Jack Mackerel Biological Reference Points (BRP)

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1. 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 factors 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 B_{MSY}.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.

2. Methodology

<u>Equilibrium Analysis</u>

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:

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

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 (SSB_0) is estimated from eq (1) and eq (3) in un-exploited 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 the 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 optimal fishing mortality is measured deriving eq. (7) with respect to fishing mortality and equaling to zero:

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

Optimal biomass B_{MSY} is calculated once F_{MSY} is known, replacing in eq.(3). 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 (new)[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* (2012).

3. Results

Identification of the selectivity period

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). For the purposes of the analysis, uncertainty referred to selectivity is assumed as represented by the period 1992-2011.

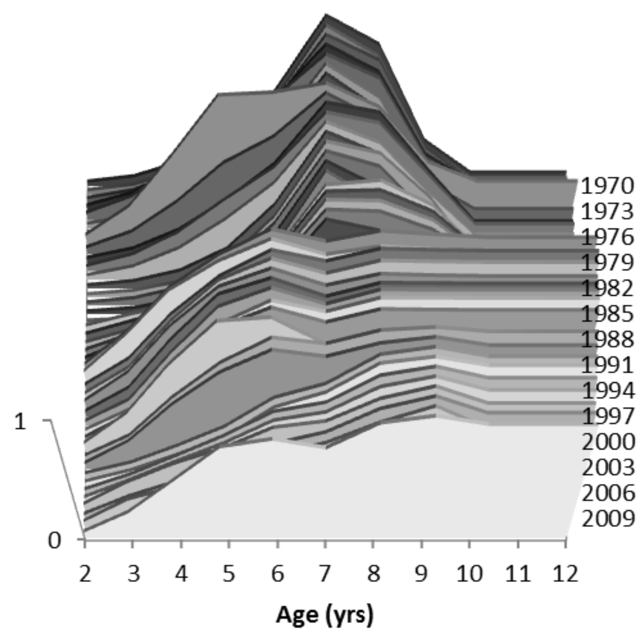


Figure 1. Selectivity of the fleet operating on jack mackerel 1970-2011

Prior of "steepness" (h)

Often, this parameter cannot be adequately estimated in the stock assessment (Hui-Hua, et al 2012, Maunder, 2012) because of its correlation with others parameters. 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)

