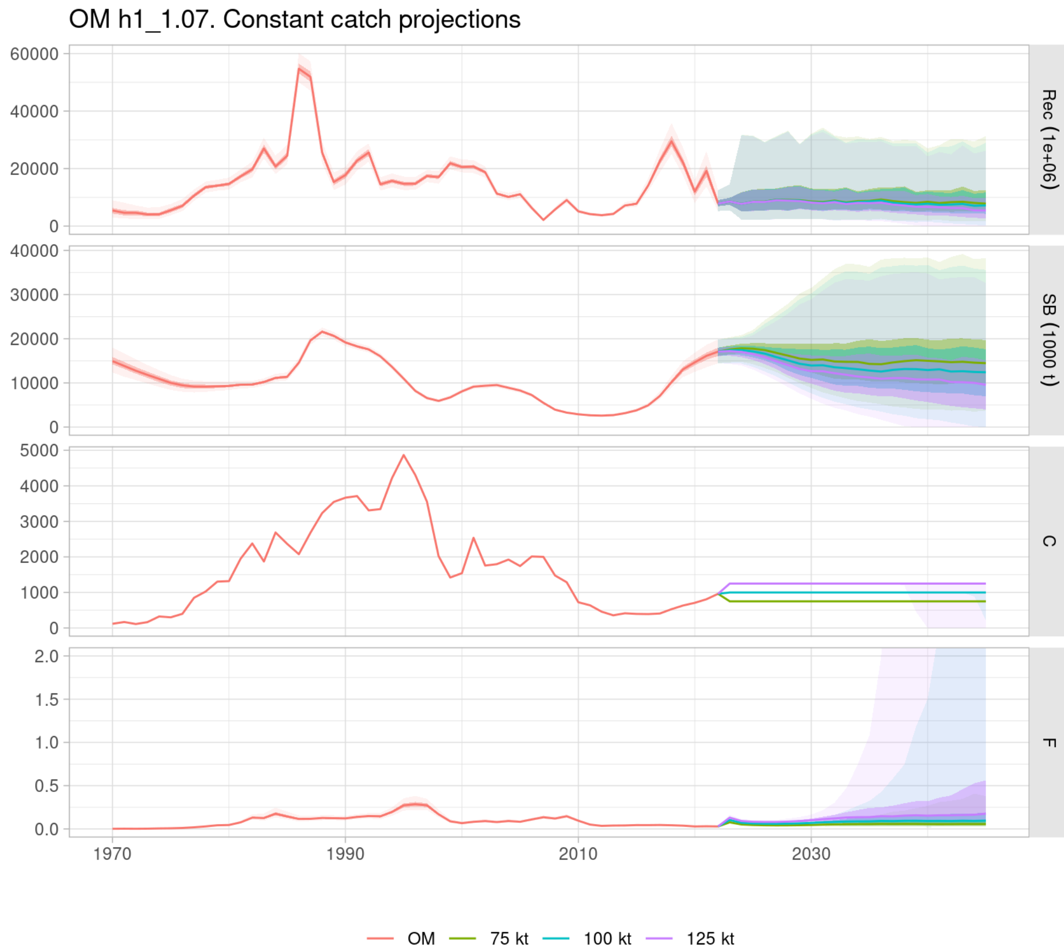

Figure 4.2: Forward projections of the single-stock OM over different levels of constant catch: 7.5 (C75), 1 (C100) and 1.25 (C125) million tonnes.

