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Harvest control rule for the recovery of the jack mackerel stock at the South Eastern Pacific

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Abstract

A harvest control rule was simulated in order to evaluate the population behaviour of jack mackerel, in comparison to the exploitation strategy "constant fishing mortality", which is often taken into account to conduct this kind of analysis.Variables related to MSY (F_{msy} and SSB_{msy}) were takenas reference points. The analysis was conducted by projecting the population 10 yrs forward with two recruitment scenarios.

Under average recruitments, the control rule permits the population to recover faster than under a constant fishing mortality, with higher catches in the long term. However, this requires a strong reduction of theharvest at the beginning of the projection. If the recruitment scenario is reduced, the results showed that management target (SSB_{msy}) is not reached, so this target should be reformulated as necessary. In this sense and while future recruitments do not reach the historical level, the best choice would be to update the fishing mortality in proportion to the spawning biomass. To implement this it is first necessary to define the target for this fishery both in terms of fishing mortality and biomass, as for example MSY variables or its "proxies".

1. Introduction

Before the establishment of the South Pacific Regional Fisheries Management Organisation (SPFRMO), and since the late nineties, the stock assessment conducted by Chile showed evidence of strong over-exploitation and a reduction of the scale of recruitment (Serra & Canales, 2008). The recent situation of the jack mackerel has been characterized by a significant population reduction and a rising fishing mortality until 2010.

Despite improvements in the (joint) stock assessment and the willingness of countries to reduce fishing effort, jack mackerel remains ata condition of general depletion with spawning biomass estimated below 10% of the virgin condition. Clear definitions regarding the state of the population, such as overfishing and overexploitation are urgently needed, so as to define the management actions aimed at the recovery of this fishery resource.

In this paper, the jack mackerel populationis simulated taking into account some management actions that could be adopted once the condition of over-exploitation is determined. This condition occurs when the spawning biomass is lower than the biomass that generates the Maximum Sustained Yield (MSY), so the action is to reduce fishing mortality, following a control rule based on a proportion of fishing mortality which produces MSY.

2. Materials and Methods

2.1. Maximum Sustainable Yield (MSY)

The analysis was done taking into account the last stock assessment carried out in 2012. The results of this work permitted to obtain the total selectivity (normalized to 1.0) taken from the sum of fishing mortality (F) matrixes over all fleets. In a similar way, for each year the Maximum Sustainable Yield (MSY) variables were estimated considering the changes on selectivity by year. As a reference, it was also considered the fishing mortality at age fully exploited (maximum F at age) by year.

The MSY and its population variables (F_{msy} and SSB_{msy}) were estimated considering an integration between a spawning biomass (SSB) "per recruit" analysis and a stock recruitment relationship; this last was based on a Beverton & Holt model with steepness h=0.75. The parameters of stock-recruitment relationship is formulated as:

$$R_y = \frac{\alpha \, SSB_{y-tr}}{\beta + SSB_{y-tr}} \qquad (1)$$

where the key parameters are:

$$\alpha = \frac{4hR_0}{5h-1}, \quad \beta = \frac{(1-h)SSB_0}{5h-1} \qquad (2)$$

Ro and SSBo correspond to the virginal recruitment and spawning biomass, respectively.The natural mortality rate was M=0.23, and the weight and maturity at age are given in **Table 1.**

Table 1

Weight and maturity at age of jack mackerel used for “per recruit” analysis.

Age (yrs)	1	2	3	4	5	6	7	8	9	10	11	12
w (kg)	0.05	0.09	0.13	0.20	0.26	0.33	0.42	0.53	0.68	0.84	1.07	1.46
Maturity	0.07	0.31	0.73	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00

2.2. Status definition and harvest control rule

Jack mackerel status is analyzed considering the relationship between the fishing mortality and the spawning biomass, both normalized to its respective MSY variables (F_{msy} and SSB_{msy}). In this sense,four stages -depending on the pair [SSB/SSBmsy; F/Fmsy]-can be considered (Cooper, 2006)

	SSB<SSBmsy	**SSB>SSBmsy**
F>Fmsy	(1) Stock is overfished & Overfishing is occurring	(2) Stock is not overfished but Overfishing is occurring
F<Fmsy	(3) Stock is overfished but Overfishing is not occurring	(4) Stock is not overfished & Overfishing is not occurring

Overfished stages (1 and 3) represent the worse situation, because reducing the fishing mortality below the target (Fmsy) does not ensure the stock rebuilding, as recovery and overfished condition will depend on the species's biology. In this case, reducing the fishing mortality in a proportional way to the biomass seems to be the best way to reach the target (assuming that future recruitments will be around a normal situation).

