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Management Plan evaluations for Jack Mackerel (*Trachurus murphyii*) – evaluating the adopted rebuilding plan

Niels T. Hintzen, Thomas Brunel, Marie-Emilie Guele

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Abstract

The South Pacific Regional Management Organization and their members (the Commission) requested an evaluation of a proposed rebuilding plan (harvest control rule (HCR), see 2nd Commission meeting, Annex K) and if possible, to design and evaluate alternatives. This document described a framework developed to evaluate the proposed rebuilding plan and potential alternative plans. The output of the 2013 Jack Mackerel stock assessment has been used as the basis for these evaluations. Based on two stakeholder consultations a number of alternative plans were developed an evaluated. The derivation and design of these plans are presented in this study. The results of the evaluation of the plans, using Management Strategy Evaluation, show the performance of these plans according to a number of performance statistics (choices by the authors were made regarding the way of calculating the performance statistics).

Introduction

Ensuring sustainable exploitation of the Jack Mackerel stock is of core interest to the South Pacific Regional Fisheries Management Organization and their members (collectively referred to as the Commission). Due to recent overexploitation, combined with an apparent shift in productivity of the stock, population biomass is now estimated to be well below the biomass level which would achieve Maximum Sustainable Yield. In order to rebuild the stock and fishery towards sustainable targets, the Commission requested an evaluation of a proposed harvest control rule (HCR) and if possible, to design and evaluate alternatives.

Harvest Control Rule designs come in many different flavors. The Commission proposed HCR for example aims to fish the Jack Mackerel stock at F_{MSY} whenever stock biomass reaches B_{MSY} or above. Below that level, the plan should ensure that jack mackerel biomass increases from year to year. Other HCRs, already in place for small pelagic fish, aim to keep a stock at or above a certain biomass threshold or to fish a stock at constant fishing mortalities. Often, in these HCRs biomass or fishing mortality trigger points are used in its design. At these trigger points, the management procedure changes. An example of such a trigger point is B_{MSY} in the Commission proposed HCR. Above this trigger point, the maximum total allowable catch (TAC) is set according to a fishing mortality equalling F_{MSY}. Below this point, the proposed fishing mortality may be reduced. In this study we designed a variety of HCRs based on preferences expressed in two stakeholder consultation meetings, one held in Lima and one in Brussels (Annex I, II). Within this variety, some HCRs make use of such trigger points too, where the value of these trigger points are informed by proposed reference points. Hence, the reference points provide guidance on potential designs of Harvest Control Rules. Trigger points may however take any value suitable and do not need to be based on reference points.

A commonly used approach to test the performance of HCRs consists of simulating the mid to long-term developments of a stock under a certain TAC setting regime / HCR. The simulations should represent plausible true stock dynamics, and take into account the various sources of uncertainty in the assessment and in the management system. A range of diagnostics can then be calculated from the output of the simulation, which can be used to describe the performance of any given HCR.

The Commission requested a review of the provisional HCR (Rebuilding Plan) adopted by the 2nd meeting of the Commission and evaluate potential other plans. To this end a management strategy evaluation tool was developed for Jack Mackerel which uses the most recent stock assessment data from which to condition an operating model. For simplicity, a single-stock hypothesis was selected. Presumably this approach could be extended to evaluate alternative stock structure hypotheses. The Commission requested a review and evaluation of their proposed Rebuilding and Conservation plan by:

- Implementing a default Harvest Control Rule (HCR) following the guidelines specified below
- Develop an operating model to test the performance of this HCR under unknown and uncertain conditions/realities
- Alternative HCRs can be entertained to set annual catch limits to evaluate as part of the rebuilding plan
- Propose performance statistics which will enable the Commission to evaluate this and other HCRs.

Further they requested reporting on performance statistics on:

1. The rate of biomass growth during a certain time frame
2. Expected catch and catch variability
3. Risks of biomass decline, and
4. Expected time to reach X% of unfished SSB (a proxy representing 80% of B_{MSY}

For illustration purposes, a number of HCR designs were constructed and evaluated using the management strategy evaluation framework that implements HCRs in a simulation framework taking uncertain conditions on stock dynamics, fisheries and TAC setting procedure into account. The performance statistics requested by the Commission provide no exact guidance on implementation. To show the performance of different HCRs however, choices by the authors were made regarding the way of calculating performance statistics. It is in the end up to stakeholder discretion to decide on the most appropriate performance statistics.

Methods

The framework used in this study to evaluate the performance of the Commission proposed HCR and alternatives is the Management Strategy Evaluation (MSE) tool. The principle of an MSE is to represent the true dynamic of the stock and of the fleets exploiting this stock as realistically as possible, and to mimic the stock assessment and management procedure. The MSE should give a correct perception of the sources of natural variability in the stock and of the uncertainty in the management system. In order to reflect these uncertainties, the simulations are run simultaneously for a large number of replicates (200 in this case) of the stock, each representing a likely version of the true stock and fisheries.

A MSE typically consists of four building blocks: 1) a biological operating model, simulating the dynamics of the Jack Mackerel stock, 2) a fleet operating model, simulating the dynamics of the four fleets targeting Jack mackerel, 3) the assessment procedure, mimicking the joint-jack-mackerel stock assessment model and 4) a TAC setting procedure or harvest control rule translating. The conditioning of these building blocks is presented in more detail below. Assessment data used to condition the model was available for the years 1970-2013. Simulations were run until 2042.

Conditioning the biological operating model

The biological operating model, which is an age structured population model (ages 1-12), represents the true stock. The biological operating model can be split into two time periods. Prior to 2013 and the period from 2014 onwards. For the period 1970-2013 the assessment provides information on stock numbers-at-age, recruits born every year, maturity of adults, weight-at-age and natural + fishing mortality encountered. For the period from 2014 onwards, assumptions have to be made on how many recruits are added yearly to the stock, how much natural mortality there is and how fast fish grow from year to year, as well as how fast they mature. The choices made for these years are based on the conditions observed in the years prior to 2014.

Recruitment

Recruitment is the key component of stock productivity and it is crucial to have an realistic recruitment function in the model. The simulated recruitment should have the same variability as the recruitment observed historically. The stock to recruitment relationship, if existing, should be accurately modelled.

A variety of stock-recruitment models are available to represent the link between SSB and the subsequent recruitment. However for many stocks, the data does not really support one of this model more than the others, and the choice of one stock recruitment model, even if supported by statistical comparison, often remain quite subjective. In addition, simply fitting a stock-recruitment model (e.g. using maximum likelihood) does not really allow to represent the uncertainty in the estimated parameters.

Here, a method combining different stock-recruitment functions, and based on a Bayesian estimation of model parameters was used to give a full representation of the uncertainty in the stock-recruitment model. A complete description of the method can be found in Simmonds et al. (2011). The basic principle are as follow :

- For a range of selected stock-recruitment functional forms (here hockey stick, Ricker and Beverton and Holt were used), a Bayesian estimation of the model parameters is performed.
- For each stock-recruitment function, a set of 1000 models are kept from the MCMC chains.
- Based on the likelihood of each of these models, a probability can be computed for each functional form.
- A subset of stock-recruitment models (one model for each of the replicates of the stock in the MSE) is then randomly sampled from the 3 sets of 1000 models, proportionally to the probability of each functional form.

In the case of jack mackerel, there was no clear indication from the data for a specific functional relationship. Fitting the hockey stick, Ricker and Beverton and Holt models with a Bayesian parameter estimation (assuming normally distributed residuals) shows that there is a large uncertainty in parameter estimates (figure 1). The most likely relationships are Beverton and Holt (50%) and Ricker (40%).

For each of the replicates of the stock in the MSE, the recruitment model is defined by the functional form, the two parameters defining the shape given the functional form, and Sigma, the residuals standard error. Recruitment for a given year *y* in the simulation is hence modelled by the following formulae :

$$R_{y,k} = rnorm\left(mu_{y,k}, sigma_k\right)$$

and $$mu_{y,k} = SRR_k\left(SSB_{y-rec\ age,k}\right)$$

Where SSR_k is the stock recruitment model for the k^{st} replicate of the stock, $sigma_k$ is the corresponding residuals standard error and rec age is the age at recruitment. The function *rnorm()* means sampling one value from a Gaussian distribution with defined mean and variance.

In order to check whether the proposed modelling framework gives an appropriate description of the distribution of recruitment values, 40 000 recruitments where simulated using this method, based on the historical SSB values. The strong similarity in the cumulated distribution of the simulated values and the observed values (figure 2) indicated that the distribution of recruitment values was correctly represented by the Bayesian approach.