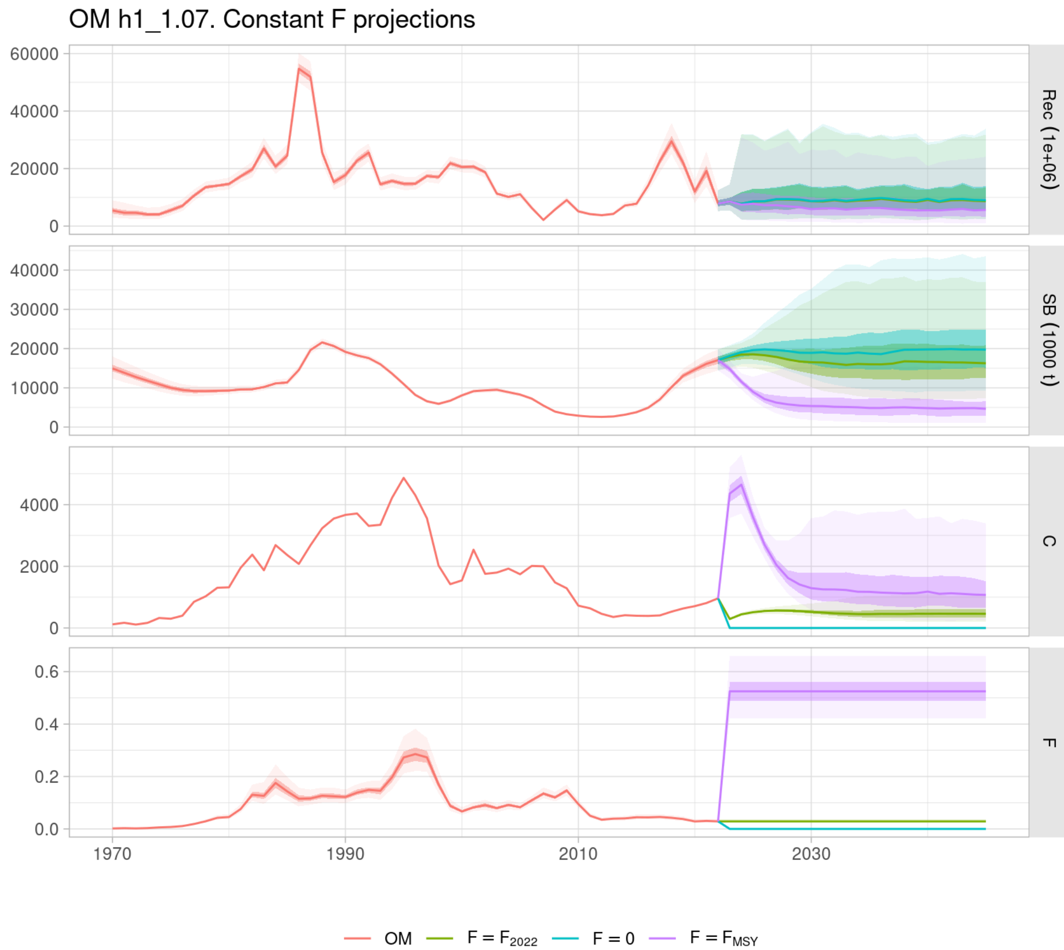

Figure 4.3: Forward projections of the two stocks OM (H1) over different levels of constant fishing mortality: F at the 2022 level (F_{2022}), no fishing mortality ($F = 0$), and at the F_{MSY} levels. Ribbons show the 50 and 90% credibility intervals and black line the median.

