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Reference toint 9stimation

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Summary

In total 4 different approaches have been explored to estimate Biological Reference Points with a strong focus on Fmsy. In all these approaches, the stock-recruitment model assumed plays an important role in the final estimate. In 3 out of 4 approaches, Fmsy is estimated around 0.15, while only in the time-varying stock-recruitment model approach, Fmsy is estimated at slightly higher values around 0.25. Different biomass and fishing mortality targets and limits are suggested for which Fcrash and overfishing is estimated above F = 0.54 (median value) and F = 0.35 respectively.

Contents

1. Jack Mackerel Biological Reference Points (BRP)

Introduction

The renewal of a stock is known to be mainly determined by the relationship between spawners and recruitments. This relation is, in turn, determined by the resilience expressed in the "steepness" parameter; when recruitment is controlled by density-dependent effects, a stock is considered to be highly resilient (e.g. $h>0.8$). The biomass of these stocks fluctuates a great deal before compromising the scale of recruitments. Environment variations are key in the recruitment variations. For jack mackerel, has been assumed a value h=0.80, which corresponds to the value used in the current stock assessment, conducted in the SGW-JMSG (SPFMRO).

Theoretically, the Maximum Sustainable Yield (MSY) is the highest catch that can be taken from a stock in a period of time for steady environmental conditions, as long as the biomass has reduced to levels around the BMSY. The concept of MSY aims at maintaining the stock dimensions around the maximum stock growth rate.

This document addresses the estimation of variables related to MSY, considering a proposal for distribution of the "steepness" parameter and uncertainty in the exploitation patterns, regardless of the uncertainty derived from the stock assessment and the scale of recruitments.

Methodology

EquilibriumAnalysis

It corresponds to the integration of biomass per recruit and yield analysis with the S/R model with respect to "steepness" (h). This parameter measures the proportion of asymptotic recruitment reduction when the biomass has reduced to 20% of the virginal condition. Equilibrium biomass per recruit is used to measure biomass at equilibrium, which determines at the same time different levels of long-term recruitment.

Age structure of equilibrium stocks is represented by:

$$N_a = \begin{cases} R_0 & a=2 \\ R_0 e^{-\sum_{i=2}^{a}(i-1)\, Z_{a-1}} & 3 \le a \le 12 \\ N_a/(1-e^{-Z_a}) & a = 12+ \end{cases} \tag{1}$$

Where R_O is long-term asymptotic recruitment assumed as 1.0, Z is total mortality. Total mortality depends on natural mortality ($M=0.23$), fishing mortality (F_{cr}) and selectivity (S) in:

$$Z_a = M + F_{cr} S_a \tag{2}$$

Spawning biomass is estimated by the middle of November:

$$SSB = \sum_a N_a O_a w_a e^{-0.875 Z_a} \tag{3}$$

Where O and w are the sexual maturity and mean weight at age vectors accordingly. Recruitment generated by equilibrium spawning biomass is represented by the Beverton and Holt model

$$R = \frac{\alpha\, SSB}{\beta + SSB} \tag{4}$$

Where

$$\alpha = \frac{4hR_0}{5h-1}, \quad \beta = \frac{(1-h)SSB_0}{5h-1} \tag{5}$$

parameter *h* ("steepness") is assumed known while the virginal spawning biomass (*SSB0*) is estimated from eq (1) and eq (3) in un-explored conditions (Z=M). From eq.(4), it can be concluded that equilibrium spawning biomass with respect to spawning biomass per recruit (SSB/R) is:

$$\alpha\left(\frac{SSB}{R}\right) - \beta = SSB \tag{6}$$

Spawning biomass per recruit can be measured from eq (1) and eq (3) for any value of fishing mortality Fcr, and, alternately la equilibrium production curve is generated by

$$Y^{eq} = R\left(\frac{Y}{R}\right) \tag{7}$$

where recruitment R comes from eq. (4) and yield per recruit is estimated as:

$$\left(\frac{Y}{R}\right) = \sum_{a=2} e^{-(a-2)Z_a} \frac{F_a}{Z_a} w_a (1 - e^{-Z_a}) \tag{8}$$

Finally, the ideal fishing mortality is measured deriving eq. (7) with respect to fishing mortality and equaling to zero:

$$\left.\frac{\partial Y^{eq}}{\partial F_{cr}}\right|_{F_{MRS}} = 0 \qquad (9)$$

and optimal biomass BMSY is calculated once FMSY is known, replacing in eq.(9). For the purposes of calculation and derivation, the production curve Y^{eq} with respect to F_{cr} was approximated to a polinomial of order 3 for the 5 points around MSY given the discrete values of F. The calculus and simulation model was implemented on SCILAB.

Uncertainty sources

Uncertainty was incorporated in the estimations through Montecarlo simulation of the "steepness" value (h) and exploitation patterns. Steepness was estimated on the basis of recruitment and spawning stock data, derived from the stock assessment (see annex). The distribution was assumed as normal (prior) around value h= 0.74 and a deviation σ=0.094.

$h \sim N(0.74;0.09^2)$

Exploitation pattern was randomly taken from the matrix of fishing mortality generated in the stock assessment. The exploitation pattern corresponds to the fishing mortality matrix normalized to values between 0 and 1. As a complement, two cases with sexual maturity changes were analyzed (Table 1). Other sources of uncertainty such as natural mortality (M) and mean weights (Wm) were discarded as they have more implications on the scale of long term yields than on the asymmetry of equilibrium curve derived from the parameters of the stock-recruit relationship.

Table 1.

Jack mackerel biological parameters used for the analysis of equilibrium production

Age (years)

	2	3	4	5	6	7	8	9	10	11	12+
Maturity (old)	0.000	0.040	0.500	0.960	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Maturirty[1]	0.312	0.725	0.939	0.989	0.998	1.000	1.000	1.000	1.000	1.000	1.000
Weight (kg)	0.064	0.106	0.167	0.251	0.328	0.415	0.518	0.625	0.752	0.898	1.206

[1] Leal *et al*

Results

Identificationoftheselectivityperiod

The selectivity of the fleet has shown significant variations over time; an initial period is identified up to 1991, in which the purse seine fleet of northern Chile prevails -its selectivity is dome-shape type (Figure 1). Since 1992, along with the international fleet (ex-URSS) operating in the EEZ and the increased activity of the center-southern Chilean fleet, selectivity took a logistic form with important variations in the mean age of selectivity and general increasing trend (Figure 2). By the end of the analysis, uncertainty referred to selectivity is assumed as represented by the period 1992-2011.

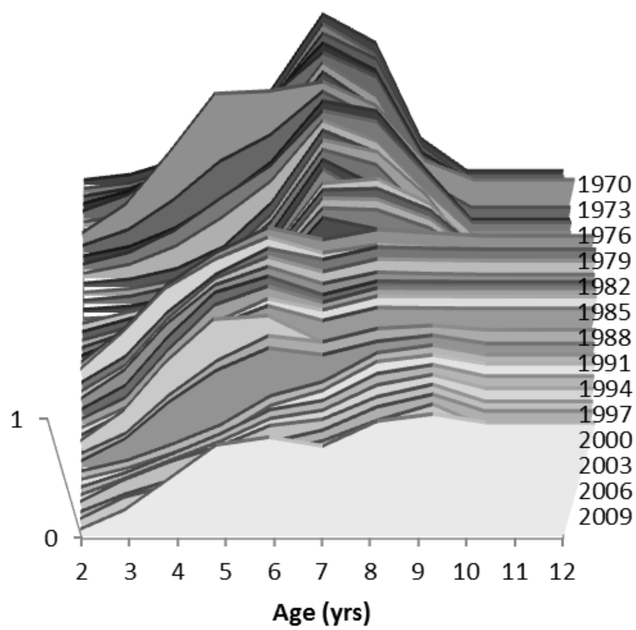


Figure 1. Selectivity of the fleet operating on jack mackerel 1970-2011

Priorof“steepness”(h)

Often, this parameter cannot be adequately estimated in the stock assessment (Hui-Hua, et al 2012, Maunder 2012) because could be correlated with others parameters to be estimated. In this work, the steepness was estimated outside the model (see Annex) and it was assumed normally distributed which at 95% of confidence should be contained between 0.54 and 0.96 (Figure 3)