This approach was repeated assuming two different recruitment scenarios. A long-term recruitment scenario and a short-term recruitment scenario. In The latter case, only Recruitment – SSB pairs were considered from years 2003-2013 while in the long-term recruitment scenario pairs from the full time-series were used. The performance of each of the HCRs is given assuming the short and long-term recruitment scenarios.

Hockey – stick = 10%	Ricker = 40%	Beverton and Holt = 50%

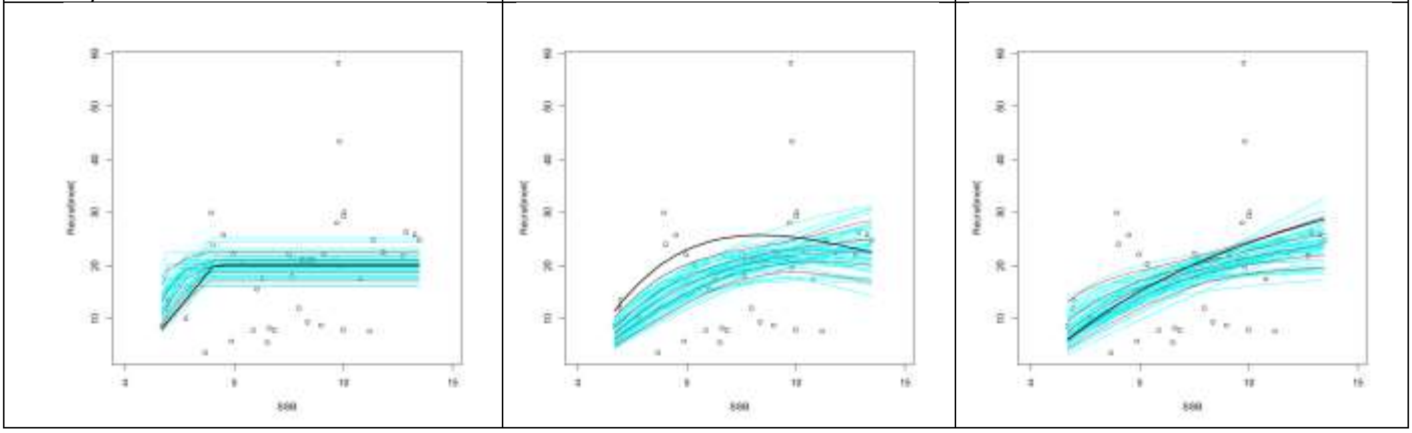

Figure 1: three stock recruitment models fitted to the historical jack mackerel data, using a Bayesian estimation. The blue lines represent a sample from the 1000 models taken on the MCMC chains for each functional relationship (with the 5%, 25%, 50%, 75% and 95% percentiles of the predicted recruitment values in red). The black line is the maximum likelihood estimate. The probability of each functional relationship is also given.

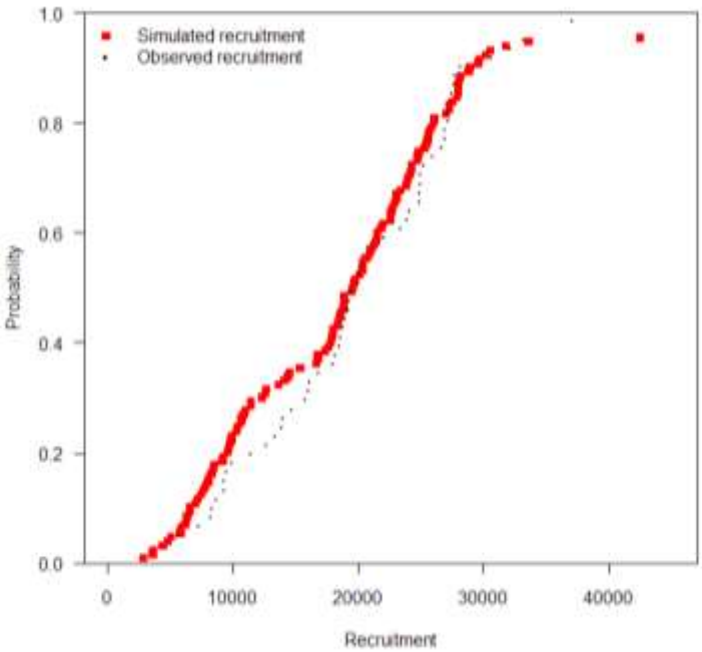

Figure 2 : comparison of the cumulated distribution of simulated recruitment based on the Bayesian approach and of the observed recruitments

Growth / Weight-at-age

Preliminary analysis on jack mackerel showed that catch weights at age exhibited a significant degree of temporal autocorrelation. Hence it seemed inappropriate to represent weight at age by purely random variations. Instead a ARMA (auto-regressive moving average) model was fitted to capture the degree of autocorrelation of the variation of the time series. The ARMA models were fitted using the fArma library in R. For each time series, the best model – the optimal set of p and q parameters, being the orders of the autogressive and moving average parts respectively, was obtained by fitting a range of models with varying p and q values and selecting the one with the lowest AIC criteria. Once an ARMA model is fitted to a time series, it can be used to simulate time series with the same characteristics as the original time series.

An ARMA model was first fitted to the time series of weights at age 1, and one weight at age 1 time series was simulated for each replicate of the stock. Then, the growth increment during the second year of the fish (i.e. weight at age 2 minus weight at age 1) was modelled by another ARMA model. Time series of weight increments from age 1 to 2 were generated for each replicate of the stock. The weight increments were added to the weights at age 1 of the corresponding cohort to generate the weights at age 2. Weights at age 3 to 12 were generated in the same way. By doing so, each cohort has a coherent growth history (e.g. no decrease in weight is possible).

This was done for each of the fleets separately. As in the assessment, the weights at age in the stock were calculated as an average of the four fleets, weighted by the historical proportion of the catch taken by each of the fleets. Here, we simulate weight-at-age in the stock too using the ARMA model, taking the stock weights-at-age as a starting condition.

Natural mortality and maturity

As in the stock assessment model, constant natural mortality and maturity at age were used in the simulations.

Starting conditions (period 1970-2013)

In order to have starting conditions reflecting the magnitude of the assessment uncertainty, a range of likely stocks was generated. In practice, for each replicate of the stock in the MSE, the recruitment, the fishing mortality and selectivity at age of each fleet in the period 1970-2013 were resampled from a multivariate normal distribution of mean and variance-co-variances taken from the 2013 assessment output. From these newly drawn parameters, the numbers-at-age in the biological operating model for 1970-2013 were set. This means that each of the 200 replicates simulated has a different starting condition, as numbers-at-age between replicates are not the same and varies according to the uncertainty in the assessment.

Simulation period (period 2014-2042)

Recruits are added to the stock yearly and due to natural and fishing mortality fish die. Based on the mortality rates, survivors from one year to the next are calculated. Fish that become older than 12 years build up in the so-called plusgroup and are being treated as still being 12 years of age.

Conditioning the fisheries operating model

The four fleets (South-Central Chile, Northern Chile, Offshore and Far North) target the Jack mackerel stock. Each of these fleets catch fish at different ages following a certain selection-at-age pattern. When these fisheries land fish, the weights-at-age of these fish are different among the four fleets too. These two elements are considered in the conditioning of the fisheries operating model. Here we distinguish between the period before and after 2014 (historic vs. simulation period).

Selectivity of the fishing fleets

Generating selectivity patterns for the four fleets for the period 2014-2042 required a number of steps. First, the period that is indicative for future selectivity patterns needed to be defined. This was done by calculating the mean selection period over the entire historic time-series but inversely weighted by the distance in years from the most recent year. Similarly, the standard deviation of the selection pattern per age was calculated for each of the four fleets. All assessment estimated selection patterns that fell outside two standard deviations from the mean were not included as being indicative for future selectivity. The second step comprised of generating new selectivity values by age, year and fleet. This was done by generating a random value for each age-year-fleet combination from a multivariate normal distribution taking the variance-co-variance structure into account of the yearly change in fleet selectivity pattern observed in the indicative years. The random values had mean 0 and allowed to construct a random walk by summing the randomly drawn values by age and fleet over time. In the third step, selectivity patterns were constructed by multiplying the random walks (with mean zero) with the mean selection pattern over the indicative years. A check was performed that generated selection values did not exceed 2 standard deviations from the long-term mean (1970-2013). Selection patterns were standardized to the mean for each fleet separately.

Allocation of the fishing fleets

Each fleet catches a proportion of the jack mackerel stock. The proportions change by fleet by year. To simulate allocation schemes for the years 2014-2042, historic allocation proportions were calculated (based on proportions in fishing mortality rather than catch). Based on the mean historic allocation and autocorrelation and co-variance between years and fleets, new allocation proportions were drawn from a multivariate normal distribution. The newly drawn allocation proportions were multiplied with the standardized selection patterns.