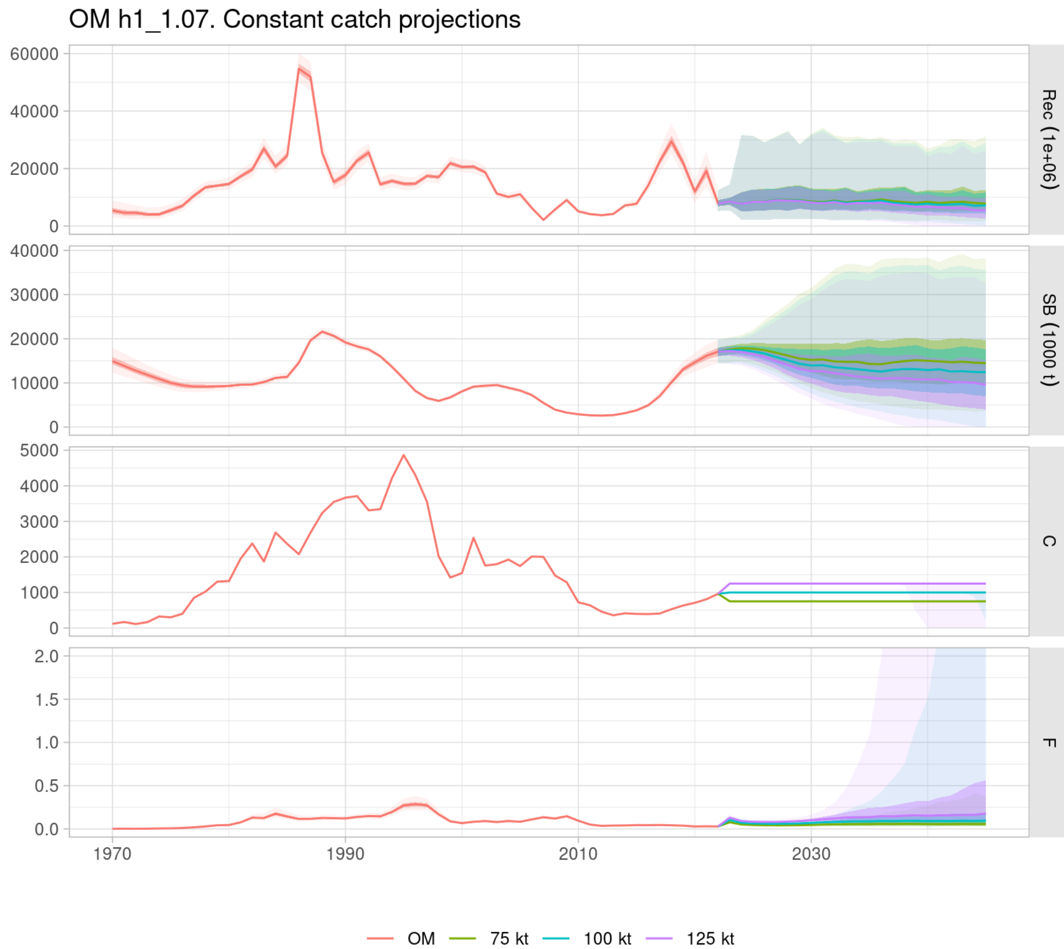

Figure 4.4: Forward projections of the two stocks OM (H2) over different levels of constant catch: 7.5 (C75), 1 (C100) and 1.25 (C125) million tonnes.

The differences in behaviour between the two-stock OMs with or without movement across the two units is summarized in Figures 4.6. The movement rates currently applied do not translate into a large difference in abundances when the same catch level (0.75 Mt) is applied every year. Robustness tests will be conducted that will attempt to evaluate the potential effect of the movement of fish across sub-stocks under other circumstances, for example when the smallest sub-stock has been severely depleted. This would allow a better understanding of the dependency of any result on the assumed results, known to be poorly estimated and likely to change in time.