In this work two rules were analized:

a. Constant F: corresponds to the strategy that often is used to analize the response of a population as a function of different values of constant fishing mortality. In this case, the fishing mortality is F=Fmsy independently of the population status.

b. Harvest rule: this scenario involves changes in F, in response (and proportionally) to the population state, particularly when an overexploitation condition occurs. This meansthat the fishing mortality to apply in a particular year (y) is represented by

$$F_{y+1} = F_{msy} \frac{SSB_y}{SSB_{msy}}$$

and if $SSB_y < SSB_{msy}$ the fishing mortality is set to F=Fmsy

3. Results

The MSY variables were estimated considering the methodology described before. Important changes in selectivity occurred inthe mid 80´s, which implied that the ratio SSB_{msy} / SSBo increased slightly.This ratio, understood as the virginal biomass reduction that generates the MSY, has been estimated around 33%(**Figure 1**). In the same sense, two recruitments scenarios were considered to conduct the analysis. The first one corresponds to the historical average (Ro) which comes from the estimated parameters in the assessment model, and the second one corresponds to the situation of the last 10 yrs, where recruitment has been around 34% of its historical level (**Figure 2**).

The most recent status of the jack mackerel was estimated to be close to 20% of SSBmsy and is defined as in overfished condition. The comparative analysis shows that the recovery of jack mackerel is slower if the constant Fmsy is applied. In fact, the biological objective set for population recovery at MSY level (SSB_{msy}/SSB_0=0.33 or SSB/SSB_{msy}=1.0) is reached after 8 years, while the constant F_{msy} indicates that to achieve the same situation more than 10 yrs are necessary (**Table2**). This situation is represented at **Figure 3** (top panel) where the diagonal line indicates the fishing mortality level that must be applied when the population is overfished (SSB/B_{msy}<1). Here, the fishing mortality Fis corrected every year by the ratio SSB/SSB_{msy}.In this same figure (bottom panel), the “constant F_{msy}” strategy shows that more time is necessary to reach the said objective. In this analysis, if the average recruitment (Ro) is assumed, the SSB_{msy} and MSY are estimated in 8.8 and 1.8 million ton, respectively.

While the spawning biomass seems to achieve the MSY level before 10 yrs, the total catches show important differences and seem to be far from the MSY. In fact, at the end of the evaluation horizon, catches could be 4.38 times the curent levels if the "F_{msy} rule" is followed. The same analysis based on the "constant Fmsy" shows that catches could be lower, reaching 3.87 times the 2012's catches.If the "F_{msy} rule" is followed, then it is necessary to reduce the recent (2012) catch (417 kt) at 26%, while the "constant F_{msy}" strategy suggests that recent catches could be maintained, but the expected future levels will be lower.

Finally, an extension of this analysis based on a lower recruitment scenario indicates that MSY and Bmsy will not be reached, this independently of the strategy to follow.**Figure 4**shows that population recovery will be 55% of the target if the "F_{msy} rule" is followed, while with the constant F_{msy} strategy biomass will only increase to less than 40% of SSB_{msy}.

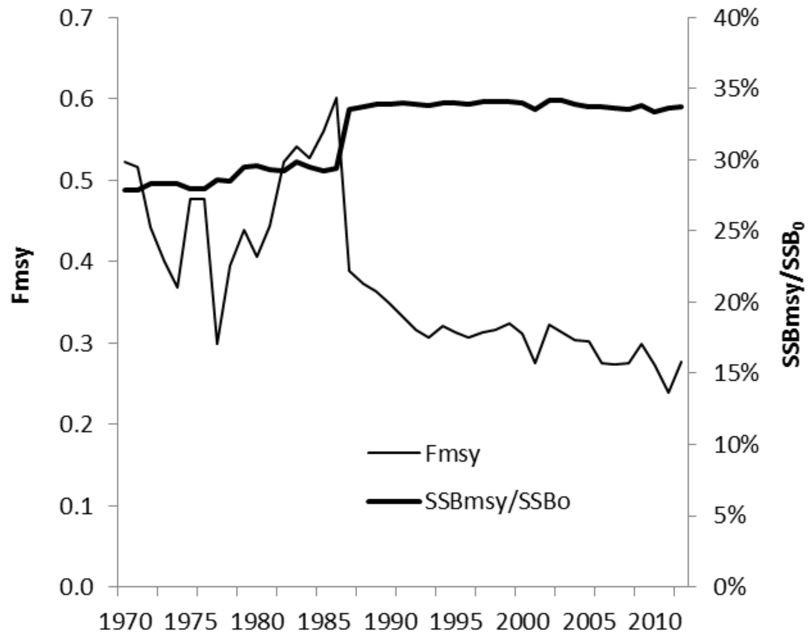

Figure 1. MSY variables of jack mackerel and its variability over time.