Weight at age in the landings

Similar to the approach to model the growth of the biological operating model, observed fisheries landings weight-at-age have been used together with the ARMA approach to simulate weight-at-age for the period after 2013 for each fishery separate. Observed weights-at-age from the assessment model output were used to generate weight-at-age per fishery in the period 1970-2013.

Starting conditions

The fishing mortality and selectivity at age of each fleet in the period 1970-2013 were resampled from a multivariate normal distribution of mean and variance-co-variances taken from the 2013 assessment output.

Simulation period (period 2014-2042)

The total fishing mortality, which is used in the biological operating model to compute at each time step the survivors, is the sum of the partial fishing mortalities of the four fleets. The fishing mortality generated by each fleet depends on the stock size of jack mackerel, the selection pattern of the fleet and total allowable catch. For every year, the total TAC is split over the four fleets according to the simulated allocation. Catches of the fleets cause fishing mortality and thereby affect the dynamics of the biological operating model.

The assessment procedure

In the simulations, as in reality, management decisions are based on the perception of the real stock provided by a stock assessment. Stock assessment gives a perception of the stock which can deviate from the real stock for a number of reasons : inaccuracy of the catch data, sampling uncertainty, noise in the survey indices, assessment model mis-specification, assessment model fit uncertainty.

At each new year in the simulation, a new perception of the stock is generated, in a way that mimics as closely as possible the uncertainty related to stock assessment. The approach taken for the jack mackerel MSE consisted in adding an error term to the output – abundance and fishing mortality at age - of the biological and fisheries operating model. This error term was defined as the product of cohort-specific normally distributed deviations and an error amplitude proportional to the assessment uncertainty of the corresponding estimate.

The cohort specific deviations were generated by sampling a random number from a standard normal distribution for each cohort of the projection period, and propagating this value to all the ages for each cohort (figure 3). One matrix of cohort-specific normal deviations was generated for each replicate of the stock.

The amplitude of the error on numbers and fishing mortality at age was calculated from the 200 replicates of the biological stock at the start of the simulation (see section starting points). These replicates were generated by resampling parameters from the stock assessment based on the variance covariance matrix and therefore the inter-replicate variability of a given estimate represents the uncertainty in the assessment output. A matrix of CV representing the amplitude of the assessment uncertainty was calculated for numbers and fishing mortality at age by computing the standard deviation of a given estimate (N or F at a given age, for a given number of years before the terminal assessment year) across all 200 replicates and dividing by the mean.

The final error was calculated by multiplying the cohort specific deviations by the uncertainty variance, calculated as square of the product between the CV and the estimate from the biological model (figure 3).

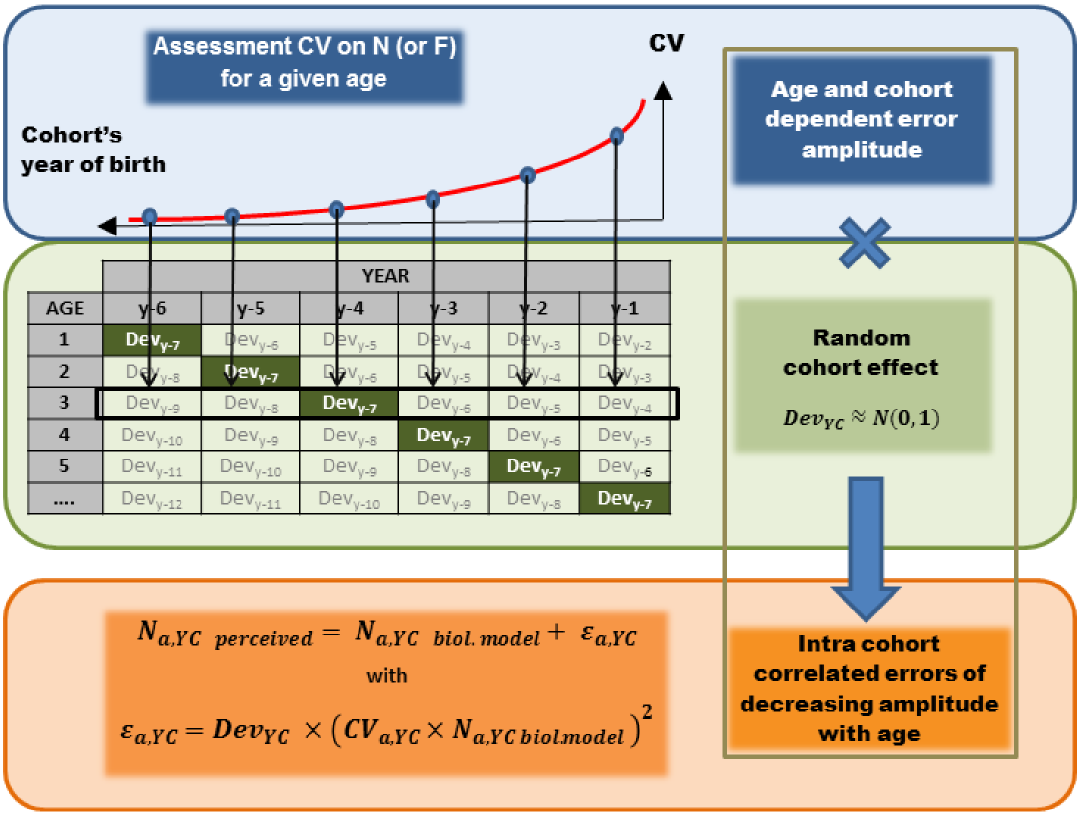

Figure 3 : simulation of assessment errors. Assessment errors are the product of a cohort effect normally distributed and an age and cohort dependent amplitude, representative of the uncertainty in the assessment, derived from on the variance-covariance matrix of the assessment parameters.

The management / TAC setting procedure

At each step of the simulation, a TAC advice is formulated based on the results of the latest assessment. In a given year y, the TAC advice is given for the following year y+1, based on a perception of the stock in the previous year y-1 (figure 4). In order to give a TAC advice, a short term projection of the stock is necessary to get the stock abundance in the advice year y+1. The short term forecast is based, as in reality, on the perceived stock.
Here, the survivors at the start of the current year, y, are projected forward to the start of the next year, y+1, using the assumption that the catch of the current year y is equal to the TAC for the same year y. Then, based on the numbers at age at the start of the year y+1, the harvest control rule is applied: this rule gives the value of the fishing mortality which should be applied in the year y+1 given the value of SSB (or any other indicator) in y+1. The advised TAC in year y+1 is calculated based on this fishing mortality. In the MSE, it is assumed that the actual catch in a given year is equal to the advised TAC, i.e. that the quotas are fully used and not overshot.

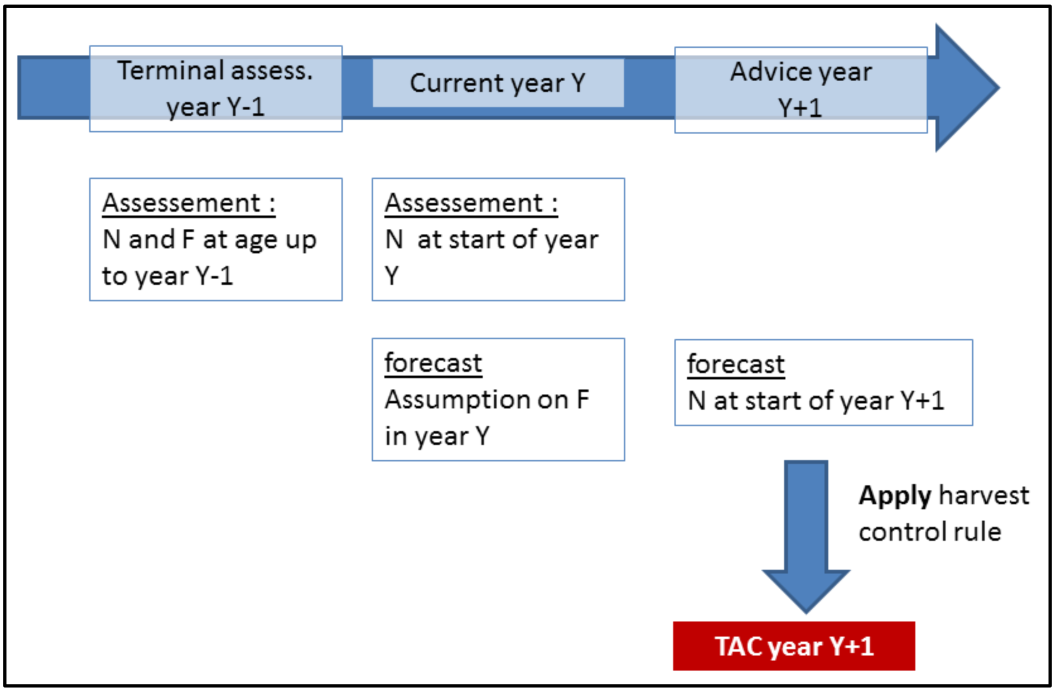

Figure 4: time line of the advisory process implemented in the MSE. In year y, advice is given for the catch of year y+1 based on a short term forecast of the stock 2 years ahead of the final year estimated in the assessment, y-1.