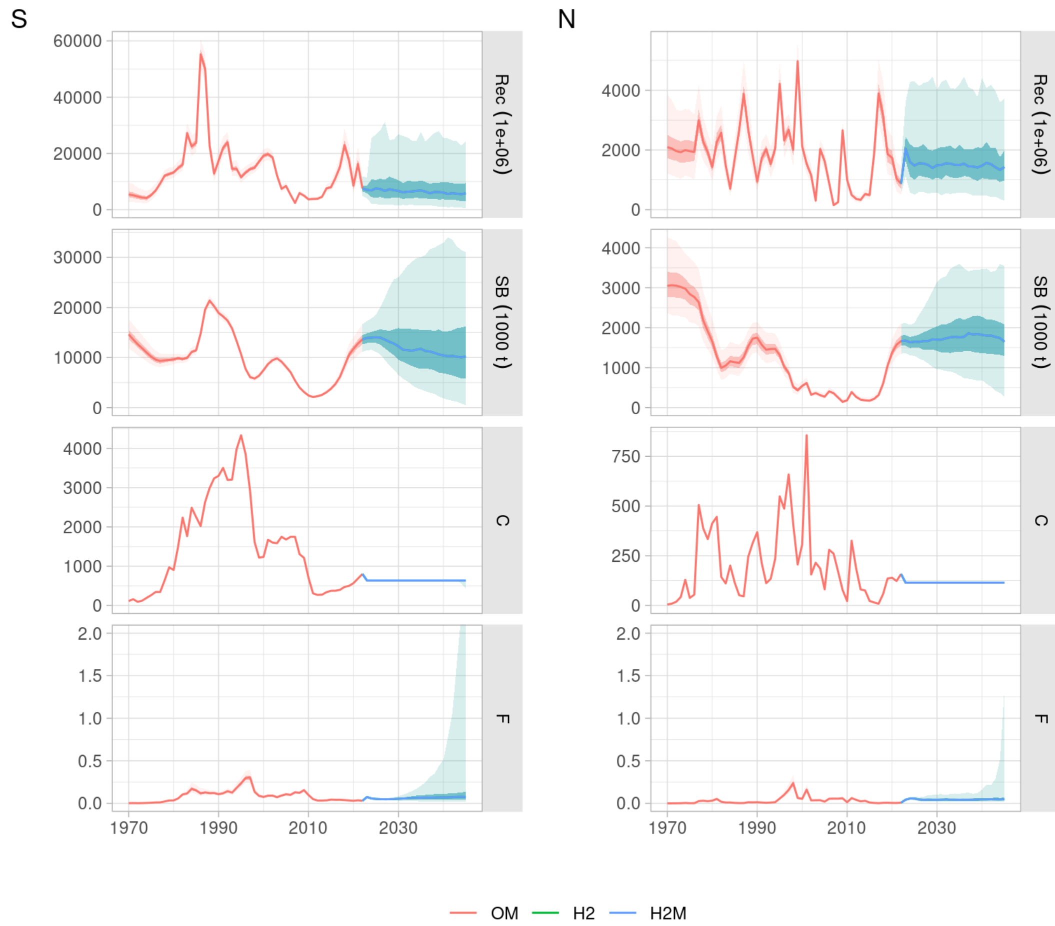

Figure 4.5: Forward projections of the two stocks (H2) and two sub-stocks (H2m) OMs over a constant catch level of 0.75 million tonnes.

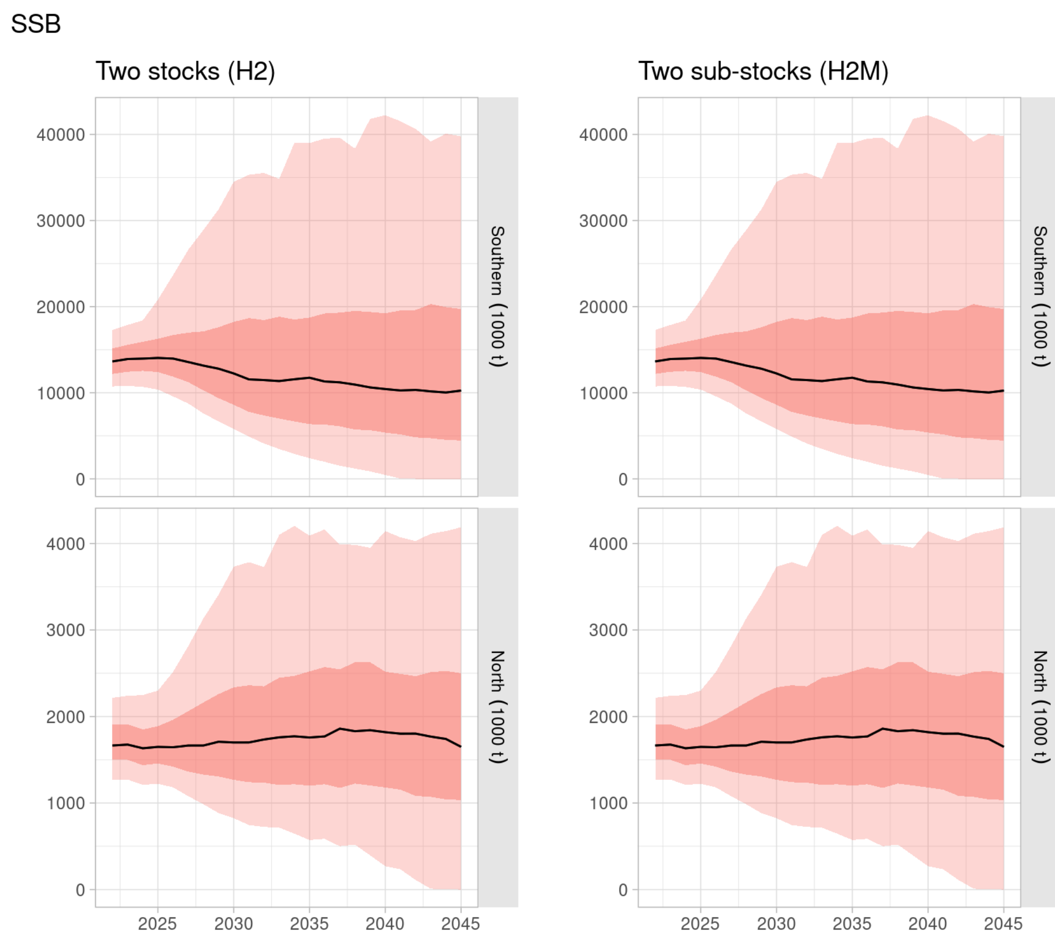

Figure 4.6: Spawning stock biomass for the forward projections of the two stocks (H1) and two sub-stocks (H2m) OMs over a constant catch level of 7.5 million tonnes.

5 Observation Error Model (OEM)

Observations on catch and abundance across the different fleets and surveys are generated from the operating models in the projection years. This model element replicates the collection of scientific and fishery data that is carried out to inform the advice process.

