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Risk of overfishing and over-exploitation of Chilean jack mackerel

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Risk of overfishing and over-exploitation of Chilean jack mackerel when its population structure is uncertain.

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1. Introduction

Although the significant amount of information regarding Jack mackerel, the definition of its units in the Southeast Pacific is still an unresolved issue. Currently, the fishing management is based on the hypothesis of a single stock unit. After the catch recommendation, the magnitude of the theoretical catch to be fished in certain fisheries determined by Peru-Ecuador within their EEZs and the remaining and most important catch (approximately 89%) operated offshore Chile by national fleets and distant-water fleets outside the Chilean EEZ are determined by a spatial allocation process.

Recently, Hintzen *et al* (2014) establish that as the population structure of Jack mackerel remains unknown, assuming spatial heterogeneity within different stock units is an action that involves a lower risk of overexploitation in respect of assuming spatial homogeneity (a single stock). In order to extent the work of Hintzen et al (2014), a simulation and projection model of the stock units is implemented and the risk of overexploitation is evaluated in assuming that it is a single stock unit when in fact there are two, and it is compared with the risk of managing two stock units when there is in fact only one. In the first case, the impact of the spatial allocation on the local stock is analyzed when the only population is well managed, while in the second case, the impact of total catches from the management of two independent stock units on the only population is analyzed.

2. Materials and methods

In order to assess the future performance of the population under different fishing management conditions based on the hypothesis of population structure and uncertainty, simulation models are implemented. The simulation model is implemented in SCILAB and, for all purposes, it assumes that the assessment model "jjm" is an appropriate estimator of the jack mackerel population parameters, so variables estimated in 2014 represent reality. For all purposes, initial configuration refers to the results obtained from the running of control files: mod1.11.ctl (northern stock), mod2.4s.ctl (Southern stock), and mod2.0.ctl (single stock) generated at the 2nd SC-SPRFMO meeting.

2.1. Stock units and projection analysis

The hypothesis on the jack mackerel population structure in the South Pacific were defined at the SPRFMO-FAO workshop (2008) and are summarized as follows

- Northern stock; comprises the EEZ from Peru and Ecuador.

- Southern stock; comprises fisheries offshore Chile, within and outside its EEZ.
- Single stock; comprises the whole FAO area 84, comprised by the two stock units defined above.

a) Management Scenario # 1: management of a single stock when in fact there are two independent populations (northern and southern).

The annual stock assessment on the single stock is conducted and the Allowable Biological Catch (ABC) is estimated according to a catch rule and then fractioned for each stock unit (northern and southern) based on the history of their fisheries (**Figure 1a**). For each stock and in each projection year, the value of fishing mortality that explains the catch level by area is resolved and the value of spawning biomass is registered. Spatial allocation of catch takes into account the history of fisheries since 1970, using as a reference criterion the 89% of catches that is concentrated in the southern stock located offshore Chile (South), and the remaining 11% for the Northern stock offshore Peru-Ecuador.

b) Management Scenario # 2: management of two independent stocks (north and south) when in fact there is just one population

Capture of Jack mackerel in the South Pacific corresponds to the sum of ABSs of each stock unit assessed independently with a harvest rule. In order to resolve global fishing mortality and calculate spawning biomass, the sum of both ABCs is introduced to the projection model of the single stock (**Figure 1b**)

2.2. Harvest rules, initial condition for projections and assumptions

When capture is not the result of a particular allocation, annual fishing mortality for each stock unit (case 2.1.a) or single stock (case 2.1.b) is based on the fishing management that takes into account a harvest rule to calculate ABC, defined as follows: F_{ABC}=F2014 if B/Brms<1; otherwise F_{ABC} =Frms.