The full MSE cycle is presented in figure 5, linking the biological operating model, to the stock assessment procedure, the TAC setting procedure and fleet operating model. The MSE framework allows to link uncertain information on the true dynamics of the stock, and the dynamics of this stock under different Harvest Control Rules, to be evaluated with a full-feedback approach.

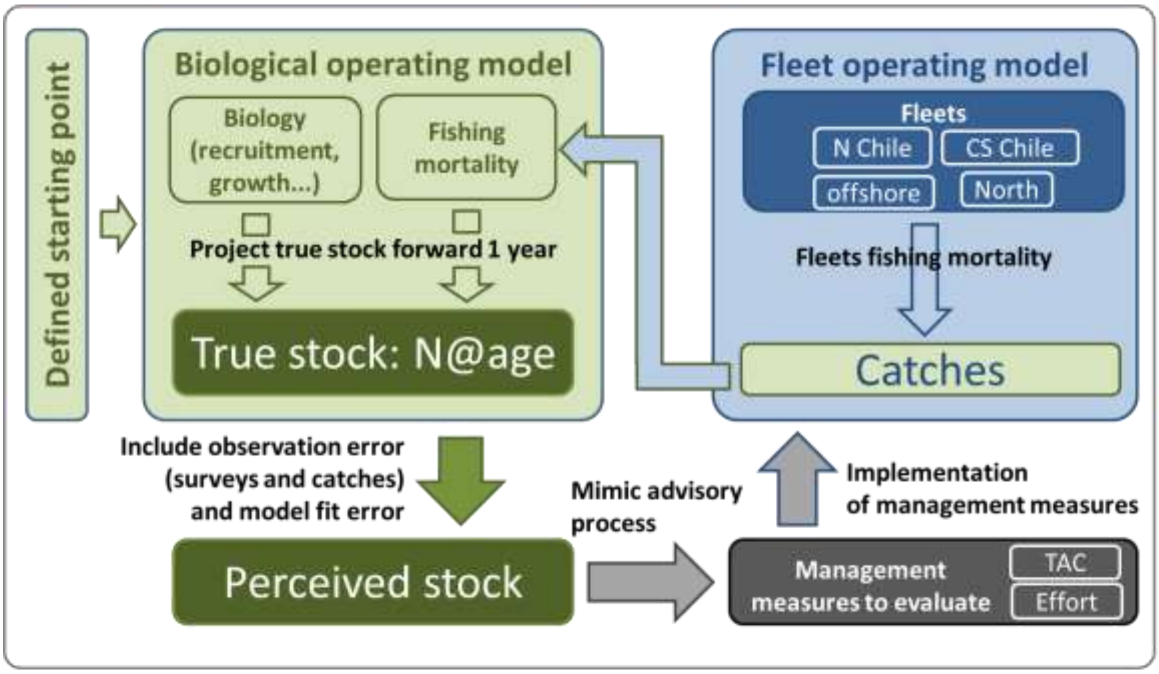

Figure 5. Conceptual representation of the management strategy evaluation where four main elements exist. A biological operating model simulating the dynamics of the fish species, the stock assessment process via the 'perceived stock' element, the incorporation of the advisory process under 'management measures to evaluate' and the implementation of these measures via the fishing fleet catching the fish species under element 'fleet operating model'.

Scenario description

A scenario is here interpreted as the combination of a recruitment regime (low – high recruitment regime) and a formalized rule to set a TAC, i.e. a Harvest Control Rule (HCR). As is described under the Material and Methods section, HCRs are evaluated under two recruitment regimes: a low-recruitment regime similar to the recruits observed from 2003 and a higher long-term regime similar to recruits observed since 1970. The HCR designs come in many different flavors. HCRs already in place for small pelagic fish such as anchovy, sprat, sandeel or herring aim to keep a stock at or above a certain biomass threshold, to fish a stock at constant fishing mortalities or to fish a stock at a fishing intensity relative to their biomass. Each of the above mentioned objectives or rationales can be translated into a mathematical rule where on the basis of, for example, stock size (Spawning Stock biomass, SSB), a fishing mortality target can be set. The exact relationship between, in this case SSB and F, is assumed here to represent one HCR.
In collaboration with stakeholders during 2014 (see Annex I for a summary) a number of potential HCRs were designed in addition to the Commission defined Rebuilding Plan. In total, this resulted in 26 different HCRs that were evaluated under both recruitment regimes. The 26 HCR can be grouped into six categories: Fishing mortality target HCRs, Biomass target HCRs, Rebuilding plans, Sloping rule plans, Productivity based HCRs and Allocation based HCRs. The categories, and specific settings of each of the HCRs, are further explained below. Trigger points in these HCRs are informed by preliminary reference points, obtained from the 2013 stock assessment outputs.

HCR 1-6 evaluate a constant Ftarget plan ranging between an F of 0.05 to 0.4 including 2013 values and F_{MSY}. HCRs 7-9 evaluate a constant Btarget plan ranging between 5 and 6 million tonnes. HCRs 10-12 evaluate the Commission rebuilding plan and two alternatives to the plan. HCR 11 here adds a TAC stabilizer of 15% when SSB is above 80% of B_{MSY} while HCR 12 adds the stabilizer above 100% of B_{MSY}. HCR 13-21 evaluate different management regimes each associated with an increase in F when SSB increases. Details are given in Table 1. HCRs 22-24 address one of the main concerns on recruitment prediction expressed by stakeholders, and evaluate a productivity based plan where historic productivity (measured as Recruitment / Spawning Stock Biomass), measured over the past 10, 5 or 3 years respectively, is calculated and considered against a HCR with 2 breakpoints (R/SSB = 0.5 and R/SSB = 3) with a constant F of 0.05 below R/SSB = 0.5 and of 0.25 above R/SSB = 3 while a slope connects the two break points (see Figure 3). To define the two productivity breakpoints, R-SSB pairs from 1970-2013 (year ranges considered in the SPRFMO assessment) were sorted from small to large for each of the 200 stock replicates (which therefore represents the uncertainty in R and SSB estimation) and breakpoints were defined by eye. HCRs 25-26 allow for the evaluation of management under changes in allocation to the four fleets targeting Jack Mackerel where the proportion of the TAC follows from the following equation (see Figure 4): fleet Northern Chile: 0.118 + 3.326e-6 * SSB, fleet South-Central Chile: 0.611 – 7.873e-6 * SSB, fleet Far North: 0.239 – 1.184e-5 * SSB, fleet Offshore: 0.062 + 6.990e-6 * SSB. The equation was derived based on glm modelling of landing proportions by fleet related to SSB. The overall TAC will be set according to F_{MSY} under these HCRs. In a way, the latter two HCRs are not different from HCR 5 (F target of 0.25), and only differ in the allocation of the TAC.

Table 1: Overview of settings in scenarios 13-21

Scenario	Biomass breakpoint I	Biomass breakpoint II	F below I	F above II	Inter Annual Variation 15%
13	5.5mt	-	Slope to F=0	0.25	No
14	5.5mt	-	Slope to F=0	F_{2013}=0.13	No
15	5.5mt	-	Slope to F=0.05	0.25	No
16	2.2mt	5.5mt	F_{2013}=0.13	0.25	No
17	2.2mt	5.5mt	F=0.05	0.25	No
18	5.5mt	-	Slope to F=0	0.25	Yes
19	5.5mt	-	Slope to F=0	0.25	Yes, only above B_{MSY}
20	2.2mt	5.5mt	F=0.05	0.25	Yes
21	2.2mt	5.5mt	F=0.05	0.25	Yes, only above B_{MSY}

Performance indicators are calculated for each of the management plan designs under the short (2015-2016), medium (2017-2024) and long term (2025-2034). Among these are:

1) Risk to fall below B_{MSY}, calculated as the percentage of iterations that fall below B_{MSY} within the given timeframe
2) SSB, calculated as the mature part (males and females) of the stock in kt, averaged over the given timeframe and median over the replicates
3) Fishing mortality, calculated as the mean fishing mortality of all fleets combined over all ages, averaged over the given timeframe and median over the replicates
4) Catch, calculated as the catch in kt from all fleets combined, averaged over the given timeframe and median over the replicates
5) Catch variability, calculated as the percentage change in catch from year to year, averaged over the given timeframe and median over the replicates
6) Growth in SSB, calculated as the average percentage increase in SSB over the given timeframe compared to 2013, taken as the median over the replicates
7) Risk of SSB decline, calculated as the percentage of iterations that fall below SSB_{2013} within the given timeframe, taken as the median over the replicates
8) Recovery time to B_{MSY}, calculated as the number of years the stock takes to grow larger than B_{MSY}, taken as the median over the replicates
9) Absolute catch variation, calculated as the absolute change in catch from year to year, averaged over the given timeframe and median over the replicates

It is in the end up to stakeholder discretion to decide on the most appropriate performance indicators.