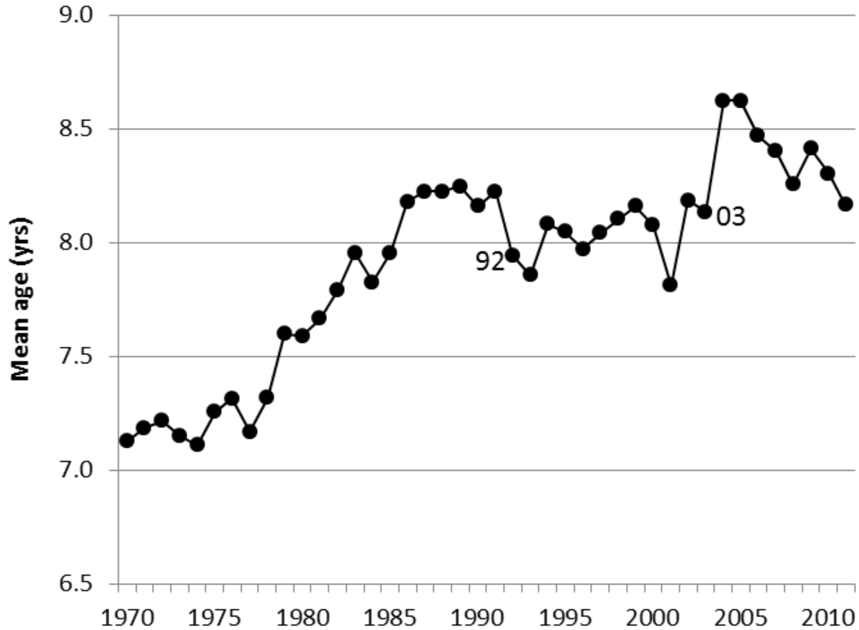


Figure 2. Mean age of selectivity for jack mackerel

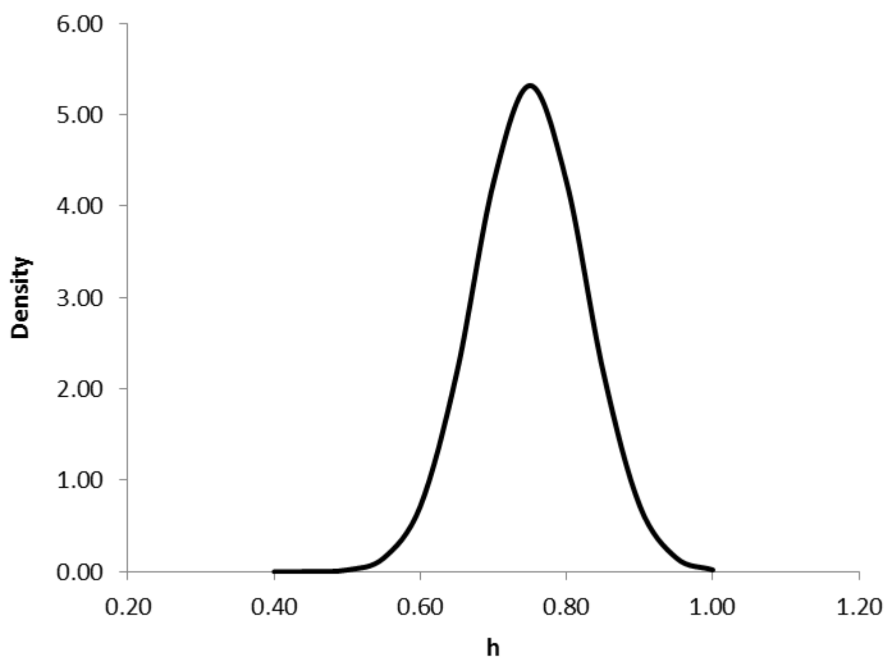


Figure 3 Probability distribution of "steepness"

<u>Equilibrium analysis</u>

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%.

Considering both scenarios, 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, values that are candidates of target and limit BRP, accordingly.