Both fishery-dependent and fishery-independent data are generated by the OEM, and for all data sources expected to be available for the stock in the future:

- Annual catch-at-age for three of the four modelled fisheries (North Chile, Chile CS and Offshore trawl).
- Annual catch-at-length for the Far North fishery.
- Relative abundances in biomass for the four ongoing indices of abundance (Chile Acoustic North, Chile CPUE, Peru CPUE and Offshore CPUE)

Initial explorations of the candidate management procedures consider no error in these observations. Appropriate distributions are then used to generate error on each of these data sources. Bias on indices of abundance, due to limitations in spatial coverage for scientific surveys or increases in efficiency for CPUE series, have not yet been considered, but could later be applied if requested.

6 Performance Statistics

The results of the application of each candidate MP during the simulation tests are evaluated using a set of performance statistics (PS). We define them as summaries of a series of stock and fishery metrics (e.g. spawning biomass or total catch), often combined with a reference value (e.g. biomass at MSY). The statistics are computed over a given time period or a set of them, annual or multi-annual, and summarized as averages, probabilities or measures of variability.

The current set of performance statistics relate to four axis of interest:

- Status: probability that the stock is in the desired biomass and/or exploitation level (e.g. the green quadrant of the Kobe matrix).
- Safety: probability of the stock not falling below certain biological limit reference point.
- Yield: catch in the projection period, in the short and long term.
- Stability: variation in yield and stock status between management cycles.

The following table lists the current set of performance statistics. All of them are computed over three time periods: short-term (1-5 years from start of projection period), medium (6-10 years) and long (11-20 years). Additionally, certain statistics are also computed yearly, in order to assess their evolution in time. That is the case, for example, of the probability of the stock biomass and fishing mortality falling in the green quadrant of the Kobe plot (*green*), or the overall yield (C).

Summary of performance statistics being applied in the analysis of MPs for SPRFMO jack mackerel.

Family	Name	Description	Definition
Status	SBMSY	Mean spawnwer biomass relative to SBMSY	SB/SB_{MSY}
	FMSY	Mean fishing mortality relative to FMSY	F/F_{MSY}
	green	Probability of being in Kobe green quadrant	P(Green)
	PSBMSY	Probability of SB greater or equal to SBMSY	P(SB>=SB[MSY])
Safety	PSBlim	Probability that spawner biomass is above SBlim	P(SB>SB[limit])
	PC0	Probability of fishery shutdown	P(shutdown)
Yield	C	Mean catch over years	mean(C)
Stability	IACC	Percentage inter-annual change in catch	IAC(C)
	IACK	Percentage inter-annual change in Kobe status	IAC(K)

7 Candidate Management Procedures

Management procedures are defined in essence as a combination of models and calculations that infer the status of a fish stock, decide on the value of a given input (e.g. effort) or output (e.g. catch) variable, and resolve on a mechanism for its implementation on the fishery. These three main steps (estimation, decision making and implementation) depend on the information and data obtained by a sampling and observation protocol.

7.1 Full-feedback JJM (*jjm*)

The stock assessment model currently applied on the stock, JJM, is employed as the estimation step in this MP. The model employs the formulation applied in the 2023 stock assessment (SPRFMO 2022), as set during the latest benchmark exercise (SPRFMO 2022).

A hockey-stick harvest control rule is then used to set the total catch level from the estimate of spawning stock biomass returned by JJM.