Results

Reference points

Reference points were directly taken from three assessment runs: the SPRFMO one stock model, the alternative two stock model representing the North and South models. For illustration purposes, reference points from the North and South model have been added together. Short term values have been calculated by averaging the time-varying estimates available per year, over the past 10 years, while long term values have been calculated by averaging the entire time series. It is remarkable that 2013 estimates are relatively far away from the short term estimates while productivity, one of the main elements in the estimation of MSY reference points, is very similar in this period. MSY values however seem to be very similar under all periods. Table 2 shows the numeric estimates of the reference point values from Figure 2.

Table 2. Estimates of reference points on the basis of the three assessment models.

Stock	2013 F_{MSY}	2013 B_{MSY}	2013 MSY	LT F_{MSY}	LT B_{MSY}	LT $_{MSY}$	ST F_{MSY}	ST B_{MSY}	ST MSY
Combined	0.257	4887	1392	0.212	5401	1334	0.2	5895	1333
North	0.205	1071	419	0.156	975	293	0.231	1109	393
South	0.245	5005	1196	0.198	5560	1144	0.183	5902	1132
N+S	0.238	6076	1615	0.192	6535	1437	0.191	7011	1525

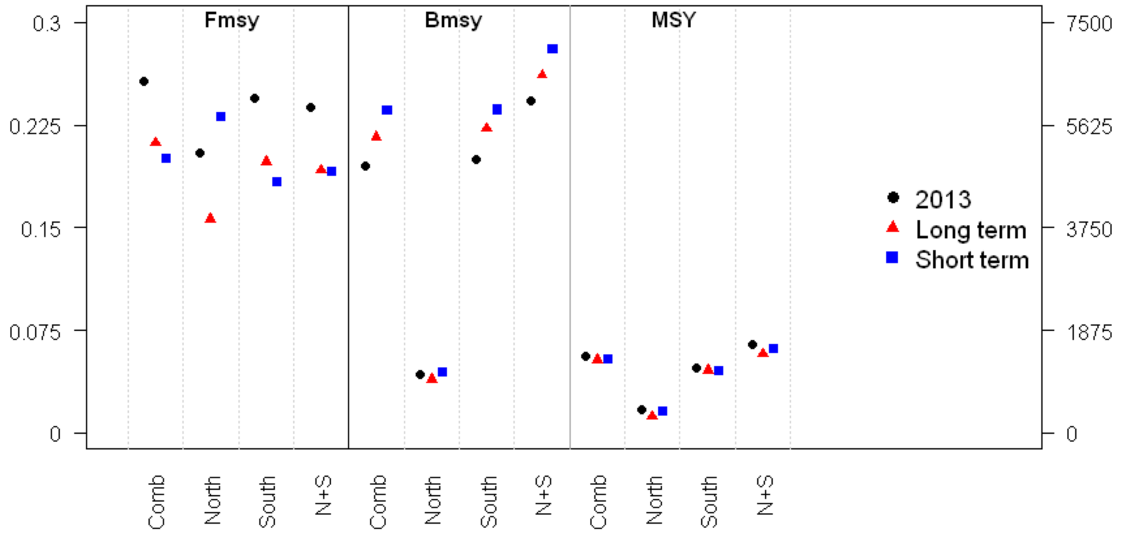

Figure 2. Graphical representation of reference points estimated on the basis of the three assessment models. Left-hand side axis refers to F_{MSY} values (per year) while the right-hand side axis refers to B_{MSY} and MSY values in thousand tonnes.

Management Strategy Evaluation

In total 26 different HCR designs were evaluated. The results are presented in Table 3 for both recruitment scenarios. The results have been scored on performance in the short, mid and long term which is given in Table 4. Colour schemes are added to compare HCRs among each other. Outer ranges of the HCR results are taken as outer ranges for the colour bars used.

To illustrate the choices made with regard to the sloping, productivity and allocation management plan designs, Figure 3 and 4 show the data analyses that were undertaken to make a choice regarding productivity breakpoints and catch proportion.

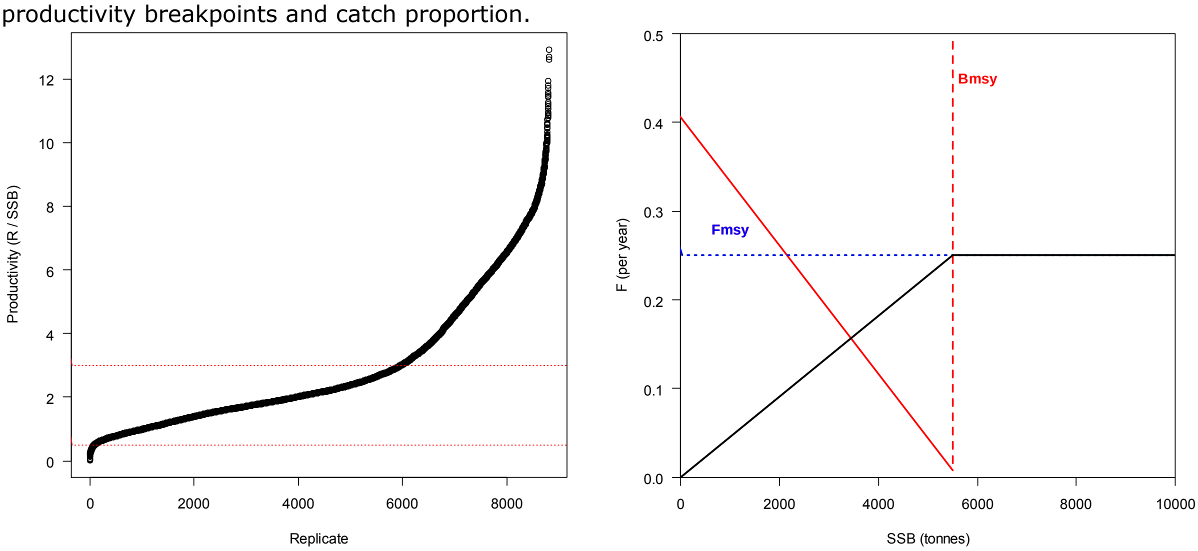

Figure 3. Left: Estimated productivity of the Jack Mackerel stock for the years 1970 – 2013. For each point estimate of SSB and Recruitment, 200 replicates. Right: Example of a sloping management plan design (scenario #13).

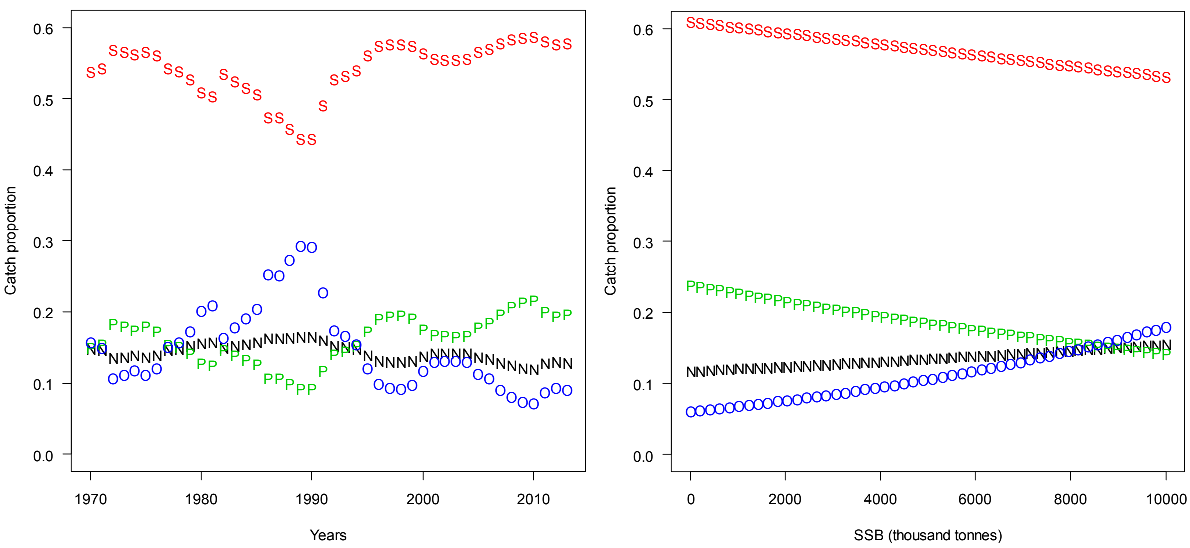

Figure 4. Left: Estimated proportion caught by fleet over time as a function of SSB. Right: Predicted proportion caught by fleet as a function of SSB. S denotes Southern Central Chilean fleet, P denotes Far North fleet, N denotes Northern Chilean fleet, O denotes the Offshore fleet.