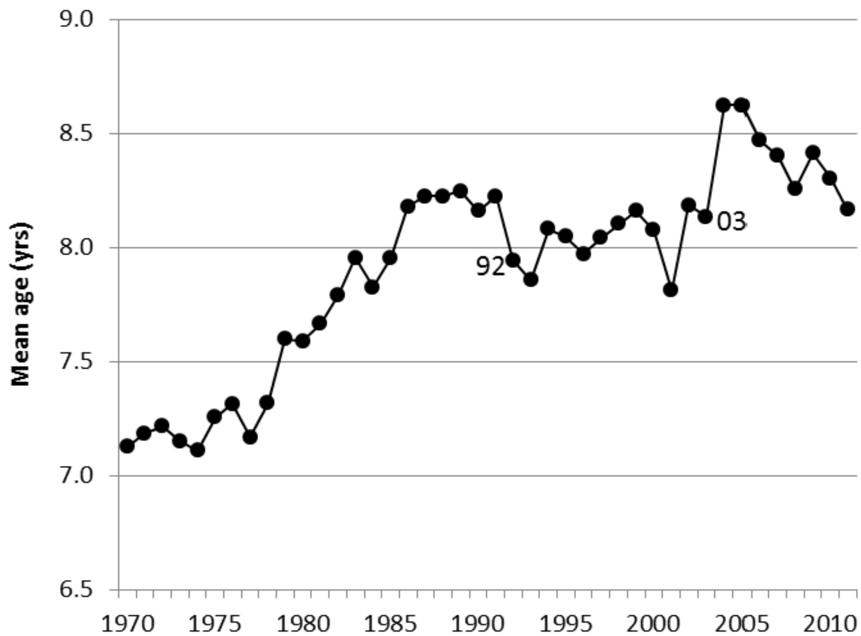


Figure 2. Mean age of selectivity jack mackerel

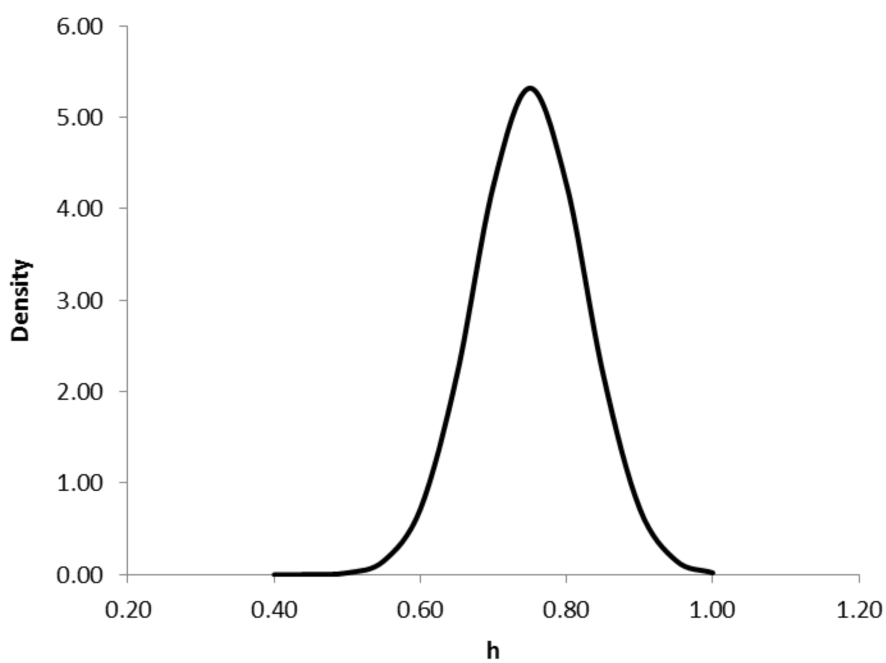


Figure 3 Probability distribution of "steepness"

Equilibriumanalysis

2,000 equilibrium yield curves were simulated with respect to the reduction of the spawning biomass and fishing mortality –details are provided in Figure 4. The reduction of the virginal spawning biomass (SSB/SSBo) that generates the Maximum Sustainable Yield (MSY) of jack mackerel is not sensitive to changes in the sexual maturity ogive and is around 0.31 (Table 2); the value of fishing mortality in MSY is $F_{MSY} = 0.24$. Distributions of probability of the SSB_{MSY}/SSBo and F_{MSY} are asymmetric (Fig. 5) with variation coefficients at 10% and 24% accordingly (Table 3). Analysis also shows that the MSY is achieved when the asymptotic recruitment has reduced to 83%-84%.

Confidence intervals at 95% of the SSB/SSB_{MSY} are located between 0.22 and 0.38, levels that for the purposes of fisheries management could be considered limit and target respectively. Table 3 shows detailed risk levels ad highlights that at 95% confidence, fishing mortality F_{MSY} is contained between 0.11 and 0.37 as candidates of target and limit BRP, accordingly.

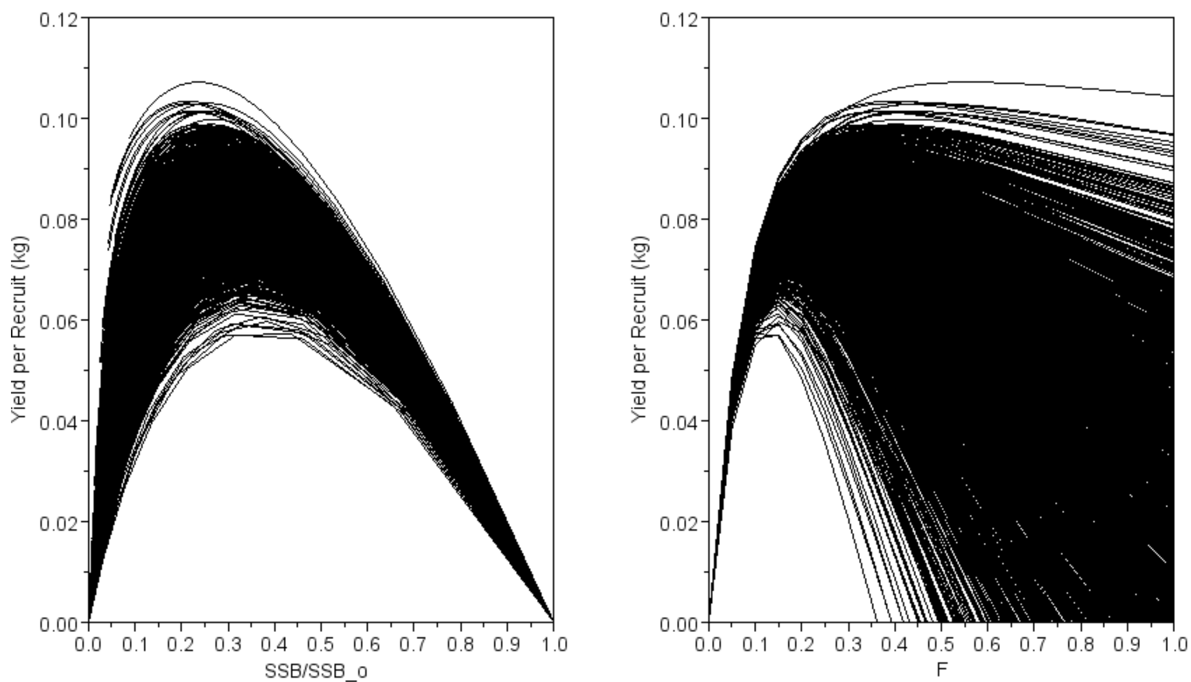


Figure 4. Equilibrium yield curves per recruit of jack mackerel with respect to the stock reduction (left) and fishing mortality (right)

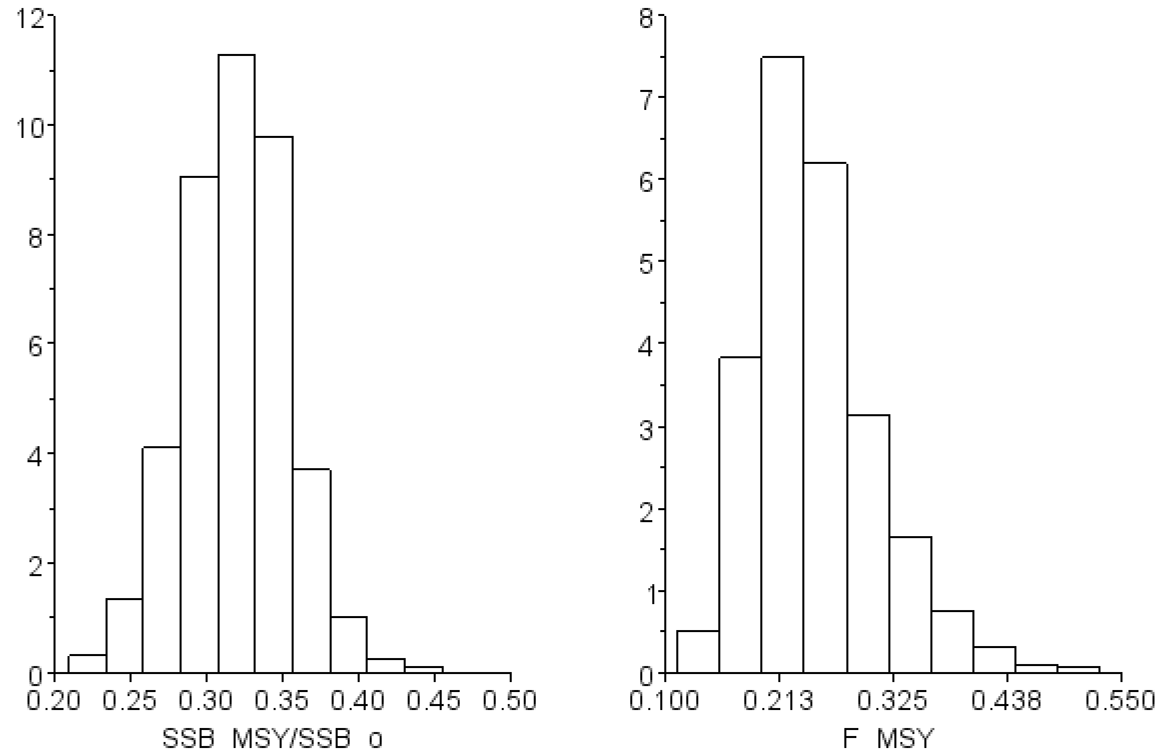


Figure 5. Distribution of probabilities of relative biomass at B_{MSY} (left) and optimal fishing mortality F_{MSY} (right).

Table 2.

Summary of variables related to analysis of jack mackerel equilibrium production

Scenario	S1	S2
Maturity Ogive	old	ne
Fmsy	0.226	0.25
MSY/R (gr)	79.3	82.
SSBmsy/R (gr)	361.5	419.
SSBo/R (gr)	1239.1	1343.
SSBmsy/SSBo	0.309	0.31
Rmsy/Ro	0.832	0.84

Table 3.