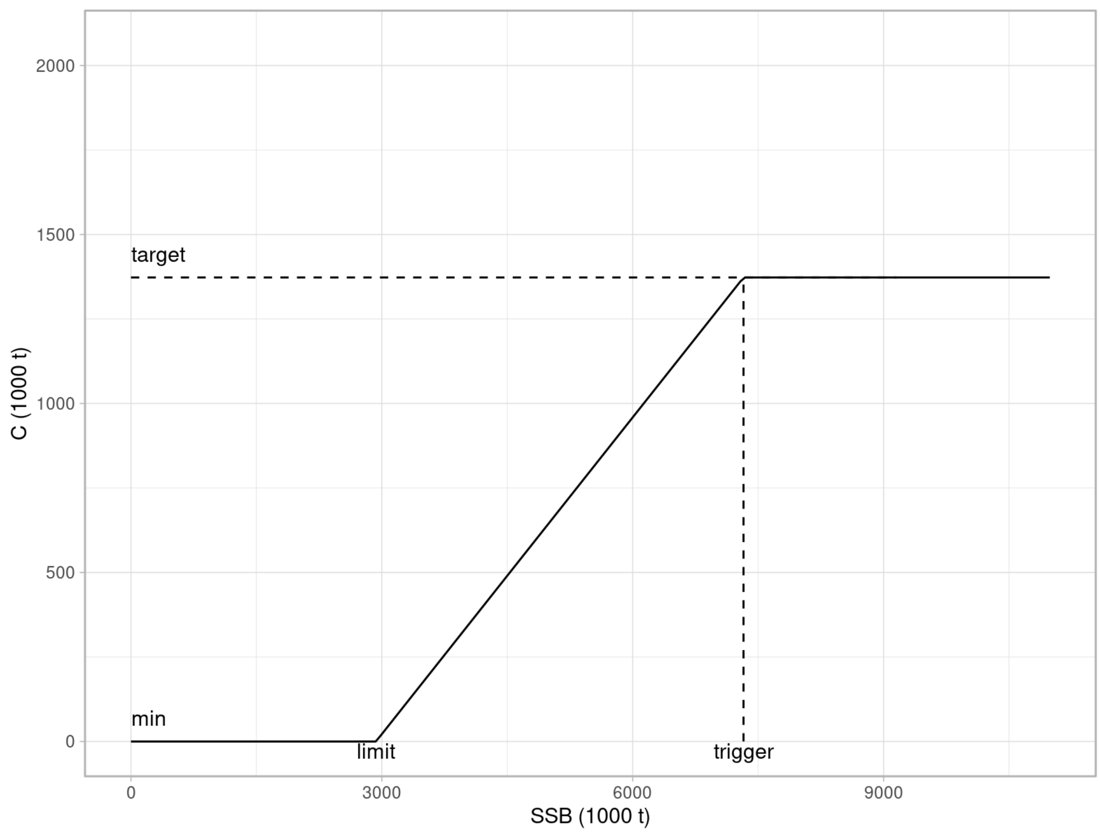

Figure 7.1: Example formulation of the hockeystick HCR, with its shape set around the current reference points for the jack mackerel stock.

7.2 CPUE-trend MP

An MP based on the recent trend and value of an index of abundance is being tested for the stock. The slope over the last five years, and a weighted average over the last three, are computed and used to derive a new catch limit (T) for year y from that in the previous year as follows,

$$T_y = T_{y-1} \cdot (1 + k_a * s + kb * (I - t))$$

where k_a and k_b are reactivity parameters for the slope s and target level (t), respectively. Both k_a and k_b can be set to respond with different intensity to decreases or increases in slope and distance from the target level. The later is commonly used as a tuning parameter, but a value could also be taken from a period where catch rates and stock status were determined to be both favourable. An initial exploration of the influence of different values of the reactivity parameters is being carried out to explore the trade-offs between speed of reaction and influence of noise and error. The Chilean CPUE index is currently being applied to this MP.

7.3 Relative harvest rate MP

Harvest rate, the ratio of the total catch over the stock biomass, is a measure of fishing pressure frequently used in stock assessment models and management rules. It provides an equivalent measure to instantaneous fishing mortality on the strength of exploitation of a stock. The concept of relative harvest rate, the ratio of total catch to a relative indicator of stock size (such as a survey index), has been proposed and tested recently for management on stocks for which a stock assessment is unavailable (Fischer et al. 2022). This stock status estimator makes use of the two main data sources: the total catch estimate and the value of a selected index of abundance, assumed to best represent the overall trends in stock biomass.

7.4 Distribution of catches

After a maximum catch level has been returned by the harvest control rule, the implementation system separates them among the four defined fisheries, as defined in the JJM assessment model: North Chile, South and central Chile PS, Far North and Offshore trawling. Future projections assume future catches will be split across fisheries with proportions equal to the average of those recorded over the last five years.

The current process by which catches for the Peruvian fishery are set, based on the results of the two-stocks JJM run is replicated as part of the implementation error model (IEM) module of the MSE evaluation. Rather than a full implementation of this process, which would require fitting the two-stock JJM model in every simulation, this is being approximated as a variable proportion of the overall catch. A set of full-feedback runs of the JJM MP, applying the two-stock model, is being used to corroborate the quality of this approximation.

Future mechanisms for catch allocation or distribution could be incorporated into the analysis at a later stage to evaluate their n any MP or proceed to retune any chosen one to incorporate this change.