The diagnostics of the 26 HCRs are presented in table 3 (low productivity) & table 4 (long term productivity).

Table 3. Performance indicators for seven groups of management plan designs. Management Strategy Evaluations were performed based on each design assuming low productivity regime.

	Ftarget						Btarget			Rebuilding plans			Sloping rules
Scenario	F = 0.05	F = 0.13	F = 0.14	F = 0.2	F = 0.25	F = 0.4	B = 5mt	B = 5.5mt	B = 6mt	Commissio	IAV above	AV above	13
Risk < Bmsy Short Term (%)	83.5	90.5	90.5	96.5	98	99.5	94	87.5	82.5	94	89	88.5	98
Risk < Bmsy Medium Term (%)	58	96	96.5	100	100	100	89.5	72.5	48	98	95	90.5	100
Risk < Bmsy Long Term (%)	49.5	97	98	100	100	100	95	84	65.5	98	85.5	73.5	100
SSB Short Term (thousand tonnes)	5098	4682	4630	4345	4150	3613	4849	5064	5206	4581	4754	4742	4366
SSB Medium Term (thousand tonnes)	6227	4710	4566	3873	3451	2577	5531	6180	6836	4886	5086	5210	4034
SSB Long Term (thousand tonnes)	6378	4501	4356	3600	3164	2221	5417	5863	6268	4818	5223	5779	3861
F Short Term (per year)	0.05	0.13	0.14	0.2	0.25	0.399	0	0	0	0.123	0.107	0.107	0.193
F Medium Term (per year)	0.049	0.127	0.137	0.194	0.241	0.381	0.02	0.005	0.004	0.102	0.104	0.084	0.173
F Long Term (per year)	0.05	0.13	0.14	0.2	0.25	0.399	0	0	0	0.123	0.107	0.107	0.193
Catch Short Term (thousand tonnes)	239	568	606	818	975	1359	2	1	1	517	544	506	798
Catch Medium Term (thousand tonnes)	373	654	675	761	794	822	145	46	37	554	586	503	717
Catch Long term (thousand tonnes)	395	636	649	704	720	691	48	8	4	546	407	294	683
TAC variability Short Term (%)	16.055	10.688	9.858	10.326	11.834	18.63	99.994	99.994	99.993	33.291	15	15	14.034
TAC variability Medium Term (%)	11.269	13.211	13.806	17.059	20.151	28.353	659.003	790.862	878.964	113.672	15	38.917	19.084
TAC variability Long Term (%)	12.605	14.381	14.863	19.126	23.389	34.656	611.321	632.031	799.5	42885.5	15	24.956	21.534
Growth in 2014 - 2016 (thousand tonnes)	46	30	29	19	12	-6	39	49	51	28	34	34	19
Growth in 2014 - 2024(thousand tonnes)	76	27	23	1	-11	-34	49	62	76	37	37	50	8
Growth in 2014 - 2034 (thousand tonnes)	74	25	20	2	-11	-41	48	65	75	37	57	71	9
Risk decline SSB Short Term (%)	0.5	4.5	5	13.5	28	69	6	3	0	4.5	1.5	1.5	11.5
Risk decline SSB Medium Term (%)	3	25.5	35.5	65.5	84.5	99	11.5	4	0.5	12	10	7	53.5
Risk decline SSB Long Term (%)	12.5	39.5	46.5	78.5	95	99.5	14.5	8	6.5	19	23.5	17.5	64.5
Recover Time to Bmsy (years)	7	25	26	29	29	29	16	11	6	25	17	15	29
Recovery Time to Blim (years)	0	0	0	0	0	10	0	0	0	0	0	0	0
TAC up (tonnes)	49	103	111	164	209	311	392	345	285	417	66	111	178
TAC down (tonnes)	60	94	101	147	183	278	758	654	546	439	181	336	160

	Sloping rules								Productivity rules			Allocation rules	
	14	15	16	17	18	19	20	21	10 year	5 year	3 year	F = 0.25	F = 0.14
Risk < Bmsy Short Term (%)	91.5	98	98	98	88	91	88	90.5	97.5	98	96	100	96
Risk < Bmsy Medium Term (%)	99	100	100	100	100	100	100	100	100	100	99	100	100
Risk < Bmsy Long Term (%)	97.5	100	100	100	100	100	100	100	100	98	96.5	100	100
SSB Short Term (thousand tonnes)	4753	4330	4330	4405	4730	4508	4735	4570	4272	4194	4497	3342	3914
SSB Medium Term (thousand tonnes)	4859	3929	3929	4190	4401	4167	4504	4320	3778	4209	4492	1412	2609
SSB Long Term (thousand tonnes)	4785	3847	3847	4122	3976	3957	4143	4132	4040	4257	4370	1995	2676
F Short Term (per year)	0.116	0.201	0.201	0.176	0.118	0.161	0.116	0.146	0.214	0.238	0.168	0.304	0.157
F Medium Term (per year)	0.117	0.183	0.183	0.158	0.166	0.166	0.153	0.153	0.193	0.149	0.137	0.278	0.149
F Long Term (per year)	0.116	0.201	0.201	0.176	0.118	0.161	0.116	0.146	0.214	0.238	0.168	0.304	0.157
Catch Short Term (thousand tonnes)	522	831	831	744	544	648	544	586	884	943	715	1061	652
Catch Medium Term (thousand tonnes)	630	732	732	697	793	728	773	710	723	647	649	415	456
Catch Long term (thousand tonnes)	638	721	721	689	703	701	690	684	686	671	666	443	404
TAC variability Short Term (%)	13.386	13.26	13.26	14.937	15	15	15	15	12.424	15.351	16.773	16.301	11.401
TAC variability Medium Term (%)	14.93	18.405	18.405	20.612	12.328	17.951	12.561	19.407	19.395	18.823	25.18	150.384	48.452
TAC variability Long Term (%)	16.07	21.267	21.267	22.707	12.075	18.913	12.346	19.53	18.751	20.021	24.974	40.767	38.506
Growth in 2014 - 2016 (thousand tonnes)	32	17	17	20	32	21	32	24	15	12	23	-11	9
Growth in 2014 - 2024(thousand tonnes)	32	6	6	14	8	9	13	14	5	17	22	-59	-39
Growth in 2014 - 2034 (thousand tonnes)	33	8	8	16	13	12	17	16	13	21	23	-39	-11
Risk decline SSB Short Term (%)	0.5	12	12	7	2	5.5	2	4	16.5	23	4	66	42.5
Risk decline SSB Medium Term (%)	16	64.5	64.5	47.5	48.5	50.5	40.5	43	72.5	46.5	33.5	99.5	89
Risk decline SSB Long Term (%)	23.5	68.5	68.5	51.5	66.5	64.5	57.5	53.5	61.5	49.5	43	98.5	93
Recover Time to Bmsy (years)	25	29	29	29	28	29	28	29	29	29	28	29	29
Recovery Time to Blim (years)	0	0	0	0	0	0	0	0	0	0	0	16	11
TAC up (tonnes)	111	176	176	179	83	140	82	136	167	177	183	140	88
TAC down (tonnes)	106	162	162	168	91	157	91	162	154	156	170	189	132

Table 4. Performance indicators for seven groups of management plan designs. Management Strategy Evaluations were performed based on each design assuming long term productivity regime.