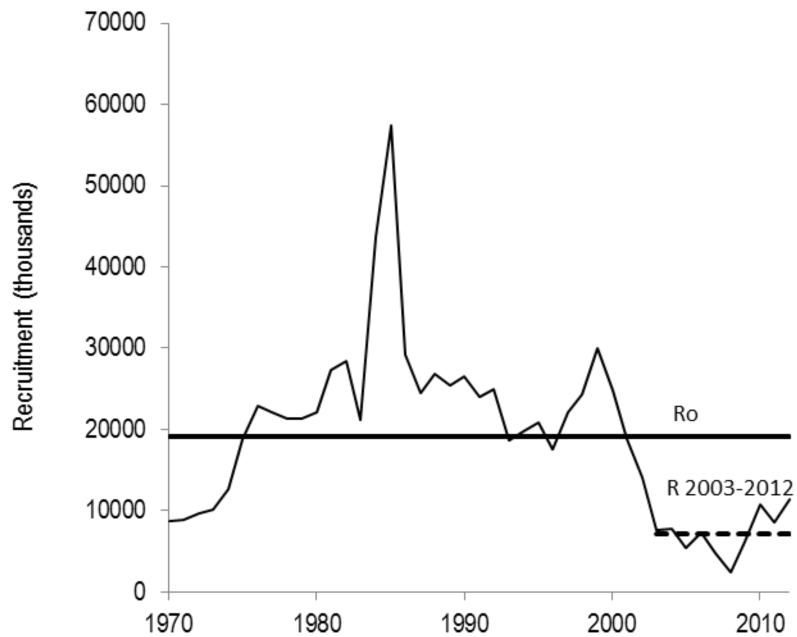

Figure 2. Jack mackerel recruitments. Lines represent two recruitment scenarios.

Table 2.

Relative spawning biomass and catches of jack mackerel simulated for the next 10 yrs and two exploitation strategies (F_{msy} rule and F_{msy} constant).

	SSB/SSB_{msy}		Relative catches to 2012	
year	F_{msy} rule	F_{msy} constant	F_{msy} rule	F_{msy} constant
1	0.3	0.3	0.26	0.92
2	0.4	0.3	0.38	1.17
3	0.5	0.4	0.69	1.49
4	0.7	0.5	1.14	1.76
5	0.8	0.6	1.78	2.13
6	0.9	0.7	2.55	2.57
7	0.9	0.8	3.20	2.95
8	1.0	0.9	3.71	3.27
9	1.0	0.9	4.14	3.60
10	1.0	0.9	4.38	3.87