For its part, the age composition of the population at the beginning of the projection (2014) is considered to have a mistake determined by a normal distribution which mean and variance are the result of the adjusting process of the jjm model in each stock:

$$N_{o,a} \sim N(N_{o,a}, \sigma_a) \tag{1}$$

while uncertainty is also included as process mistake in the annual recruitment:

$$R_y = \frac{SSB_{y-r}}{\alpha+\beta * SSB_{y-r}} * \exp(-\delta_y) \qquad \delta \sim N(0, 0.6^2) \qquad (2)$$

Parameters α and β are calculated considering h=0,8 with the recruitment and virgin biomass values. The main assumptions include that the stock assessment provides real estimations of the population and that the estimations of variables related to the MSY are robust to new information. For practical purposes, it is assumed that the exploitation pattern calculated to the year 2014 in each fishery/stock will remained constant over time. Regardless of the case of analysis, the probability that the biomass falls below B_{MSY} p(B/Bmsy<1) and that mortality exceeds F_{MSY} in the long term is considered as a measure of performance and are calculated in frequentist terms. The projection is conducted 15 years in the future and repeated 100 times in each scenario. Detail of initial parameters for each stock unit is provided in Annex.

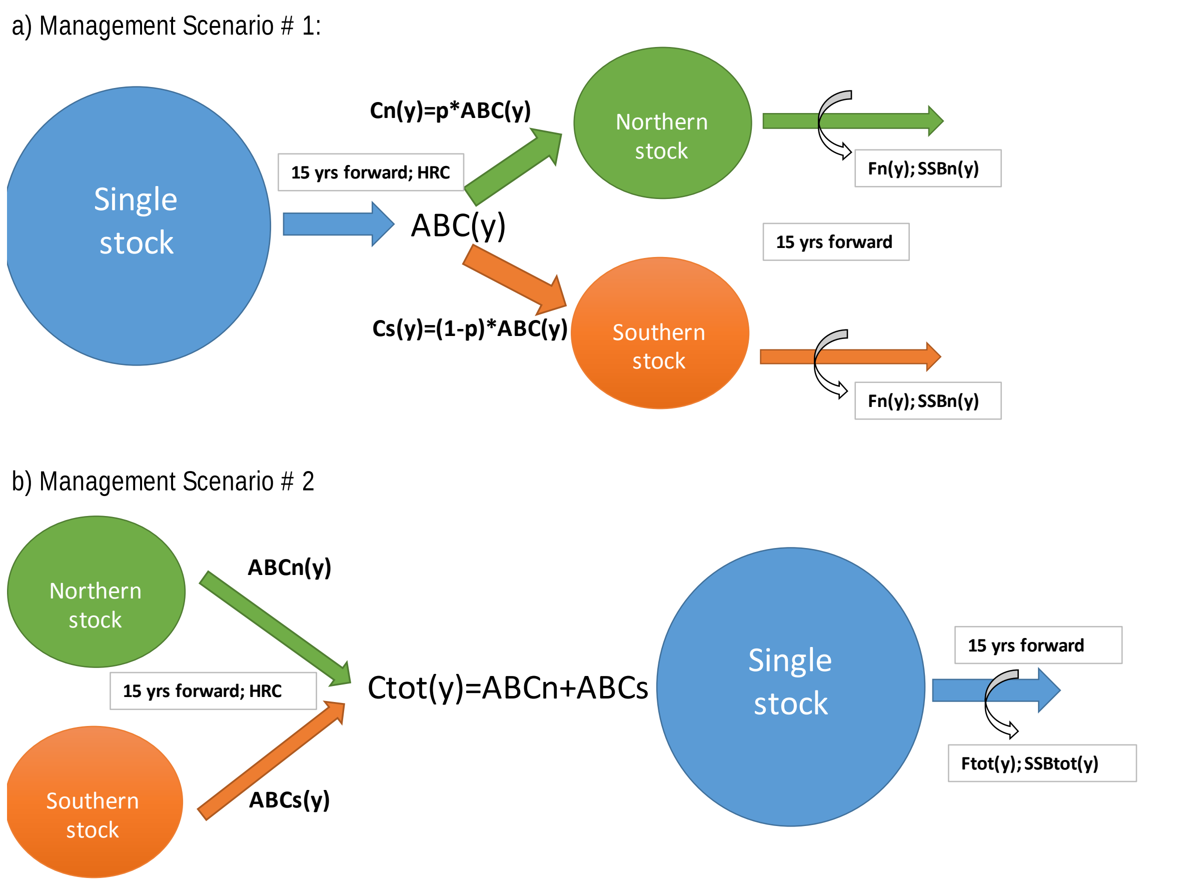


Figure 1. Simple illustration how the simulations were implemented. ABC represents the Allowable Biological Catch, HRC indicates when a harvest rule was required, F is the fishing mortality and SSB is the spawning biomass