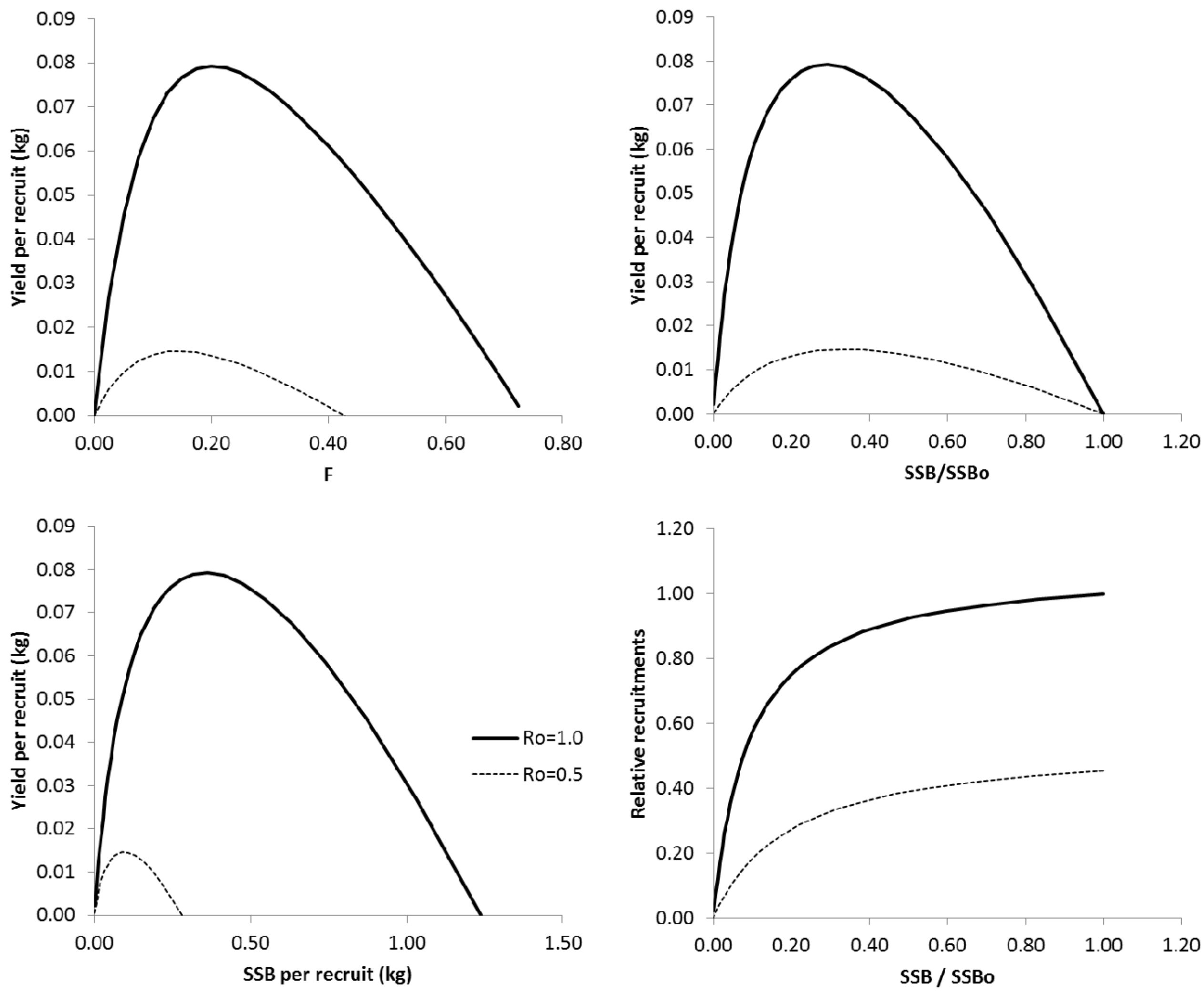
Stock reduction and fishing mortality relating to MSY and different risk levels

	Scenario	SSB/SSBmsy S1	SSB/SSBmsy S2	Fmsy S1	Fmsy S2
	mean	0.309		0.226	0.248
		0.319 std		0.055	0.061
Risk	10%	0.363	0.361	0.156	0.170
	20%	0.344	0.347	0.180	0.197
	30%	0.331	0.336	0.197	0.216
	40%	0.320	0.327	0.212	0.233
	50%	0.309	0.319	0.226	0.248
	60%	0.298	0.311	0.240	0.263
	70%	0.287	0.302	0.255	0.280
	80%	0.274	0.291	0.273	0.299
	90%	0.255	0.277	0.297	0.326
CI	2.5%	0.227	0.254	0.118	0.128
	97.50%	0.391	0.384	0.334	0.368

Regimeshift

Complementarily, the impact of changes in the regime on the productivity of the resource in the long term and values referred to MSY was analyzed. A change of regime or productivity has been posed for this resource since mid-1980s, which could have been translated into a decline of the long-term average recruitment level (Ro). This scenario would determine new values of parameters of the S/R relation, as shown in Fig 6.

Results indicate that when a 50% reduction of the long-term productivity occurs, all the variables associated to the MSY show a significant decline. Fishing mortality FMSY falls 40% and the MSY falls 82%. Same thing occurs with the virginal biomass, which decreases 79%. Nonetheless, the virginal biomass decrease caused by the MSY (SSBMSY/SSBo) does not vary a great deal and reaches 0.32, similar to the original situation (Table 4)



Figur6. Long-term recruitment and production curves of Jack mackerel, for two productivity regimes

Table 4.

Variables related to the analysis of equilibrium production of Jack mackerel for two productivity regimes (Ro).

	Low (Ro=0.5)	High (Ro=1.0)
Fmsy	0.15	0.25
MSY/R (gr)	14.6	82.4
SSB_{MSY}/R (gr)	90.5	419.5
SSBo/R (gr)	281.608	1343.001
SSB_{MSY}/SSBo	0.321	0.319

ExploitationDiagram

The diagnosis of this resource is established considering the level of reduction of the virginal biomass and the fishing mortality with respect to the reference points previously defined. These values were taken from the 2011 stock assessment, and the fishing mortality was standardized to the value of F_{MSY} for each year, according to the changes in the exploitation patterns (Fig. 7). Overfishing occurs when relative fishing mortality is $F/F_{MSY}>1.39$, and overexploitation occurs when the stock reduction is SSB/SSBo<0.22. In addition, an advisable conservation condition occurs when $F/F_{MSY}<0.6$ and SSB/SSBo>0.38.

Jack mackerel exploitation history shows that overfishing and overexploitation occurred simultaneously since 1995 and variations in fishing mortality has been steady to date, generating a steady reduction of the stock along with low levels of recruitment. Catch reduction has been caused mainly by the low abundance of the stock and high levels of fishing mortality (Fig. 9). In accordance, and considering the objective to rebuild the stock, the first measure should be reducing fishing mortality to levels at least around $F_{MSY}=0.25$. In addition, SSB/SSBo=0.1 is proposed as the hard limit that indicates the level of collapse of the resource, in which recovery is uncertain (Anon, 2007). This value is obtained by approximating the stock reduction when $F=F_{crash}$.

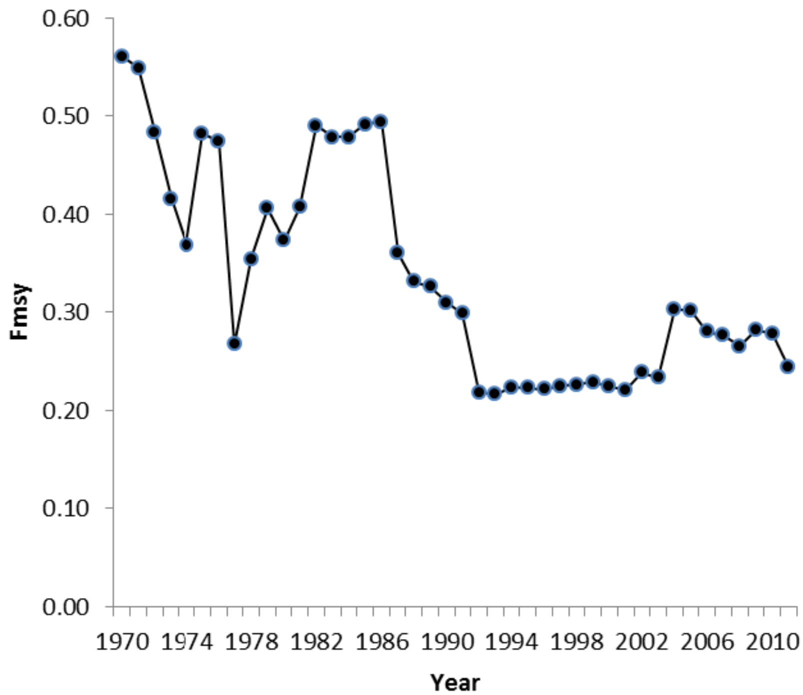


Figure 7. Fishing mortality FMSY by year according to selectivity

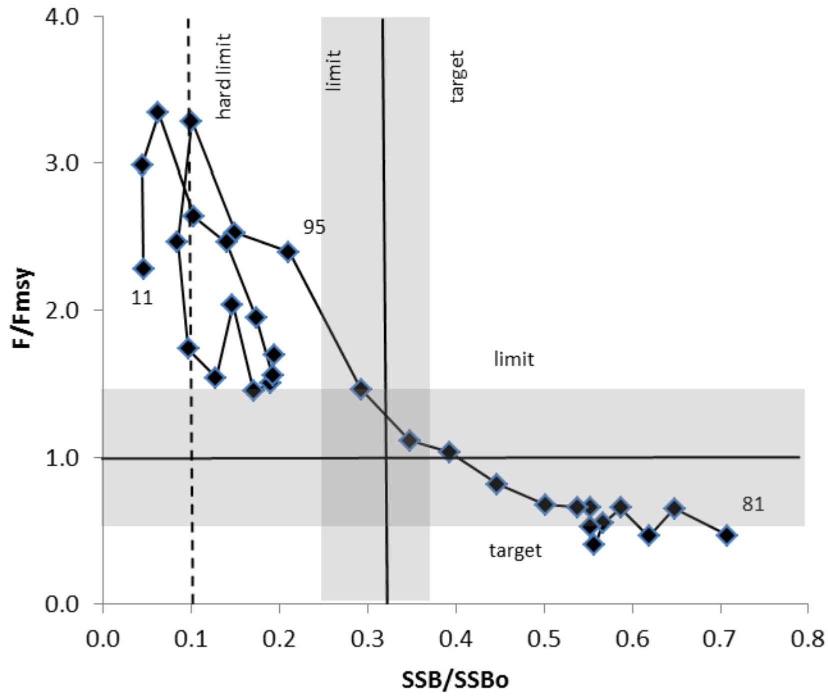


Figure 8. Jack mackerel exploitation diagram.