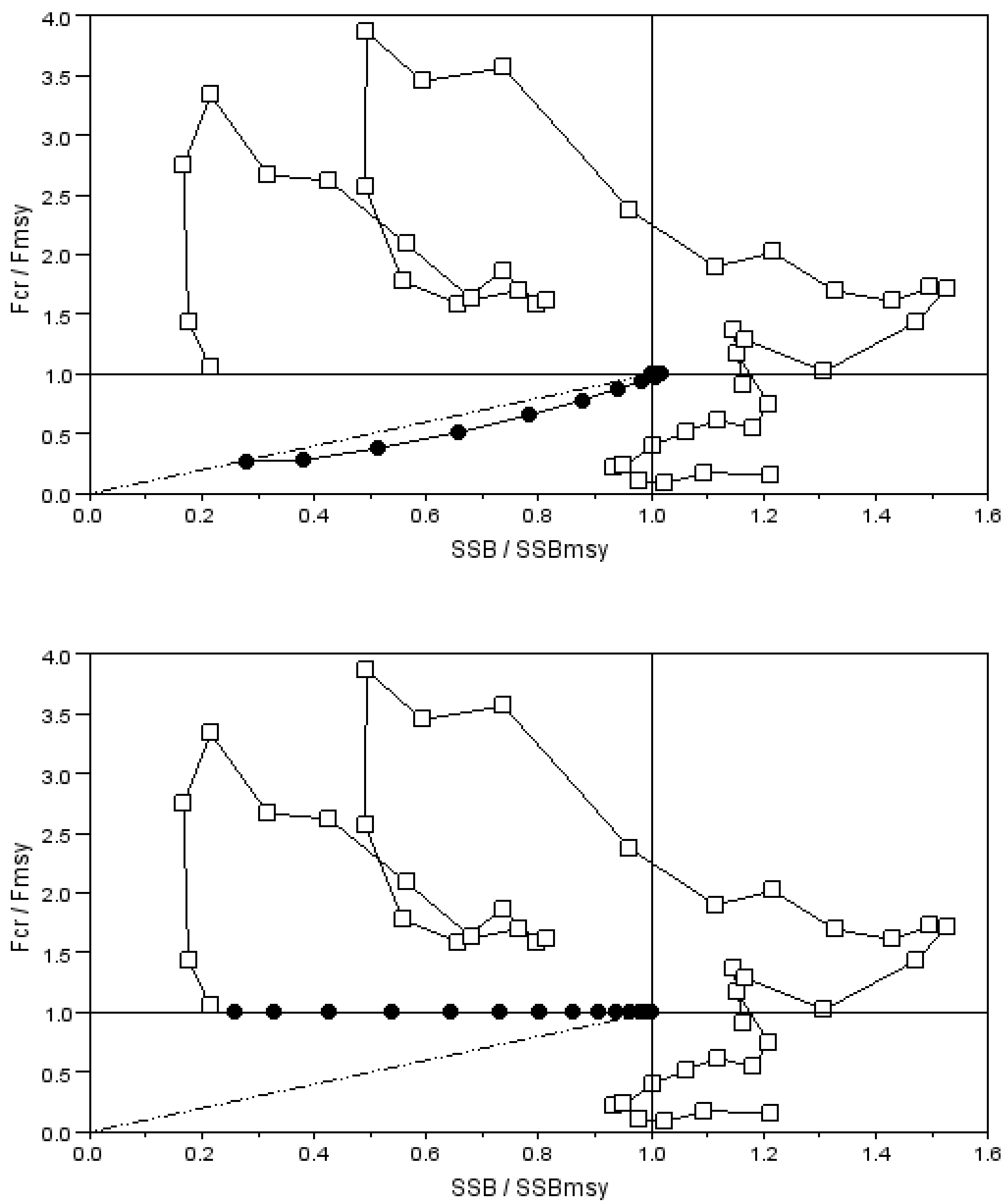

Figure 3. Relationship between the spawning biomass and fishing mortality,both relative to MSY. Diagonal line represents the exploitation rule. Horizontal and vertical lines represent the limits of overfishing and overfished conditions. Squares represent the actual stock assessments. Black circles represent simulations considering historical recruitments. Top panel: strategy of "F_{msy} rule" and bottom panel, strategy of "constant F_{msy}".