8 Simulation Testing

Simulation runs across the OM and MP sets are starting to be carried out. Candidate MPs will be tuned for three management objectives: 50, 60 and 70% probabilities for the stock falling in the green quadrant of the Kobe plot. That indicates that both SSB is larger than the value of SSB at MSY while the fishing mortality is below its MSY reference. Tuning is being carried out initially over the H1 base case OM. The resulting tuned MPs will then be applied to the other OMs in the reference set and their performance compared. If this is found to degrade beyond some reasonable level, tuning will be carried out using them as well, so MPs are found that work across the whole reference set.

Robustness testing of the tuned MPs will then be carried out. The focus will be on finding the point at which certain assumptions being broken lead to an MP performance not being deemed acceptable. For example, the ability of the MP to work if the stock moves from a high recruitment to a low recruitment regime, and responds fast enough to that change, will be computed.

8.1 Status of simulation testing exercise

The following sections contain a reduced set of example runs of the MPs described above and for some of the OMs in the set. Runs shown here have been carried out on a limited number of 50 iterations (stochastic replicates) for computational reasons.

8.1.1 H1 OM, *jjm* MP

The *jjm* MP, which employs the JJM assessment model to provide an estimate of SSB to compare with the trigger and limit points of a hockey-stick HCR, has been shortcut here for computational simplicity. Lognormal error is added to a direct observation of the OM SSB to provide the MP with an unbiased indicator of stock status. Alternative values for the maximum and long-term target catch parameter (1, 1.5 and 2 Mt) are compared in Figures 8.1 and 8.2. The first one applies a standard hockeystick HCR while second uses an alternative formulation that returns catches higher than the target value if the stock is above an upper buffer level, and only reduces them when it falls below a lower buffer.

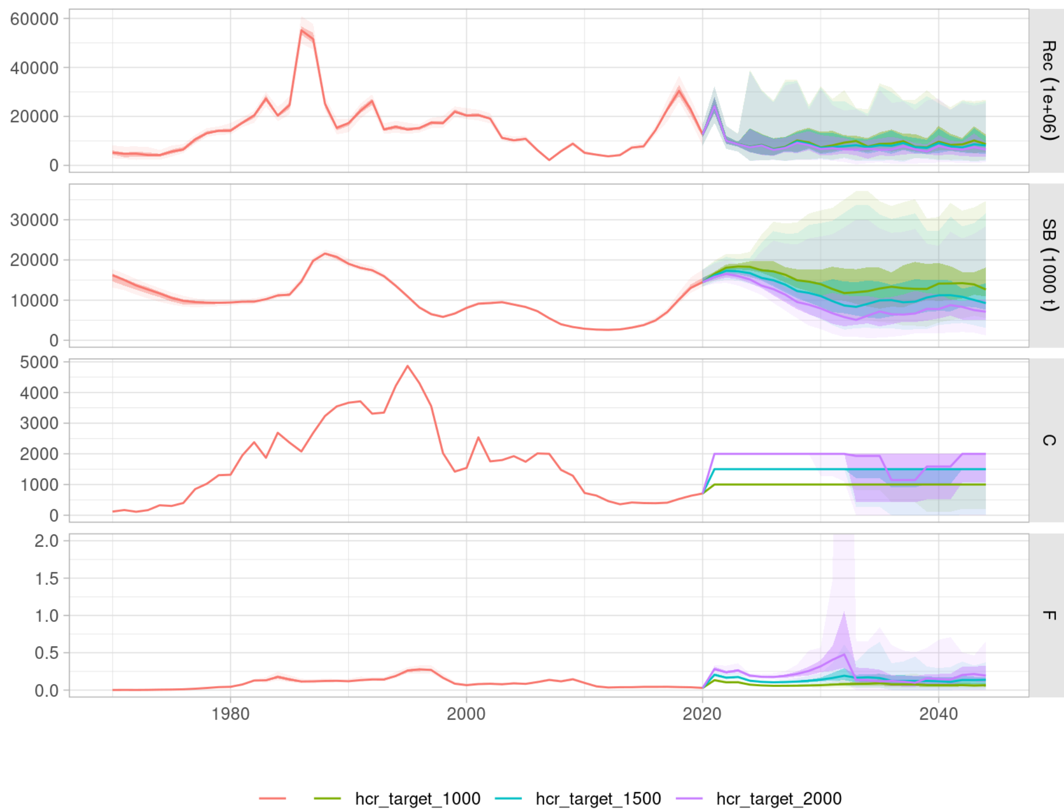

Figure 8.1: Runs of the jjm MP with alternative values for the maximum catch level. Plot shows the time series of the main stock metrics (recruitment, SSB, catch and F). Ribbons show the 50 and 90% credibility intervals with the median as a solid line.