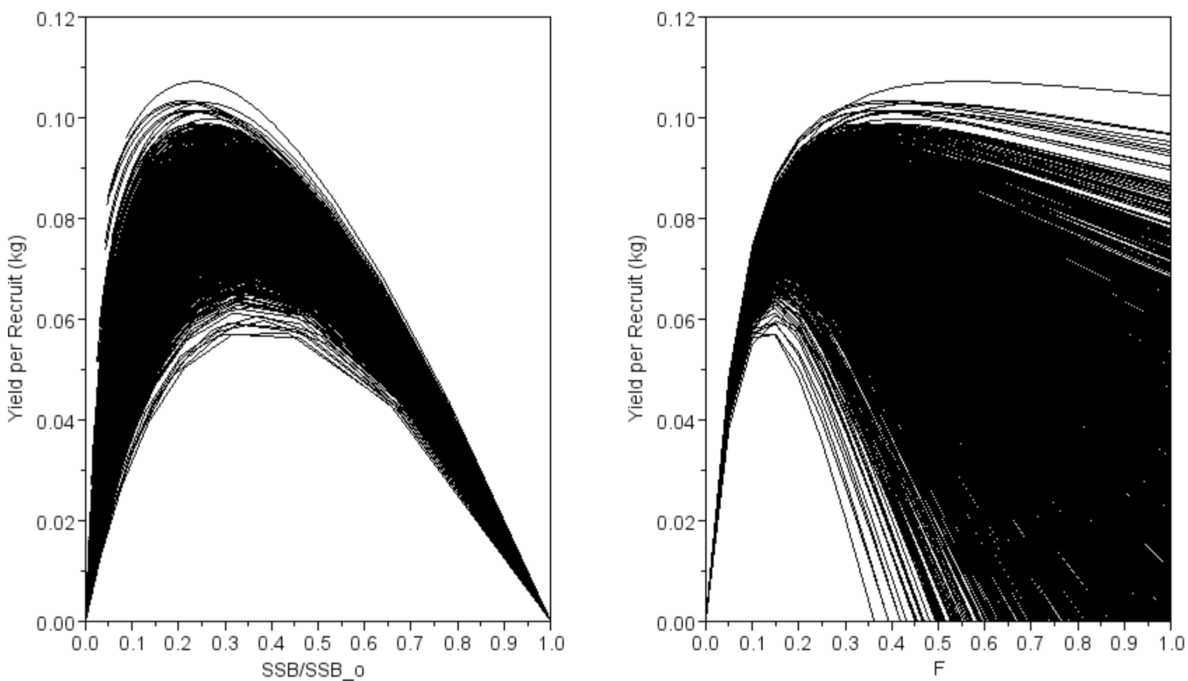


Figure 4. Equilibrium yield curves per recruit of jack mackerel with respect to the stock reduction (left) and fishing mortality (right)

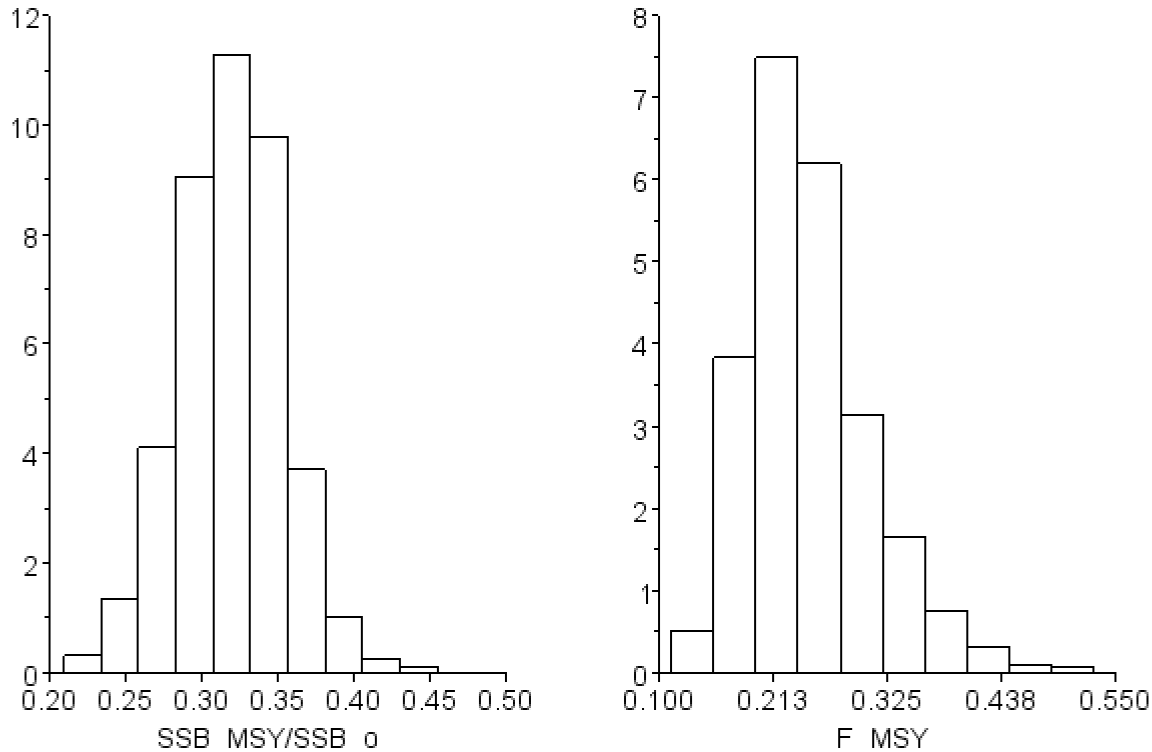


Figure 5. Distribution of probabilities of relative biomass at B_{MSY} (left) and optimal fishing mortality F_{MSY} (right).