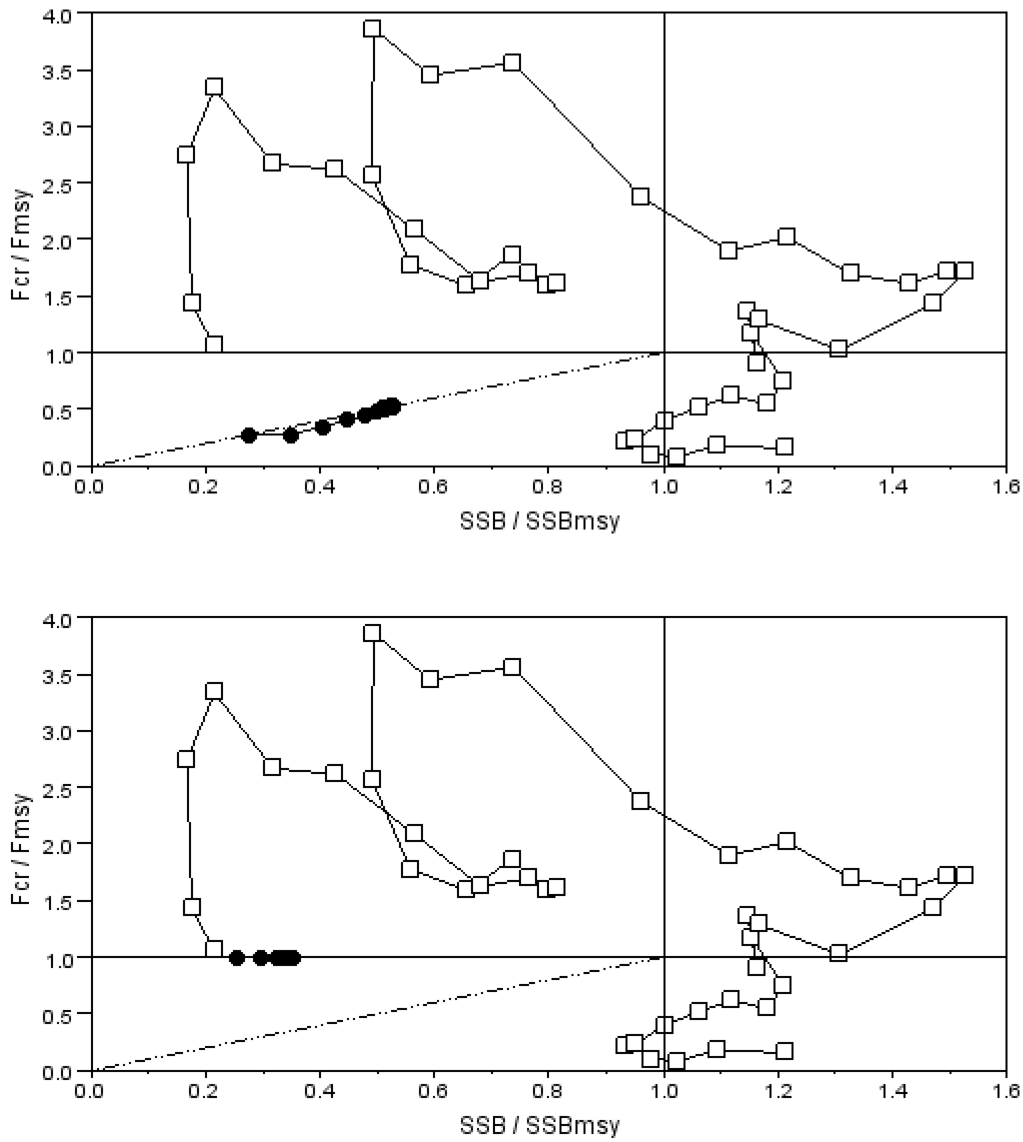

Figure 4. Relationship between the spawning biomass and fishing mortality, both relative to MSY. Diagonal line represents the exploitation rule. Horizontal and vertical lines represent the limits of overfishing and overfished conditions. Squares represent the actual stock assessments. Black circles represent simulations considering the average of recruitments 2003-2012.Top panel: strategy of "F_{msy} rule" and bottom panel, strategy of "constant F_{msy}".

4. Discusion

The present analysis allows to evaluate the expected population performance when a control rule is implemented to recover the jack mackerel biomass. This analysis was conducted by projecting the population 10 yrs forward, and updating the fishing mortality as a proportion of F_{msy}. This proportion was applied over the current fishing mortality rate when the overfished condition is determined, that is whenthe biomass is below a target defined here as SSBmsy (or $SSB/SSB_{msy}<1$). These results were compared with the exploitation strategy of "constant fishing mortality".

In general terms and under historical recruitments, a control rule permits the population to recover faster than when a constant fishing mortality is used. This rule provides higher catches in the long-term, but requires a strong reduction of the catches at the first two years. When the recruitment scenario is reduced, the results showed that the management target (SSB_{msy}) is not reached, so this target should be reformulated as necessary. In fact, if a regime shift occurs, both the virginal biomass as well as the SSB_{msy} should be re-estimated, which certainly could affect the conservation status of the resource.

From a precautionary approach, and while future recruitments do not reach the historical level, the best management choice would be to update the fishing mortality in proportion to the spawning biomass. The implementation of this control rule will permit the recovery of the jack mackerel stock (with a low risk ofexperiencing population reductions) but it is first necessary to define the target for this fishery both in terms of fishing mortality and biomass, as for example MSY variables or its "proxies".

5. References

Serra R. & C. Canales, 2008. Updated Status of the Chilean Jack Mackerel Stock. Technical Summary. Document SPRFMO-V-SWG. Fifth Scientific Working Group Meeting. Instituto de Fomento Pesquero. Guayaquil, Ecuador: 10 pp.

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