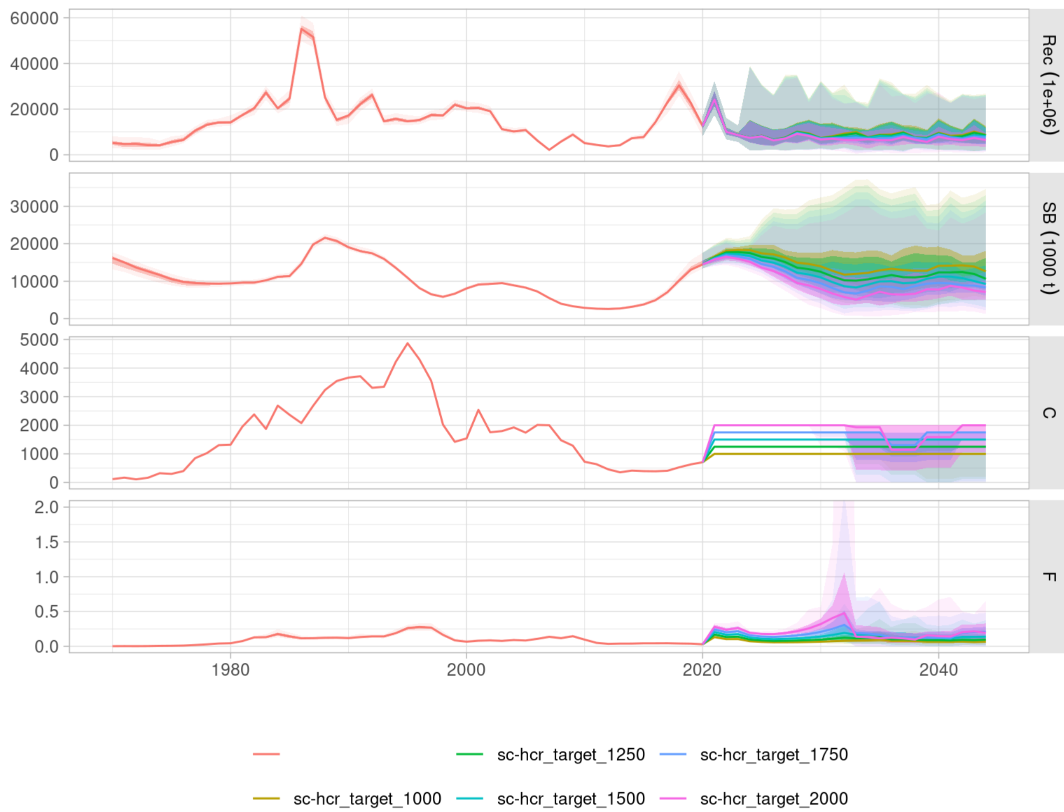

Figure 8.2: Runs of the jjm MP plus the catch buffer HCR with alternative values for the maximum catch level. Plot shows the time series of the main stock metrics (recruitment, SSB, catch and F). Ribbons show the 50 and 90% credibility intervals with the median as a solid line.

9 Discussion

This brief document reports on the current status of work on the development and implementation of operating models, management procedures and simulation tests for the Chilean jack mackerel stock under the SPRFMO mandate. At this stage, a clear formulation of the sources of uncertainty, alternative scenarios, candidate MPs and simulation design has been agreed through meetings of the SPRFMO CJM WG MSE taskforce.

Initial tests have been carried on most MP and OM combinations. The full set of simulation runs in the agreed design will be run over the next weeks. The results are expected to provide SPRFMO scientists and managers with a set of candidate MPs that are shown to be sufficiently robust and successful at achieving the management objectives for the stock.

10 Acknowledgements

The work presented here has been carried out under contract with SPRFMO and financed by European Commission projects 101058576 (Support to Management Strategy

Evaluation for Jack mackerel in the South Pacific Regional Fisheries Management Organisation) and 101089755 (Support to science-based decision making in SPRFMO). This document cannot be considered to reflect the views of the SPRFMO and/or the European Commission on this matter.

Work has benefited greatly from the valuable contributions of and fruitful discussion with the members of the Chilean Jack Mackerel working group MSE taskforce.

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