Table 2.

Summary of variables related to analysis of jack mackerel equilibrium production

Scenario	S1	S2
Maturity Ogive	old	new
Fmsy	0.226	0.251
MSY/R (gr)	79.3	82.4
SSBmsy/R (gr)	361.5	419.5
SSBo/R (gr)	1239.1	1343.0
SSBmsy/SSBo	0.309	0.319
Rmsy/Ro	0.832	0.845

Table 3.

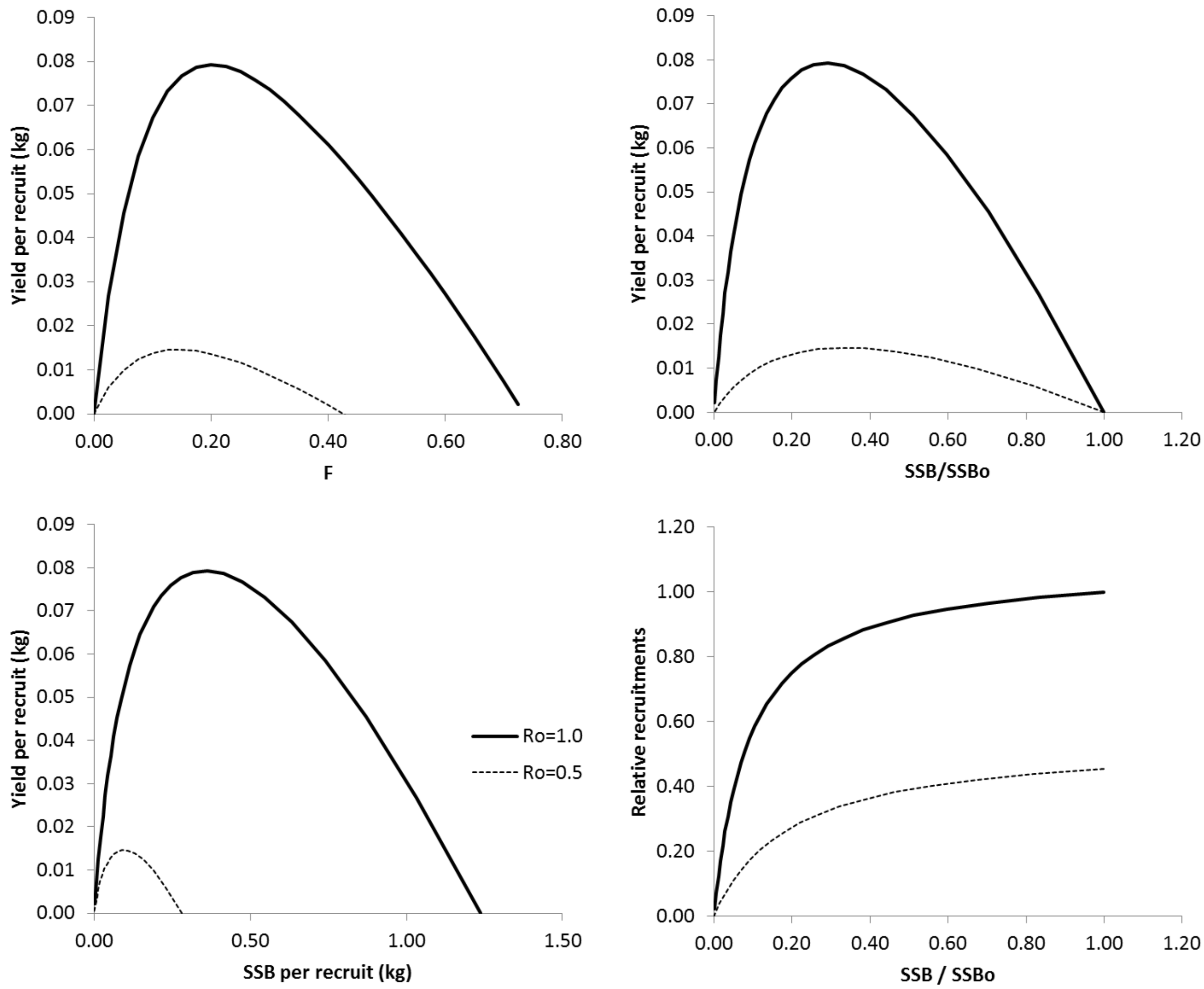
Stock reduction and fishing mortality relating to MSY and different risk levels