3. Results

3.1. Management Scenario # 1: management of a single stock when in fact there are two independent populations (northern and southern).

Results show that under the assumption of a single population unit, the use of the catch rule would allow to generate the population recovery at the level of biomass SSBmsy after 7 years. After these years, fishing mortality could be approximated to its referent Fmsy. Catches would increase until reaching stability (MSY) after 12 years around 1.4 million tons (**Figure 2**). Notwithstanding this perception, the performance of the two underlying population units shows that the population recovery would be reflected before and after 8 years in the northern zone and 10 years in the southern zone. As a result, after 15 years of projection the spawning biomass in the northern zone could reach 3 times its referent SSBmsy (**Figure 3a, Table 1**) while in the southern zone, this would stabilize around 1.5 times the value of SSBmsy (**Figure 3b**).

The risk of decreasing the biomass of the single stock below SSBmsy in a 15-year term is estimated in 0.15, which is higher if stocks are considered separately, reaching values of 0.2 in the southern stock with a risk of 0.25 that mortality exceeds Fmsy. Under this management measure, the northern stock does not register overfishing or overexploitation risks (**Table 1**).

This analysis shows that the management of a single stock unit would mainly favor the recovery of the northern stock through the sustained reduction of mortality well below Fmsy. While in the southern stock, something similar occurs and Fmsy is reached only at the end of the analysis period, error distribution suggests that there is, although lower, a risk that the resource will not recover (**Figure 3**).

Table 1. Performance variables and risk measures of overfishing and over-exploitation of jack mackerel. **Scenario # 1: Management a single stock when in fact there are two**.

10 yrs

	F/Fmsy	cv	B/Bmsy	cv	p(F>Fmsy)	p(B<Bmsy)	ABC (kt)	cv
Single stock	1.00	0.16	1.08	0.15	0.00	0.20	1329	0.21
Northern	0.15	0.54	2.30	0.31	0.00	0.03	146	0.21
Southern	0.69	0.45	1.39	0.25	0.21	0.12	1182	0.21

15 yrs

	F/Fmsy	cv	B/Bmsy	cv	p(F>Fmsy)	p(B<Bmsy)	ABC (kt)	cv
Single stock	1.00	0.13	1.18	0.19	0.00	0.15	1440	0.21
Northern	0.12	0.35	3.00	0.25	0.00	0.00	158	0.21
Southern	0.68	0.90	1.49	0.36	0.25	0.20	1282	0.21

3.2. Management Scenario # 2: management of two independent stocks (north and south) when in fact there is just one population.

Results show that the administration of the two independent stock units does not assure the single population to reach safe or sustainable levels. Log-term projection shows not only a higher uncertainty (**Figure 4**), but also that the spawning biomass and catches could decline once SSBmsy and MSY are reached at a local level as a consequence of the increase of fishing mortality over Fmsy that is the sum of local ABSs (**Figure 5**).

In fact and although the recovery of performance variables close to the MSY (SSB>SSBmsy) (**Figure 5**) might be seen at the local level, and with sustained catches MSY that would reach in northern and southern stocks 500 thousand and 1.4 million tons (**Figures 5 and 6**), respectively, the risk of reducing biomass of the single stock after 15 years under SSBmsy would reach 0.64 while the risk of exceeding Fmsy reaches 0.80 (**Table 2**).