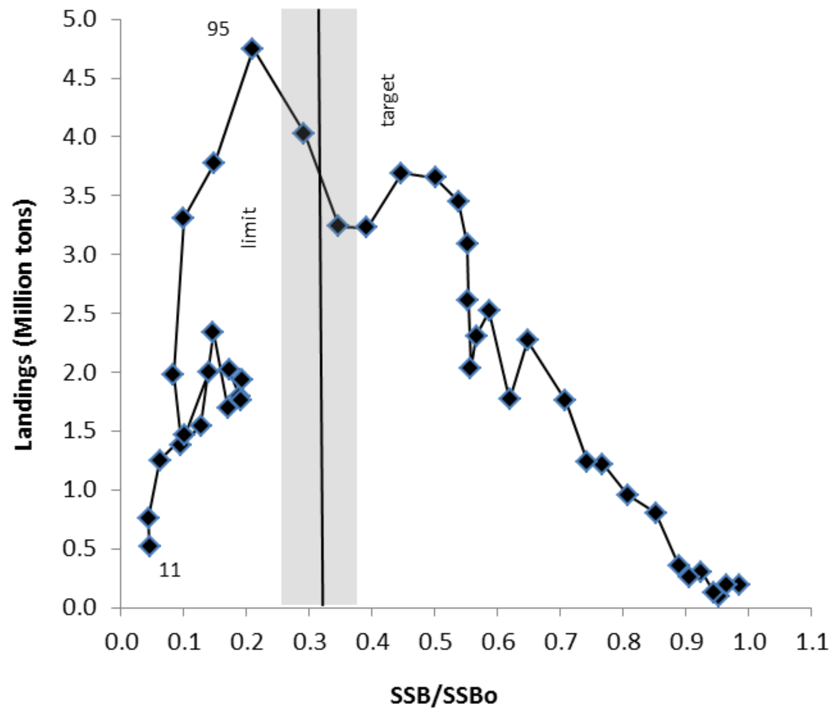


Figure 9. Relation between Jack mackerel catches and stock reduction.

Conclusions

An equilibrium analysis under uncertainty conditions was conducted for different scenarios of sexual maturity and productivity. Results showed that the virginal spawning biomass reduction generated by the MSY is robust to the different sources of uncertainty and is close to SSB/SSBo=0.32. Considering the confidence interval at 95%, a lower limit is proposed to define overexploitation is the stock reduction is lower than 0.26, and as target limit the top limit estimated at 0.37. At the same time, confidence intervals of fishing mortality FMSY suggest as overfishing limit when F>0.35 and as target a value F=0.15. Besides, a hard limit equivalent to 10% of the virginal spawning biomass is proposed, under which the recovery of the resource is uncertain.

The stock condition is over-exploitation, with levels of fishing mortality compatible with over-fishing. To rebuild the stock to target levels, the implementation of a new strategy of constant fishing mortality is proposed, as well as a reduction of the current fishing mortality at least to values of FMSY.

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2. Estimating Fmsy assuming a variety of Stock-Recruitment relationships

During the 2nd Preparatory Conference, held in Cali, Colombia, the Preporatory Conference requested the Science Working Group to consider a number of points related to Jack Mackerel stock assessment and Management. Among these, the SWG was requested to look at '*Catch levels likely to achieve particular fishing mortality and/or biomass reference points, within particular time frames*'. Within this study, an attempt has been made to provide insights into the reference points of F_{MSY} and B_{MSY}.

Key to determining F_{MSY} and B_{MSY} reference points is the inclusion of a stock-recruitment model inside a population age structured simulation model. The equilibrium situation of the population model is primarily determined by the productivity of the SR-model. However, in many instances, as well as in this case at first sight, a clear relationship between Spawning Stock Biomass and Recruitment is lacking and on biological grounds no stock-recruitment model can be assigned such as a Ricker or Beverton and Holt curve. As this information is lacking, and to refrain from making arbitrary choices, a multiple stock assessment approach has been taken, as described by Simmonds et al. (2011), and applied to the Jack Mackerel stock.

Materials & Methods

As indicated above, the methods applied to the Jack Mackerel stock follow closely the methods as described by Simmonds et al. (2011). Simmonds et al. however assumes 6 types of curves, and fits these models with each 3 different residual distributions (normal, lognormal, gamma), while in this study we only consider 3 models, the Ricker, the Beverton and Holt and Segmented regression model, fitted assuming normally distributed residuals, as shown in their mathematical form below.

Beverton and Holt	$\alpha \cdot S / (\beta + S)$
Ricker	$\alpha \cdot S \cdot \exp(-\beta \cdot S)$
Segmented Regression	$if\ S \le \beta\ then\ \alpha \cdot S\ else\ \alpha \cdot \beta$

At first, each model was fitted to the data, and based on the variance-co-variance matrix, and a multi-dimensional random distribution, 3000 new parameter sets were generated for each of the models. For each of these newly generated models, the likelihood fit was calculated. The harmonic mean of the likelihood by model type was calculated from these fits, and up to 1% of the models was removed if they influenced the harmonic mean to a large extend.

For simulation purposes, only 1000 models were needed, hence, some of the 9000 models available in total had to be dropped (see figure 1). The harmonic mean ratio between the models finally determined which proportion of the 1000 models was going to be represented by what model type (e.g. if model 1 to 3 has a likelihood of resp. -10, -15 and -25, the first model will make up 10/40th of the 1000 models etc.). The total of 1000 models were used in a population age structured simulation model to estimate F_{MSY}. Population characteristics as maturity-at-age and weight-at-age were obtained from last year's Jack Mackerel assessment, as well as the most recent Fpattern as estimated in 2011. For each simulation, calculations were run into equilibrium where F, SSB and yield were calculated based on the population equilibrium conditions. The population was scanned for 100 F multiplier values (0 to 100) which represents an F range of approximately 0 to 1.

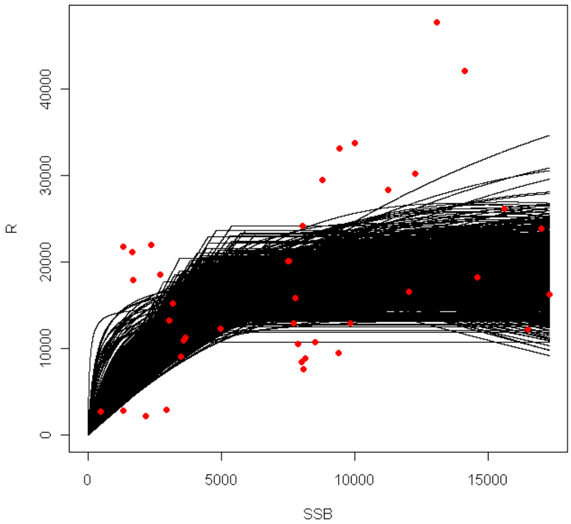


Figure 1: Graphical representation of the 1000 models that have been selected. Black solid lines represent selected models, red dots represent SSB-Recruitment points as observed for Jack Mackerel.

Results

Two main results can be distilled from this study. At first, yield is plotted against fishing mortality to estimate F_{MSY}, as is shown in figure 2.

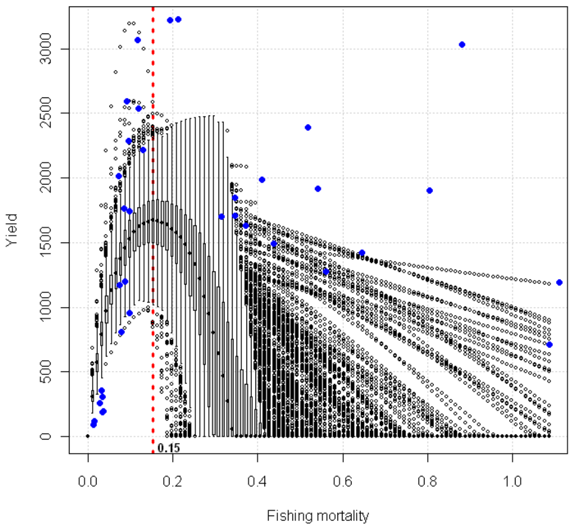


Figure 2: Yield plotted against fishing mortality for all 1000 runs, where the spread in the boxplot indicates the spread in the 1000 models. The median of the 1000 models is given by a small black dot, inside the dark grey boxes. The blue points represent the observed yield versus fishing mortality values as obtained from the assessment. The vertical red dotted line indicates the top of the curve, F_{MSY}.

From figure 2 we can obtain an F_{MSY} value, which lies in the top of the curve. There is little doubt about the top of the curve, with specific reference to the median top of the curve. This is estimated to lie at F = 0.15.

In a similar approach, also SSB can be shown against Fishing mortality (see figure 3).