		SSB/SSB_{msy}		F_{msy}	
	Scenario	S1	S2	S1	S2
	mean	0.309	0.319	0.226	0.248
	std	0.042	0.033	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

Regime shift

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 (SSB_{MSY}/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

Exploitation Diagram

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 $SSB/SSBo<0.25$. 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 $F=F_{crash}$.

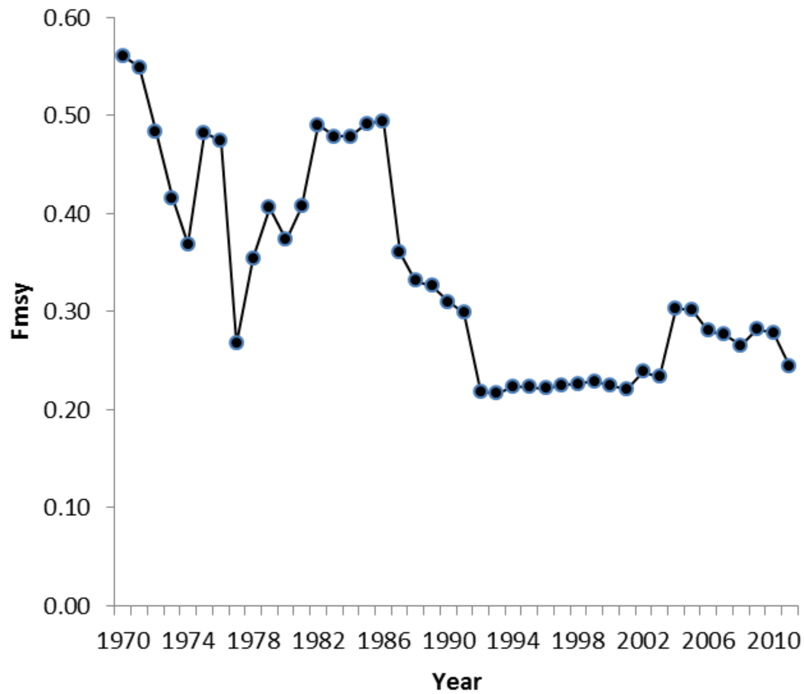


Figure 7. Fishing mortality $F_{MSY}$by year according to selectivity

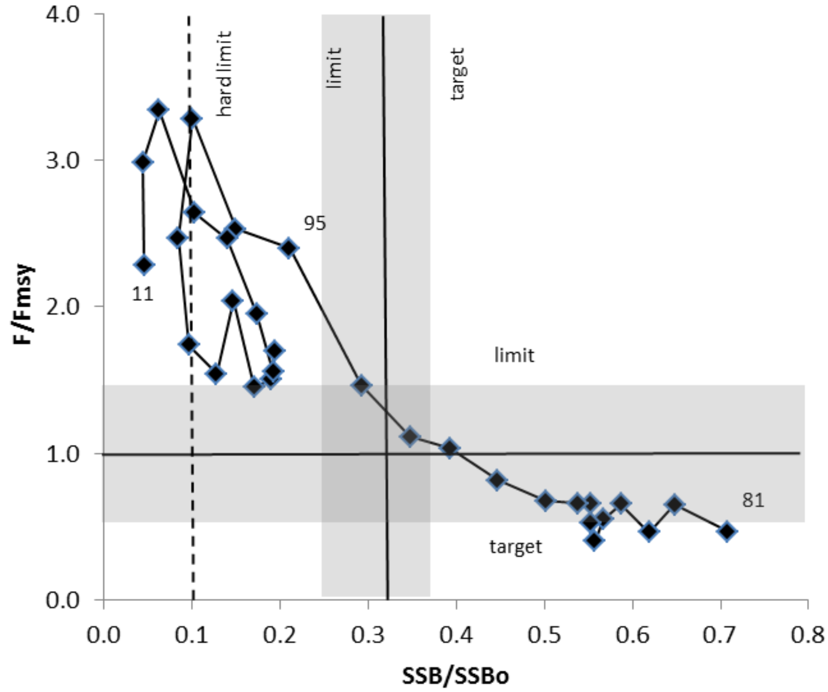


Figure 8. Jack mackerel exploitation diagram.

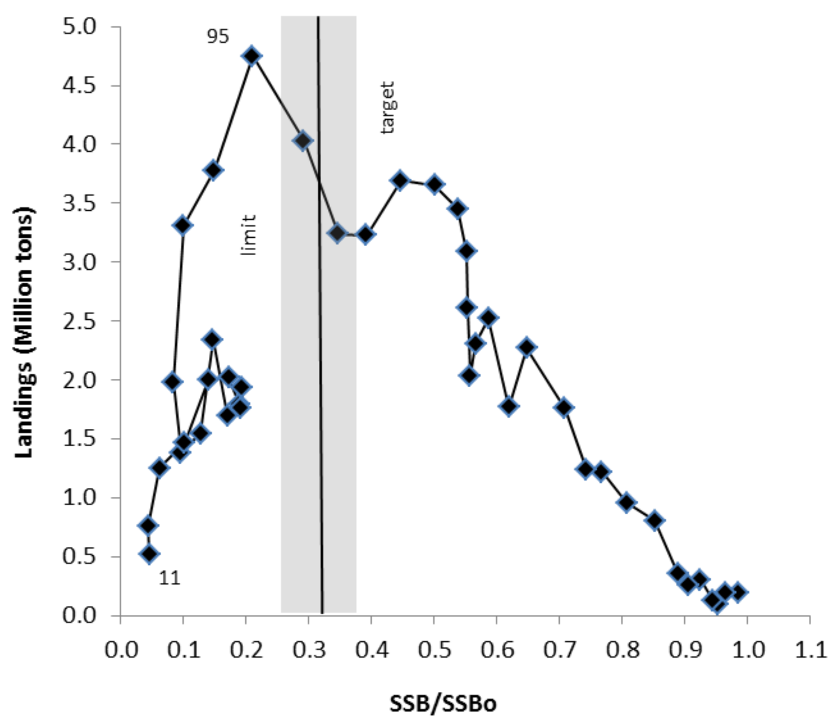


Figure 9. Relation between Jack mackerel catches and stock reduction.

4. 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 when the stock reduction is lower than 0.25, and the top limit estimated at 0.38 is proposed as target limit. At the same time, confidence intervals of fishing mortality F_{MSY} suggest F>0.35 as overfishing limit and F=0.15 as a target value. 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 F_{MSY}.

5. References

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Annex: Estimation of jack mackerel steepness

In this document, the estimation of steepness "h" is based on a Beverton & Holt S/R model fit, considering the data that comes from the last stock assessment.

$$R = \alpha S * (\beta + S)^{-1}$$

and whose parameters (α and β) in function of h were given in Eq 5. The virginal biomass (So=25 mill ton) is calculated from an average recruitment Ro (=18,7 mill) under equilibrium conditions without exploitation. The model parameters were estimated in ADMB and the error model considers a concentrated likelihood function as:

$$logL(x|h) = 0.5 * n * \log\left(\sum_i \left(logR_i - log\widehat{R_i}\right)^2\right.$$

The data of recruitments and spawning biomass were taken from the last stock assessment for the period 1970-2008; the last 3 years (2009-2011) were excluded as they are the most uncertain in the retrospective estimations. The model fit is shown in **Fig 1**, where we can see that the confidence interval converges to asymptotic value of Ro, while model parameters are given in **Table 1**. The results indicate the steepness has a central value h=0.74 and a symmetric distribution (like a normal) with a variation coefficient of 13% (**Fig 2**), whose confidence intervals at 95% are [0.54 – 0.96].