	Ftarget						Btarget			Rebuilding plans			Sloping rules
Scenario	F = 0.05	F = 0.13	F = 0.14	F = 0.2	F = 0.25	F = 0.4	B = 5mt	B = 5.5mt	B = 6mt	Commissio	IAV above	AV above	13
Risk < Bmsy Short Term (%)	64	76	77.5	83	88	95.5	78.5	69.5	63.5	81	73.5	75	86
Risk < Bmsy Medium Term (%)	11	24.5	26.5	36.5	47	79	80	63	46	37.5	19.5	20	44
Risk < Bmsy Long Term (%)	0	1	2	12.5	24.5	70	93.5	84.5	76	24	28	28.5	23.5
SSB Short Term (thousand tonnes)	5871	5452	5397	5130	4919	4327	5409	5760	5968	5319	5564	5563	5088
SSB Medium Term (thousand tonnes)	13025	10349	10103	8814	7995	6202	7036	8075	9111	8278	11627	11689	8125
SSB Long Term (thousand tonnes)	19363	13286	12802	10530	9209	6697	6494	6892	7335	9280	12281	12360	9255
F Short Term (per year)	0.049	0.127	0.137	0.195	0.244	0.386	0	0	0	0.147	0.103	0.103	0.196
F Medium Term (per year)	0.049	0.126	0.136	0.194	0.241	0.38	0.141	0.129	0.105	0.232	0.086	0.086	0.232
F Long Term (per year)	0.049	0.127	0.137	0.195	0.244	0.386	0	0	0	0.147	0.103	0.103	0.196
Catch Short Term (thousand tonnes)	249	599	639	857	1016	1422	2	1	1	684	544	539	880
Catch Medium Term (thousand tonnes)	645	1207	1253	1456	1566	1706	924	1031	942	1661	1148	1103	1589
Catch Long term (thousand tonnes)	1201	1876	1912	2033	2064	2023	527	641	633	2097	2554	2438	2073
TAC variability Short Term (%)	24.356	17.78	17.522	15.23	14.228	18.105	331.558	912.056	946.347	66.786	15	15	25.234
TAC variability Medium Term (%)	21.743	24.671	25.15	28.113	30.508	39.063	597.692	680.006	783.456	37.709	15	15	31.958
TAC variability Long Term (%)	13.434	15.461	16.139	20.184	24.805	35.907	670.703	648.045	670.139	26.459	15	15	25.048
Growth in 2014 - 2016 (thousand tonnes)	78	62	60	49	41	23	64	77	82	55	66	67	46
Growth in 2014 - 2024(thousand tonnes)	376	261	249	192	156	90	71	95	117	158	310	304	159
Growth in 2014 - 2034 (thousand tonnes)	425	264	248	183	143	72	68	79	99	146	149	161	149
Risk decline SSB Short Term (%)	0	1	1.5	6.5	12.5	27	6.5	1.5	0.5	1	0.5	0.5	4.5
Risk decline SSB Medium Term (%)	0	1	1.5	4.5	14.5	38.5	38	22	15.5	0.5	0	0	3
Risk decline SSB Long Term (%)	0	0	0	1.5	7	30	53.5	47	37	1.5	7	2.5	5
Recover Time to Bsmy (years)	2	2	2	3	4	10	11	8	6	3	3.5	3	4
Recovery Time to Blim (years)	0	0	0	0	0	0	0	0	0	0	0	0	0
TAC up (tonnes)	150	303	323	443	536	763	1441	1441	1439	591	204	199	527
TAC down (tonnes)	155	288	307	417	503	723	2713	2682	2784	566	447	509	511

	Sloping rules								Productivity rules			Allocation rules	
	14	15	16	17	18	19	20	21	10 year	5 year	3 year	F = 0.25	F = 0.14
Risk < Bmsy Short Term (%)	77	86.5	86.5	85	75.5	79.5	75.5	78	86.5	87.5	84	95.5	90
Risk < Bmsy Medium Term (%)	18.5	43	43	40.5	21.5	29.5	20.5	27	45.5	41	32.5	85	72
Risk < Bmsy Long Term (%)	0	24	24	23.5	20	36.5	20	30.5	16.5	8.5	4.5	81	68.5
SSB Short Term (thousand tonnes)	5658	5216	5216	5302	5702	5502	5702	5588	5197	5127	5336	4426	4932
SSB Medium Term (thousand tonnes)	10556	8288	8288	8344	11816	10492	11897	10765	8281	8528	8918	4767	6554
SSB Long Term (thousand tonnes)	12838	9162	9162	9170	11814	9882	12087	10145	9680	10657	11341	5895	8150
F Short Term (per year)	0.117	0.203	0.203	0.184	0.11	0.15	0.107	0.137	0.215	0.236	0.182	0.267	0.148
F Medium Term (per year)	0.134	0.232	0.232	0.229	0.101	0.143	0.097	0.132	0.231	0.214	0.196	0.275	0.147
F Long Term (per year)	0.117	0.203	0.203	0.184	0.11	0.15	0.107	0.137	0.215	0.236	0.182	0.267	0.148
Catch Short Term (thousand tonnes)	582	925	925	869	544	681	544	617	958	1019	850	1125	694
Catch Medium Term (thousand tonnes)	1288	1609	1609	1627	1148	1245	1148	1192	1589	1517	1469	1041	887
Catch Long term (thousand tonnes)	1900	2052	2052	2054	2563	2451	2561	2477	1925	1875	1838	1265	1203
TAC variability Short Term (%)	30.969	21.663	21.663	34.618	15	15	15	15	19.14	18.783	42.894	14.001	13.244
TAC variability Medium Term (%)	24.644	30.087	30.087	30.855	15	15	15	15	30.225	33.296	39.276	63.184	31.786
TAC variability Long Term (%)	17.622	26.106	26.106	26.178	12.917	15	13.004	15	26.598	28.153	32.671	61.058	44.62
Growth in 2014 - 2016 (thousand tonnes)	74	58	58	61	77	72	77	73	57	56	61	26	47
Growth in 2014 - 2024(thousand tonnes)	231	143	143	143	274	217	279	233	145	157	185	33	84
Growth in 2014 - 2034 (thousand tonnes)	266	164	164	165	173	135	175	136	195	218	229	75	136
Risk decline SSB Short Term (%)	0.5	4.5	4.5	2.5	1	3	0.5	1.5	6	8	0.5	37.5	26.5
Risk decline SSB Medium Term (%)	0	4	4	1.5	0.5	1.5	0	0.5	5.5	3.5	0.5	70	61
Risk decline SSB Long Term (%)	0	1	1	0.5	5	6	5	4	1.5	1	0	70	58
Recover Time to Bsmy (years)	2	4	4	3.5	3	4	3	4	3	3	2	16	12
Recovery Time to Blim (years)	0	0	0	0	0	0	0	0	0	0	0	6	5
TAC up (tonnes)	331	518	518	525	203	248	202	243	506	530	584	326	216
TAC down (tonnes)	308	518	518	521	294	443	294	450	489	504	566	445	350

Discussion

The estimation of reference points inside the assessment model runs is an easy and elegant way to track changes in F_{MSY} or B_{MSY} on a yearly basis. However, in this instance, the differences between 2013 values and the estimated values in the 10 years before that time, are markedly different, while productivity hasn't changed considerably in this period. Fisheries selectivity does vary by year but not to a large extend in the most recent period. It is therefore unclear why 2013 values differ to such an extend from the most recent 10 year period. It is advisable to investigate the estimation in more depth prior to advising on reference points.

The 26 harvest control rule designs evaluated show marked differences in performance among them. In the short term especially scenarios associated with low fishing mortality (Ftarget = 0.05 and Btarget = 6mt) result in a rapid rebuilding of the stock towards B_{MSY}. Under these scenarios however, estimated fishing mortality is lower than F_{2013} and catches in the medium to long term are lower than the catches reported in 2013. These two HCR types are the only ones that succeed in rebuilding the stock above B_{MSY} under the low recruitment scenario.

The sloping control rules result in a build-up of SSB to around 4mt, being harvested with an average fishing mortality between 0.11 and 0.20 with associated catches between 500 – 800kt. The catches are among the highest of all HCRs tested. Under none of the sloping rules however will SSB rebuild, with certainty, to above B_{MSY} in the medium term (low recruitment regime). Under the high-recruitment regime however, risk to stay below B_{MSY} is much lower and catches increase to levels well above twice MSY in the long term.

The productivity rules are associated with the highest catch levels among all HCRs tested, either under the low or high recruitment scenarios. Under none of the productivity rules however will SSB rebuild to above B_{MSY} under the low recruitment regime. Under the higher recruitment regime, catch variability is average compared to other HCRs.

The allocation rule, though not specifically a HCR, shows lower SSB and lower catches compared to the similar F_{MSY} and $F_{0.14}$ runs. The catch stability is significantly higher under the allocation schemes. The comparison of the F_{target} and allocation HCRs is difficult however as the contribution of each fleet to the total fishing mortality changes over time with changes in SSB. Under the anticipated increase of SSB, the Far North and South Central Chilean fishery will decline and the Offshore fleet, primarily targeting adults, will go up. Therefore, the fishing pressure on juveniles decreases and may be the reason for a greater increase in SSB under the allocation HCR runs. As the forecast model doesn't take this shift into account, the risk to overexploitation increases.