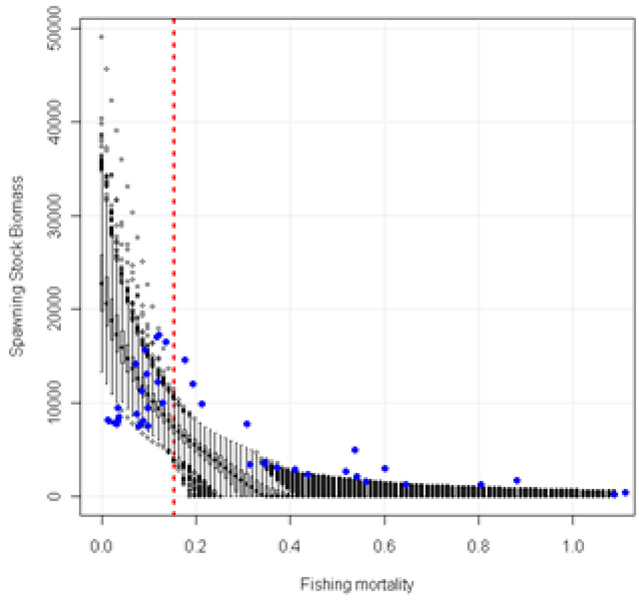


Figure 3: Spawning Stock biomass plotted against fishing mortality for all 1000 runs, where the spread in the boxplot indicates the spread in the 1000 models. The median of the 1000 models is given by a small black dot, inside the dark grey boxes. The blue points represent the observed SSB versus fishing mortality values as obtained from the assessment. The vertical red dotted line indicated the top of the yield-curve and is introduced in this figure to refer to B_{MSY}.

Based on the SSB calculations, we obtain the median B_{MSY} value of 7.4 million tonnes which corresponds with an F of 0.15, F_{MSY}.

Conclusions

Fmsy calculations calculated without uncertainty, except for the stock-recruitment curve and parameters considered, median Fmsy can be determined at 0.15 and Bmsy at 7.4 million tonnes.

References

Simmonds, E.J., Campbell, A., Skagen, D., Roel, B.A., Kelly, C., Development of a stock–recruit model for simulating stock dynamics for uncertain situations: the example of Northeast Atlantic mackerel (Scomber scombrus), ICES Journal of Marine Science 68(5), 848-859

3. Estimating Fmsy assuming a variety of Stock-Recruitment relationships and uncertainty in their parameters as estimated from the 2011 Joint-Jack Mackerel stock assessment

Introduction

A software tool named plotMSY, developed by CEFAS, UK, has been used to estimate reference points for Chilean Jack Mackerel. The core goal of this software is to combine biological data and their uncertainty estimate together and, based on MCMC, calculate the frequency distribution of Fmsy and other biological reference points. It provides a quick and easy tool to estimate these reference points but lacks the possibility to include co-variance structures among parameters. The equations embedded within the software are similar to those used under method 1 and 2 and assume states in an equilibrium situation.

Material and Methods

Yield per recruit and MSY reference points and their associated uncertainties were estimated by means of the plotMSY software. Derivations of yield- and SSB-per-recruit follow from equilibrium considerations. F0.1 and Fmax are derived calculating the derivative with respect to F of the YPR function. MSY quantities are also derived from the YPR equation, but they also incorporate the stock-recruit relationship. In order to do this, the stock-recruit functions are reformulated in terms of spawning biomass per recruit and multiplied by the YPR equation. Following appropriate substitutions an expression of yield in terms of F is obtained.

The software plotMSY uses Markov Chain Monte Carlo (MCMC) methods to infer the distribution of stock and recruitment and yield per recruit parameters. In general terms MCMC is an attempt to simulate direct draws from a given complex distribution. MCMC approaches are so-named because they use the previous sample values to randomly generate the next sample value, generating a Markov chain (as the transition probabilities between sample values are only a function of the most recent sample value, in a similar way to a random walk). MCMC provides a good tool for exploring the posterior and hence for drawing inferences about models and parameters.

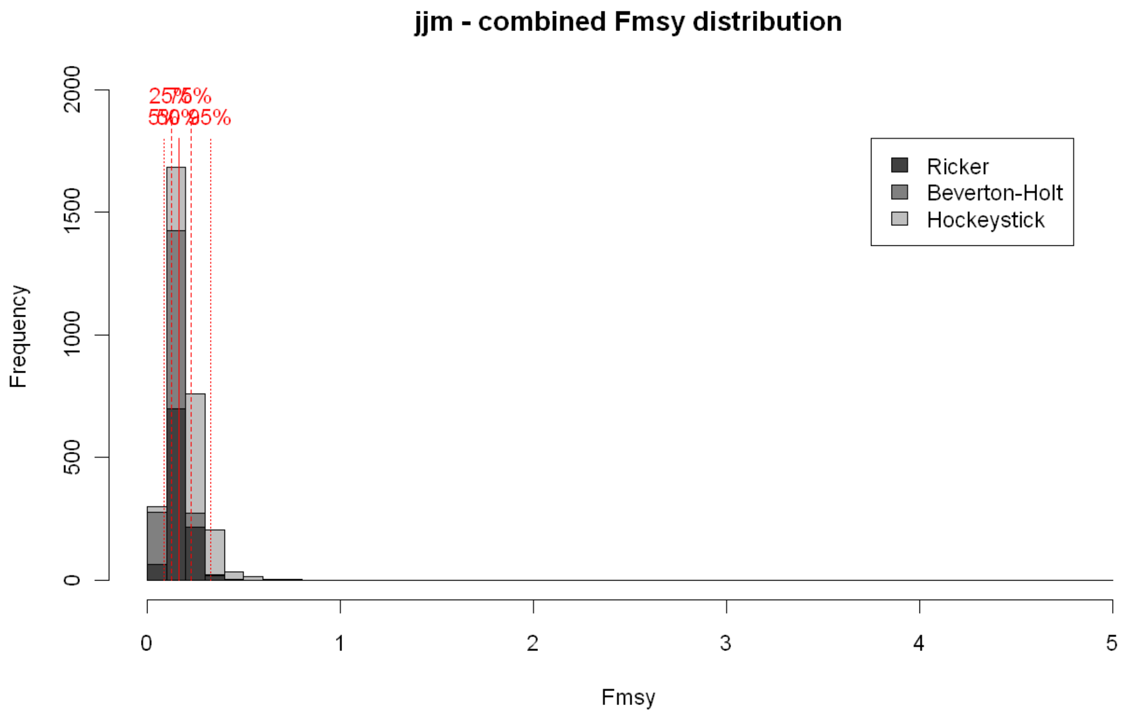
Estimates of Fmsy based on the three common stock recruit relationships: Ricker, Beverton-Holt and Hockey stick (approximated by a continuous function as suggested by Mesnil & Rochet) were compared. A thousand iterations of the MCMC were output.

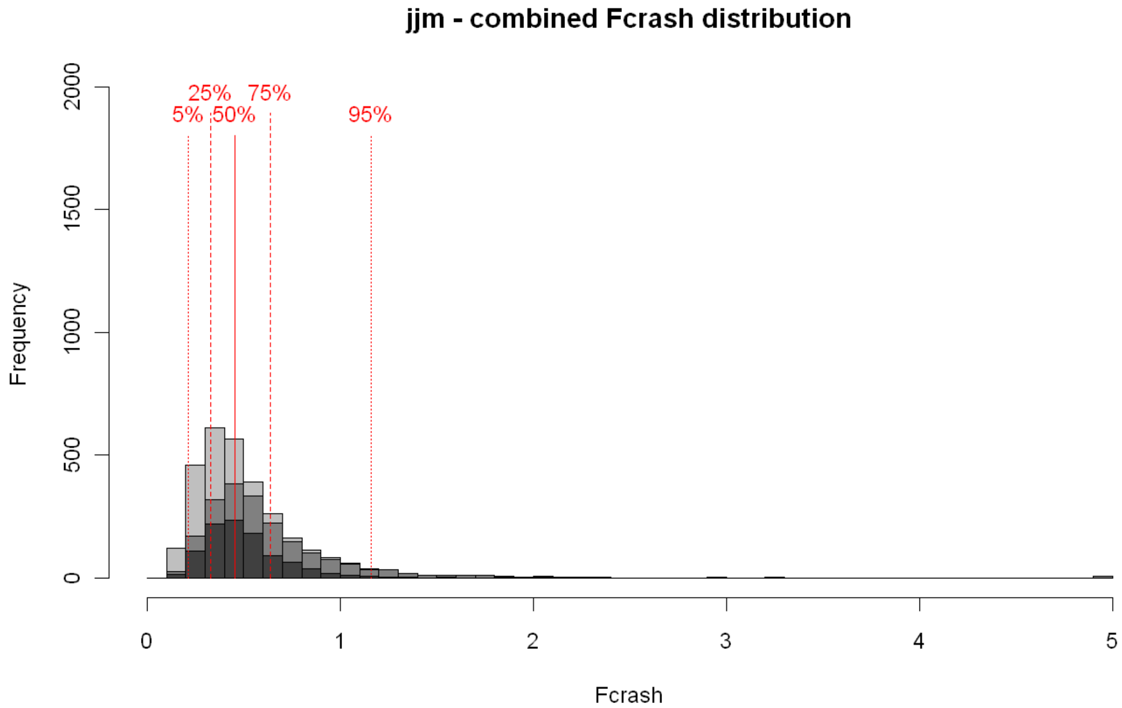
Reference points were estimated based on historic data from 1972 to 2011 and estimates from the 2011 JJM assessment. Input data were

- Mean weights at age (1972 – 2011), maturity (fixed but with cv of 0.1) and natural mortality (fixed but with cv of 0.1);
- Numbers at age in the most recent year and associated CVs as in 2011 assessment output;
- Selection 2011 with cv 0f 0.235;
- Stock and recruitment pairs for the whole time series (1972-2011) as estimated in 2011 assessment.