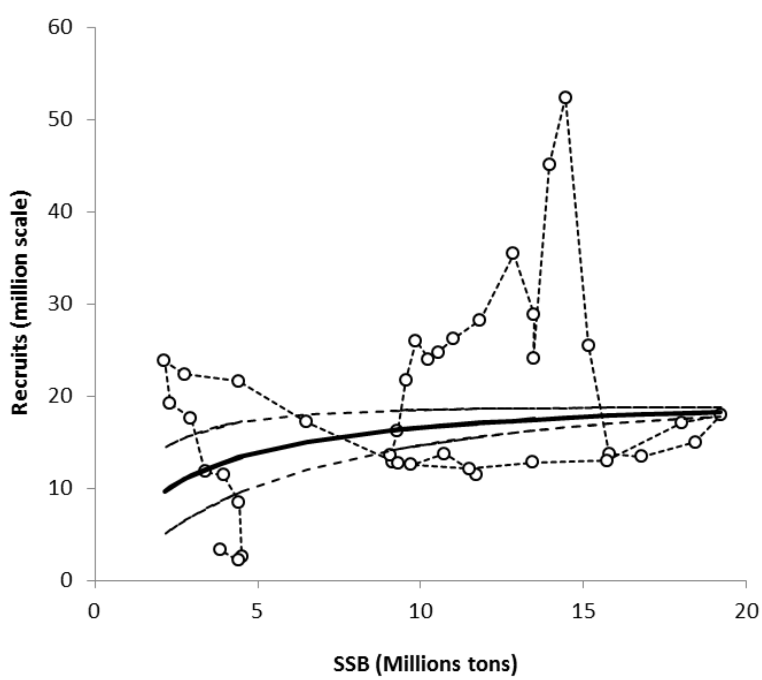

Figure1. S/R model fitted to jack mackerel data in the period 1970-2008. Confidence intervals at 95% are shown.

Table 1.

S/R model parameters fitted to jack mackerel data in the period 1970-2008.

parameter	value	std
h	0.74	0.09
alfa	2.05E+07	9.65E+05
betta	2.39E+06	1.30E+06

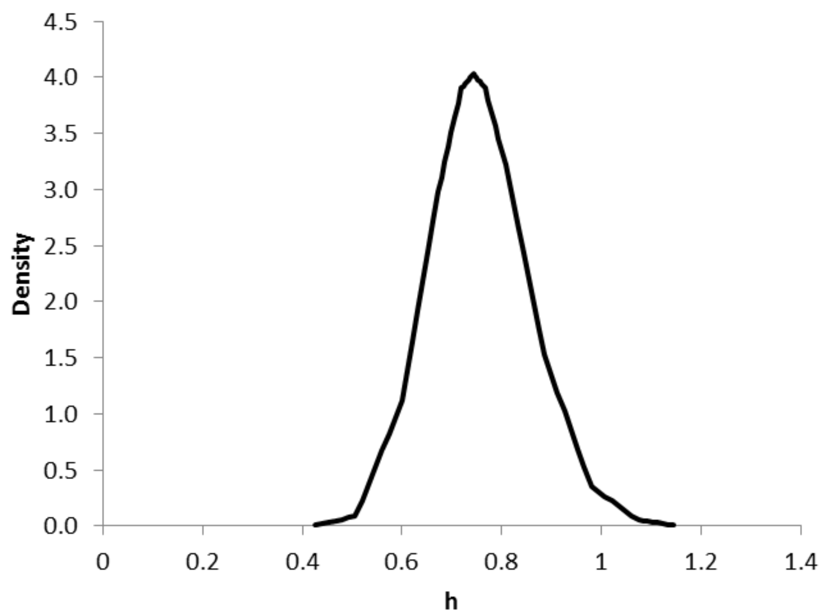

Figure2. Steepness likelihood profile of jack mackerel.