The rebuilding plan adopted by the Commission shows a moderate increase in SSB compared to the other runs with moderate catches too being 1 – 1.25x as large as the 2014 proposed catch. The estimated catch variability under the Commission plan is well outside the variability seen in other HCRs. This may be due to alternations of nearly closing a fishery to allowing a substantial catch due to a sudden appearance of recruits. The alternative Commission plans score better on this performance statistic with variability in between years up to 15 – 25%. Under both alternative plans, SSB is able to rebuild to values close to B_{MSY} under the low recruitment scenario, thereby being associated with moderate to low catches when compared to the other HCRs. Under the long-term recruitment scenario, the alternative plans stand out in terms of anticipated increase in SSB, above twice B_{MSY}. This HCR is also being associated with among the lowest catches reported. The original Commission proposed plan scores on average on nearly all performance statistics evaluated, compared to the other HCRs.

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Annex I

Managing Jack Mackerel: problem, solutions and the role of fishing vessels

30th of April 2014, Niels Hintzen

During the international workshop on 'Fishing vessels as scientific platforms: indicators and protocols for an Ecosystem Approach to Pelagic Fisheries', a work session was held to discuss current problems in Jack Mackerel management and potential solutions were given. Participants from four different countries (Chile, Colombia, France and Peru) joined the discussions. Among them were scientists and industry members (7 and 3 respectively).
The workshop was structured such that local and international regulations related to management were listed, followed by two sub-group discussions to detail problems related to management and solutions to these problems. In between the two sub-group discussions, a priority list of the problems were made. This enable the second round of sub-group discussions to focus on solutions tailored specifically towards the top two problems.

Current management regulations in place

The Jack Mackerel fishery is partially regulated through the SPRFMO convention. Advice on Jack Mackerel catches is yearly prepared by the scientific committee of the SPRFMO and follows the MSY approach to setting Total Allowable Catches. Outside the SPRFMO area and inside territorial waters of Chile and Peru, additional regulations are in place.
For example, in Peru, the Minimum Landing Size (total length) is set at 31cm, there are regulations towards mesh size and the percentage of juvenile catches is limited to a max of 30%. The catches of Jack Mackerel may only be used for human consumption. Advice on catches inside Peruvian waters is prepared by the national fisheries institute IMARPE and follows from a stock assessment taking a summer-acoustic survey into account.
In Chile, the regulations adopted by the SPRFMO are enforced in territorial waters of Chile as well. Minimum Landing Size is set at 26cm (total length) and allowed mesh sizes to be used vary from 12mm in the North (where Jack Mackerel is considered a bycatch species in the anchovy fishery) to 50mm in the South where it is targeted predominantly for human consumption.

Defining the problems with management

During the first sub-group meetings (consisting of two subgroups) the following problems with Jack Mackerel management were noted.
Group 1:

- Recruitment is not well defined
- Minimum landing size might not be relevant for management (protect older fish)
- The spatial distribution of Jack Mackerel is not well defined and the possible existence of sub-populations needs better understanding.
- The influence of environmental conditions on Jack Mackerel are not well understood
- In the North of Chile, the fishery does not target Jack Mackerel but rather bycatch it in the Anchovy fishery, hence management in place might not be fit for this area
- Having similar management regimes in place for Jack Mackerel in Peru and Chile might be counter intuitive as fish in either region grow and mature differently
- The migration patterns of Jack Mackerel are not well understood

Group 2:

- Underestimation of the Jack Mackerel stock due to problems in the design of the acoustic survey
- Recruitment is not well defined
- Artisanal landings are not well documented and make up for approximately 10% of the catch
- Environmental conditions are not taken into account in the advisory process
- Management measures such as maximum allowed percentage of juvenile bycatch are not justified

- The artisanal fishery is not regulated
- Data collection program in place in Peru is not aimed at Jack Mackerel

  From these list, the following six generic problems were identified

  1. Understanding recruitment process
  2. Call for management measures that are relevant for Jack Mackerel
  3. Distinction between management targets when biology of fish is different
  4. Data collection targeted on all Jack Mackerel fisheries
  5. Understanding of ecological processes that determine distribution of Jack Mackerel are necessary
  6. Underestimation of biomass by acoustic survey is problematic

Solutions for identified problems

From the top 6 list, number 1 and 6 were identified as the most important concerns. Another round of sub-group meetings were held, each group consisting of a different set of people, to discuss 1) what potential solutions are and 2) how management could be helped by the suggested solution.

The solutions given by group 1 were:

- Acoustic survey: run a pilot survey before the acoustic survey starts to define the area that needs to be covered
- Recruitment: the bycatch of juveniles should be reported to inform on young incoming fish. The fine associated with the catch of juveniles should be suspended

The solutions given by group 2 were:

- Define the area that the acoustic survey should cover which is in agreement with the area where Jack Mackerel is supposed to be present
- Include adaptive management according to biological / hydrographical conditions

Implementation of these solutions in management

The problems identified and solutions suggested will be communicated to the SPRFMO Scientific Committee. In addition, simulation modelling, based on Management Strategy Evaluation, will be applied to evaluate a number of the problems identified above. This should result in recommendations made to the Scientific Committee on what potential management plan designs might encompass, illustrated with performance indicators related to catches, stock recovery and stability.

Annex II

Notes Stakeholder workshop Brussels

19th of May, Niels Hintzen

Present: Angela Martini, Luis Molledo, Rafael Duarte, Dan Eskard, Agne Razmislaviciute-Palioniene, Martin Pastoors, Carian Emeka, Vincent Lelionnais. Marie-Emilie Guele, Niels Hintzen

Opening:
Opening by Angela Martine. Angela presents the general objective of the EU study and provides information on processes going on in the SPRFMO commission meetings. She indicated that Chile suggest to follow the quota advice suggested by them, which resulted in a reduction of quota outside the EEZ as most fish were present inside the Chilean EEZ. This year, the EU didn't make use of the quota allocated. During the commission meeting, the EU put forward a rebuilding plan, designed together with other member states. The aim is that this should prevent further discussions on quota in the future. She indicates that the main aim of the EU project is to, regardless of the stock structure considered, sustainable management options.
Study overview:
Rafael Duarte presents the overview of the study and the reason why the study got funded by the EU. Originally, the SPRFMO wrote a proposal for a large stock structure project but as the plan was too expensive, the project was not funded. The EU therefore suggested to look first at the data that is available to bring the discussion further.
Martin Pastoors asks what national programs were carried out with regards to sampling. Rafael mentions there are only bits and pieces available, but that the work forms no coherent part.

Current problems in Jack Mackerel management:

Niels Hintzen leads a session to investigate what stakeholder views are on current problems related to Jack Mackerel management. Points mentioned during this session are given below.

- It is key that management plans have a sufficient scientific basis:
    - Would it be possible to have a good scientific basis for the distribution and size of the stock the year after the assessment (projection) given the large distribution area
    - How uncertain is recruitment
    - How much does the environment Jack Mackerel lives in change and affects the dynamics of Jack mackerel

- The SPRFMO commission proposed rebuilding plan is complex in its nature as it always depends on conditions previously observed
- The plan stipulates no condition by which the fishing mortality is reduced to 0
- Agreeing on an overall TAC is not seen as a problem, the split among member states however seems to be difficult to agree on
- There is a need to predict the distribution of Jack Mackerel in the future

The main problems identified were:

- distribution
- recruitment
- quota share

Potential solutions to the problems mentioned:

The stakeholders were used to think in terms of already established rules, thereby limiting the ability to consider solutions on management plans 'outside the box'.

- The distribution of fish affects the allocation (more fish inside EEZ affects allocation of quota to high-seas fisheries). A solution could be to set the allocation based on expected proportion of fish density on high-seas versus TAC split.
  - Further questions: How is stock size related to fish distribution
  - How would the interact with historic rights
  - Would the distribution result in predictability for the industry as well

- Adapt fishing mortality in areas where density is higher
  - Possible, school aggregation may be an indicator to use here

Additional comments

- Relevance of using CPUE as an indicator: Currently, the input to the stock assessment consist of abundance indexes and CPUE , even though CPUE might hamper the efficiency of the Stock Assessment due to a lack of standardization among countries.
- Revision and adaptation of the risk criteria: the risk criteria used currently are applied under the ICES process which may not be as relevant for the CJM. DG MARE is committed to submit a proposal on different options on risks criteria to the Council in order to obtain an EU prepared proposal for the SPRFMO Scientific committee.