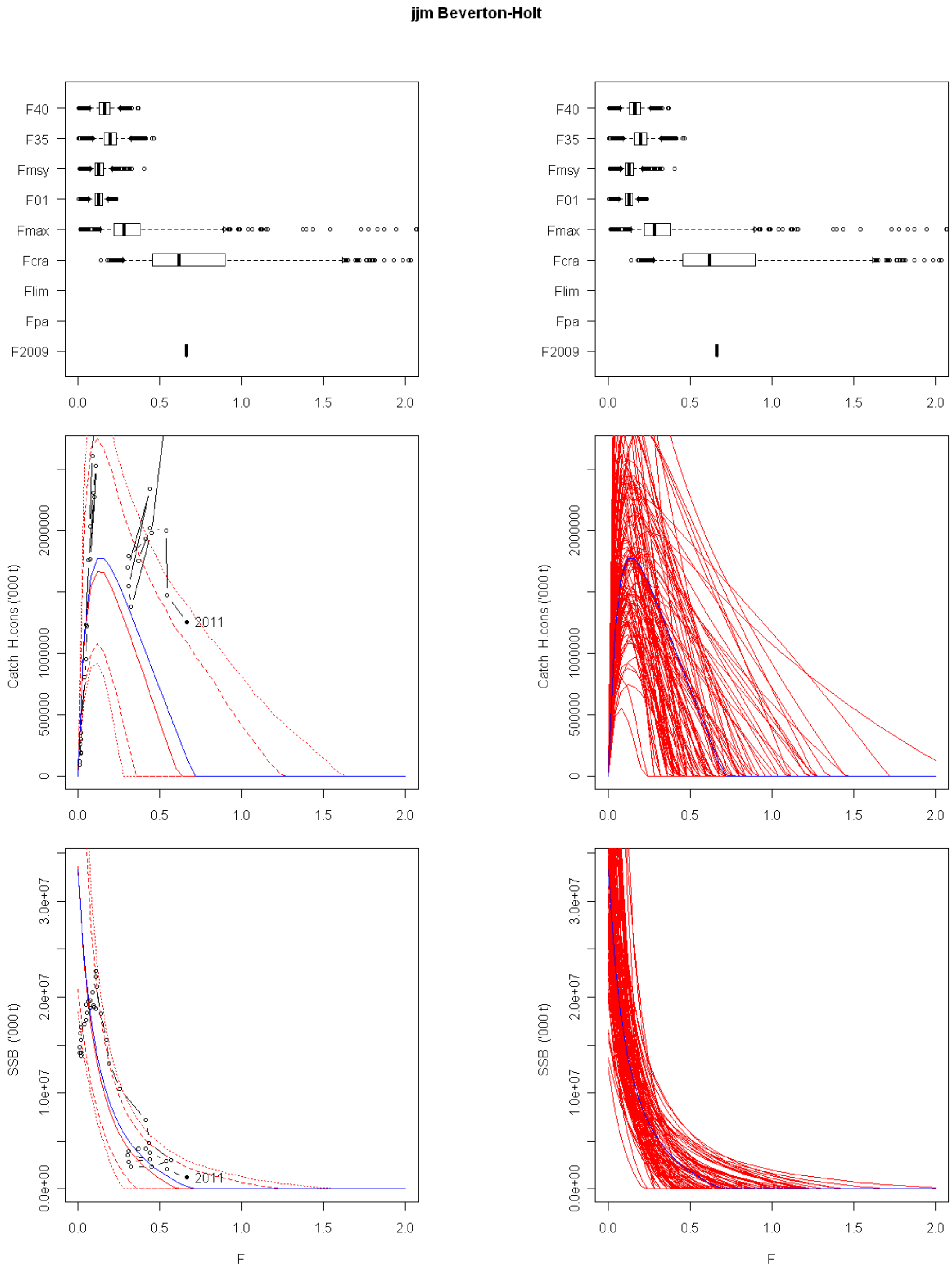
Results

Based on the procedures and data described above, the resulting distributions of Fmsy have been combined. In general, there is very little information to decide which stock-recruitment model fits the data best, and for that reason, combining the three forms explored here, informs about a large range of potential processes. The figure below shows the frequency distribution of Fmsy values binned in steps of 0.1F. Both the Ricker and Beverton and Holt combination contribute to the large peak in the 0.1-0.2 binn. The Hockey-stick approach adds most to the 0.2-0.3 binn. When considering Fmsy, it is equally important to also consider Fcrash. The closer Fmsy and Fcrash are situated together, the higher the risk that inaccurate management might result in a collapse of a stock. The median Fcrash value estimated is situated in the 0.4-0.5F binn, while managing at Fmsy (0.1-0.2 binn) is associated with a very low risk (<5%tile).

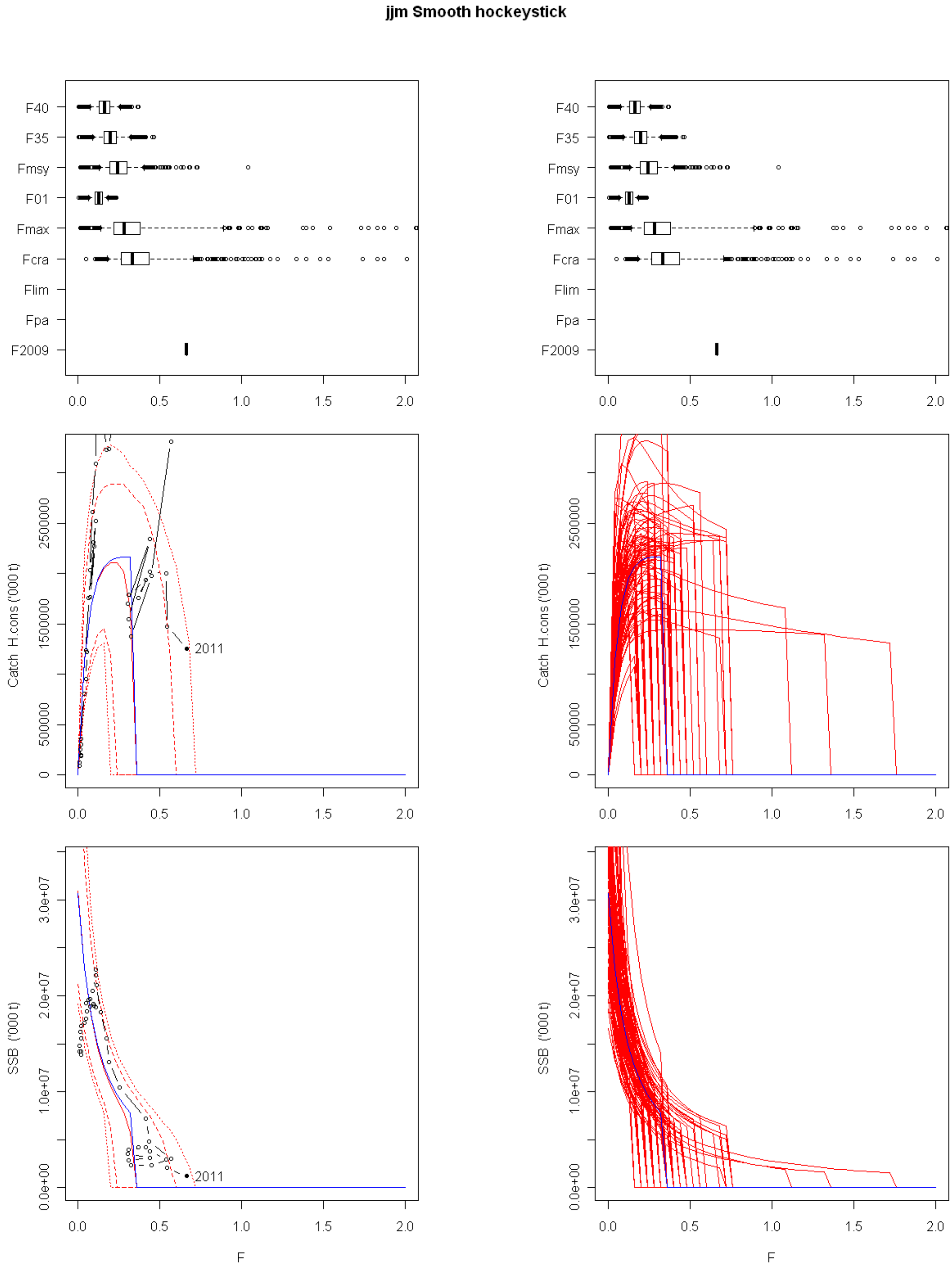




For each of the stock-recruitment forms, a figure showing the results of the MCMC process is given. The top left panel shows the quantile distribution per F reference point. Fmsy is for the beverton-holt combination close to the F01 proxy and also F40 and F35 are located rather close to the, in this instance, most precautionary Fmsy value. The middle row describes the expected catch in equilibrium while the bottom row shows the expected Spawning Stock Biomass values including the observed values in the left-hand panels.

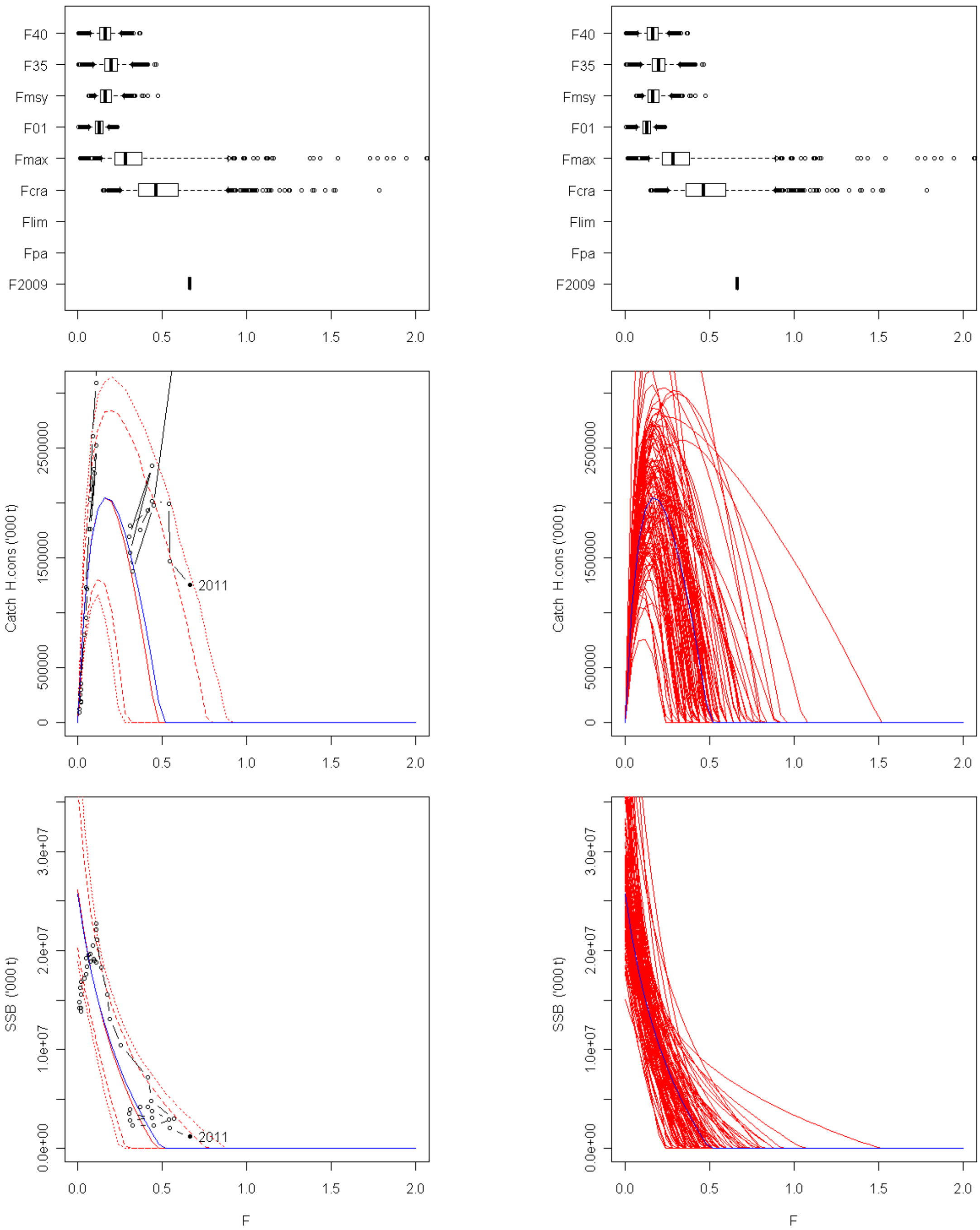


Fmsy is for the hockey-stick approach considerably different from the F01, F40 and F35 estimates. Fmsy is estimated at a value close to 0.25 while Fcrash has a considerable overlap in F range. The hockey-stock approach is not considered to provide reliable Fmsy values in this instance.



Fmsy is for the ricker approach rather similar to the beverton-holt approach with estimates close to 0.15 and F40, F35 and F01 estimates similar to Fmsy estimates. There is only a slight overlap among estimated Fcrash and estimated Fmsy values.

jjm Ricker



The combined results are given in the table below also specifying all quantile results given they were generated with a 1000 replicates. The combined Fmsy estimate indicates Fmsy at 0.17 associated with an Fcrash of 0.45. The combined values are however influenced by the hockey-stick approach.

Ricker	Fcrash	Fmsy	Bmsy	MSY	Alpha	Beta	AICc
Deterministic	0.50	0.17	11962900	2052330	3.71	6.72314E-08	73.87
Mean	0.50	0.17	12484640	2154416	3.82	6.69187E-08	76.05
5%ile	0.25	0.10	8799933	1194546	2.60	4.33613E-08	73.97
25%ile	0.36	0.13	10488925	1702285	3.23	5.66483E-08	74.48
50%ile	0.46	0.16	11964250	2121215	3.75	6.67498E-08	75.37
75%ile	0.59	0.20	13834900	2549590	4.31	7.71065E-08	76.92
95%ile	0.89	0.27	17995665	3237952	5.37	9.05178E-08	80.24
CV	0.41	0.32	0.24	0.31	0.22	0.22	0.03
Beverton-Holt	**Fcrash**	**Fmsy**	**Bmsy**	**MSY**	**Alpha**	**Beta**	**AICc**
Deterministic	0.71	0.14	12281800	1786320	25235500	4942410	74.10
Mean	0.75	0.13	15579173	1870715	26576560	6142968	76.27
5%ile	0.27	0.07	6759353	965731	18081030	1783166	74.23
25%ile	0.45	0.10	9434993	1350065	21648025	3455348	74.76
50%ile	0.62	0.13	12106050	1729400	24950400	5230225	75.62
75%ile	0.90	0.15	16371650	2245238	29774225	7565643	77.15
95%ile	1.61	0.21	27830980	3236569	39495190	14247290	80.45
CV	0.71	0.33	1.26	0.39	0.30	0.72	0.03
Smooth hockeystick	**Fcrash**	**Fmsy**	**Bmsy**	**MSY**	**Alpha**	**Beta**	**AICc**
Deterministic	0.35	0.28	8566430	2164670	1.38	7324470	75.79
Mean	0.38	0.25	10839113	2251612	1.51	7374815	78.14
5%ile	0.18	0.13	5962580	1434259	1.04	4151483	75.92
25%ile	0.26	0.19	7567388	1827850	1.24	6254820	76.47
50%ile	0.33	0.24	9313380	2180925	1.40	7392130	77.37
75%ile	0.43	0.30	11358975	2574543	1.60	8516490	78.95
95%ile	0.70	0.40	17723955	3302929	2.06	10714350	83.48
CV	0.59	0.37	0.96	0.26	0.40	0.27	0.03
Combining all SRRs							
Percentage	**Fmsy**	**Fcrash**					
5%	0.09	0.21					
25%	0.13	0.33					
50%	0.17	0.45					
75%	0.23	0.64					
95%	0.33	1.16					

Conclusions

Assuming that the beverton-holt and ricker curve are good approximations of the stock-recruitment process, Fmsy can be determined at 0.15 and Fcrash at 0.54.

4. Estimating time-varying stock recruitment to inform reference point estimation

Introduction

The assumption that recruitment and spawning stock biomass are related and can be described by a mathematical formula might be considered a crude one. This assumption is however the basis of most MSY calculations and is therefore a difficult one to escape. Most often, stock-recruitment relationships are criticized because they assume stationary stock dynamics and do not leave little room for variability other than at the cost of a poor fit. Even when assuming stationarity, the residual pattern that follows from a certain model fit is not always indicative of the variability in biology and neither does it reflect our observation error of the process. Correlating stock-recruitment processes with environmental processes does in some cases provide a useful insight, however, finding a clear mechanistically understanding has proven to be difficult. Here I present a hybrid approach between assuming stationary stock-recruitment relationship and allowing for year-to-year variability. The approach allows time-variation in the stock-recruitment model, where changes from year to year are described by a random walk. The conceptual approach of a random walk seems fit here as between years the changes in recruitment process might be small while in the longer term, larger differences can be observed. Allowing the recruitment model to deviate from year to year should explain part of the variability in nature and should also provide more insight in the observation error involved, the part not necessarily explained by variability. Trends in estimated parameters do inform whether recruitment processes have changed over time or if they can be considered 'stationary'.

Methods

(This section is a near exact copy of Payne et al. 2012, submitted)

Incorporating time-variation into a standard stock-recruitment relationship is conceptually simple: the parameters of the SRR, rather than being constants, are allowed to display a time-dependent variation. However, particularly given the short nature of the time series in question, over-parameterisation can arise quickly, and generally limits attempts to adding time-variation. State-space models, however, are much less vulernable to over-paramerisation issues. The parameters of the stock-recruitment relationship are assumed to follow a random-walk in the parameter state-space, so that the value of the parameters at a given time point also informs about the values at another, nearby, time point. Such a mathematical model seems an appropriate formulation of non-stationarity: it is reasonable to expect a degree of stationarity on short-time scales (i.e. variability in the SRR is not-simply a random process) but that changes occur when viewed across longer-time scales. The random-walk, in spite of its complex nature, is characterised by only a few parameters, thereby allowing a high-degree of flexibility at low cost". The set of equations that describe the process are given in equations 1-3. The random walk can be described by an additive or multiplicative process, both equally valid.

$$\hat{R} = \alpha_r S \exp\left(-\beta_r S\right) \tag{1a}$$

$$\hat{R} = \frac{\alpha_b S}{1 + \beta_b S} \tag{1b}$$

$$p_t - p_{t-1} \sim \mathrm{N}\left(0, \sigma_p\right) \tag{2a}$$

$$\log\left(\frac{p_t}{p_{t-1}}\right) = \log\left(p_t\right) - \log\left(p_{t-1}\right) \sim \mathrm{N}\left(0, \sigma_p\right) \tag{2b}$$

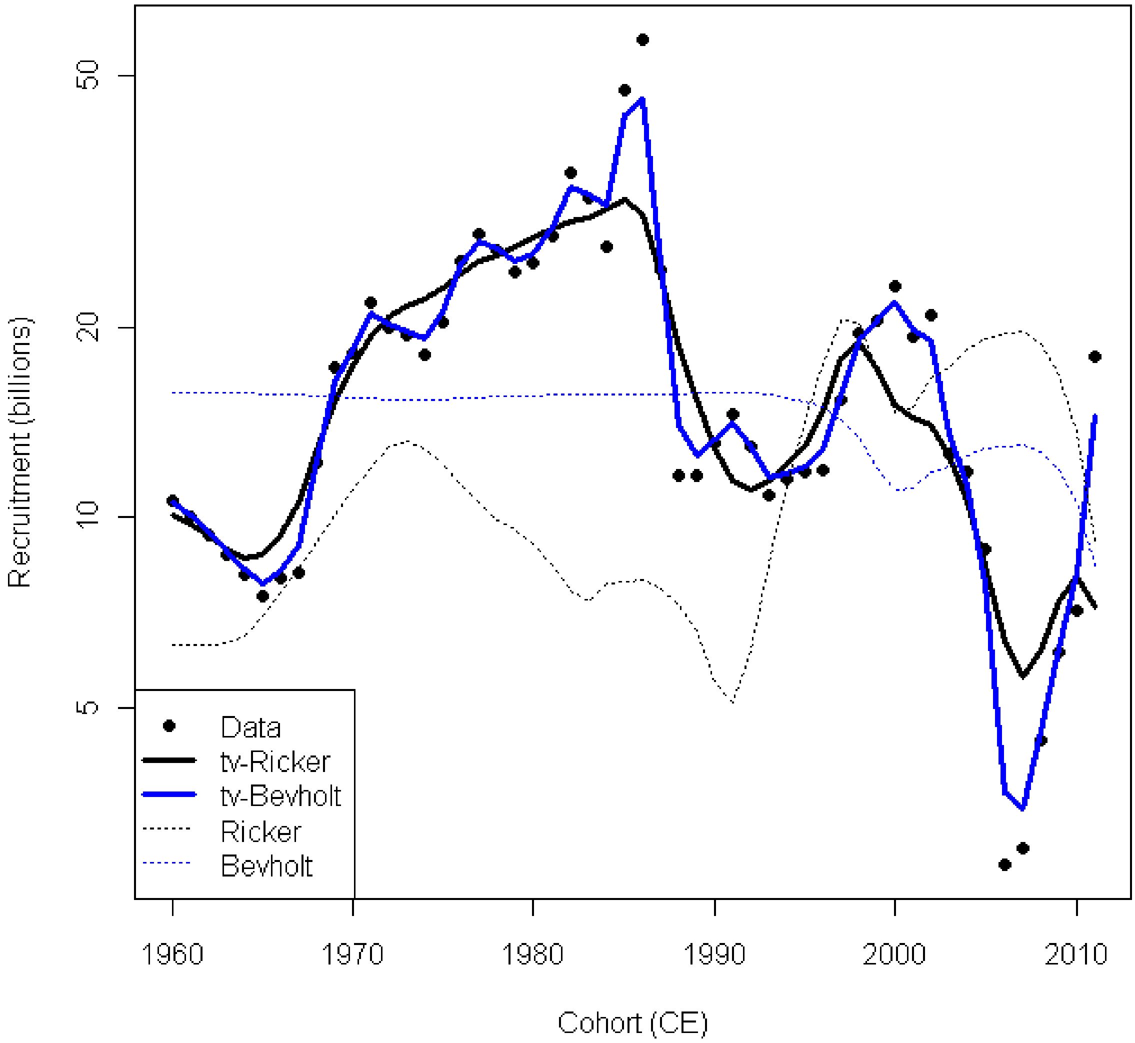
$$R = \hat{R} + \epsilon_t, \quad \epsilon_t \sim \mathrm{N}\left(0, \sigma_e\right) \tag{3a}$$

$$R = \hat{R} \exp\left(\epsilon_t\right), \quad \epsilon_t \sim \mathrm{N}\left(0, \sigma_e\right) \tag{3b}$$

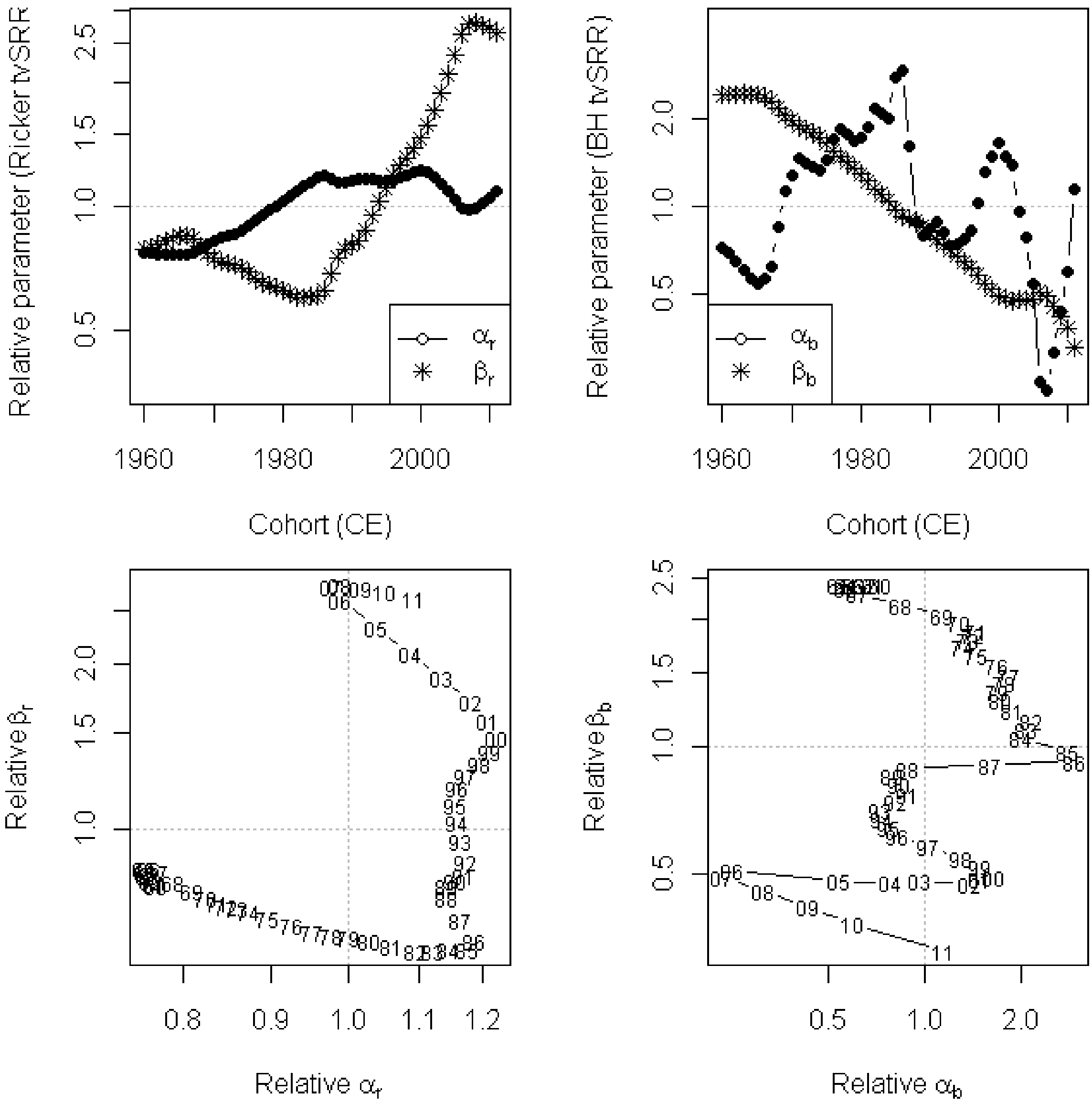
After estimating time-variant stock-recruitment relationships, the most recent parameter deviance estimate from the time-variant approach is used to perform deterministic Fmsy calculations. This is based on the random-walk assumption where next year recruitment function is most similar to this year's estimate.

Results

The figure below shows the recruits as estimated in the Joint-Jack Mackerel stock assessment in dots while the time-variant (tv) and time-invariant Ricker and Beverton-Holt stock recruitment lines are given in black and blue respectively. The time-variant approaches give similar results while a disclaimer must be added to the Ricker line as the model did not properly converged and observation error was assumed to be similar to the converged estimation of the Beverton and Holt approach. As can be observed, the observation error is markedly different from the time-invariant approach.



As a core result, the method provides yearly estimates of alpha and beta parameters of the stock-recruitment relationship as measured by deviance from a time-invariant approach. This allows us to study potential trends in parameter changes. It is clear that for both the Bevholt and Ricker approach, the beta parameter shows strong trends over the past 20 years while trends in the alpha parameter are less pronounced. Also the parameters shown over alpha-beta space (bottom row) indicate clear time trends.



The most recent estimates (2010, not 2011 due to uncertainty) of alpha and beta for the ricker curve are: 9.75 and 4.42e-7 respectively (against 9.28 and 1.64e-7 for the entire time series). For the behvolt curve they amount to: alpha: 9.9e6 and beta: 4.5e5 (against 1.6e7 and 1.2e6 for alpha and beta respectively for the entire timeseries).

Using these estimates to estimate Fmsy results in values for the ricker and beverton and holt curve of 0.28 and 0.19 respectively.

Conclusions

The approach in which a time-variant stock-recruitment model is used does provide insight into the changed dynamics of the stock-recruit relationship for jack mackerel. When using the time-variant estimates of 2010 results in markedly higher deterministic Fmsy values. This result can be expected as due to low recruitment, one should fish harder to prevent too many individuals die off because of natural causes. Simply waiting to let the fish grow is not paying off in this instance.

References

Payne et al. Submitted. Time-varying stock-recruitment relationships.