Equally, in comparative terms and considering the measures of central tendency, under management scenario #1, management of a single stock allows in all cases the long-term biomass at the local stock level to surpass its referent SSBmsy and fishing mortality to be less or equal to Fmsy is highlighted. For its part, in management scenario #2, management of the two independent stock units which causes the single stock to maitain its overfished and overexploitation condition (F>Fmsy) in the long term (BzBBmsy).

Table 2. Performance variables and risk measures of overfishing and over-exploitation of jack mackerel. **Scenario # 2: Management two stocks when in fact there is only one**.

10 yrs

	F/Fmsy	cv	B/Bmsy	cv	p(F>Fmsy)	p(B<Bmsy)	ABC	cv
Single stock	1.68	1.27	0.96	0.47	0.74	0.55	1756	0.09
Northern	0.89	0.06	1.04	0.29	0.00	0.42	429	0.12
Southern	1.00	0.18	1.16	0.18	0.00	0.18	1338	0.19

15 yrs

	F/Fmsy	cv	B/Bmsy	cv	p(F>Fmsy)	p(B<Bmsy)	ABC	cv
Single stock	2.22	1.28	0.75	0.81	0.80	0.64	1726	0.09
Northern	1.00	0.05	1.11	0.24	0.00	0.32	493	0.10
Southern	1.00	0.15	1.16	0.20	0.00	0.16	1358	0.21

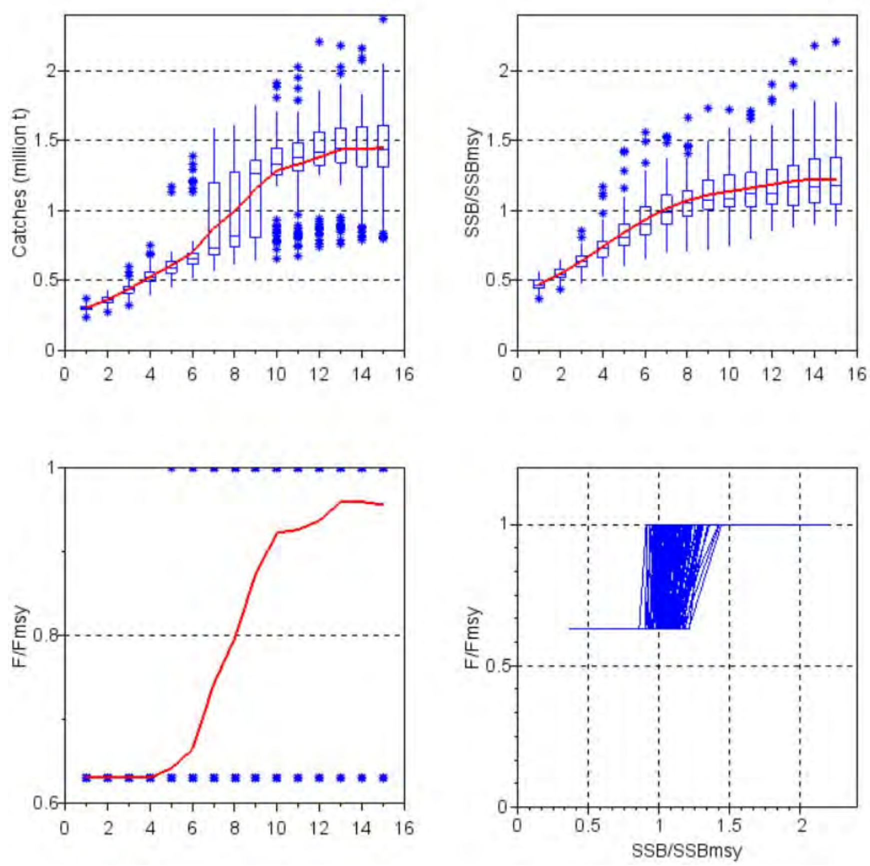


Figure 2. Box-plot and performance of the state variables of single stock based on the management of a harvest rule. The red line represents the average. **Scenario # 1: Management a single stock when in fact there are two**.

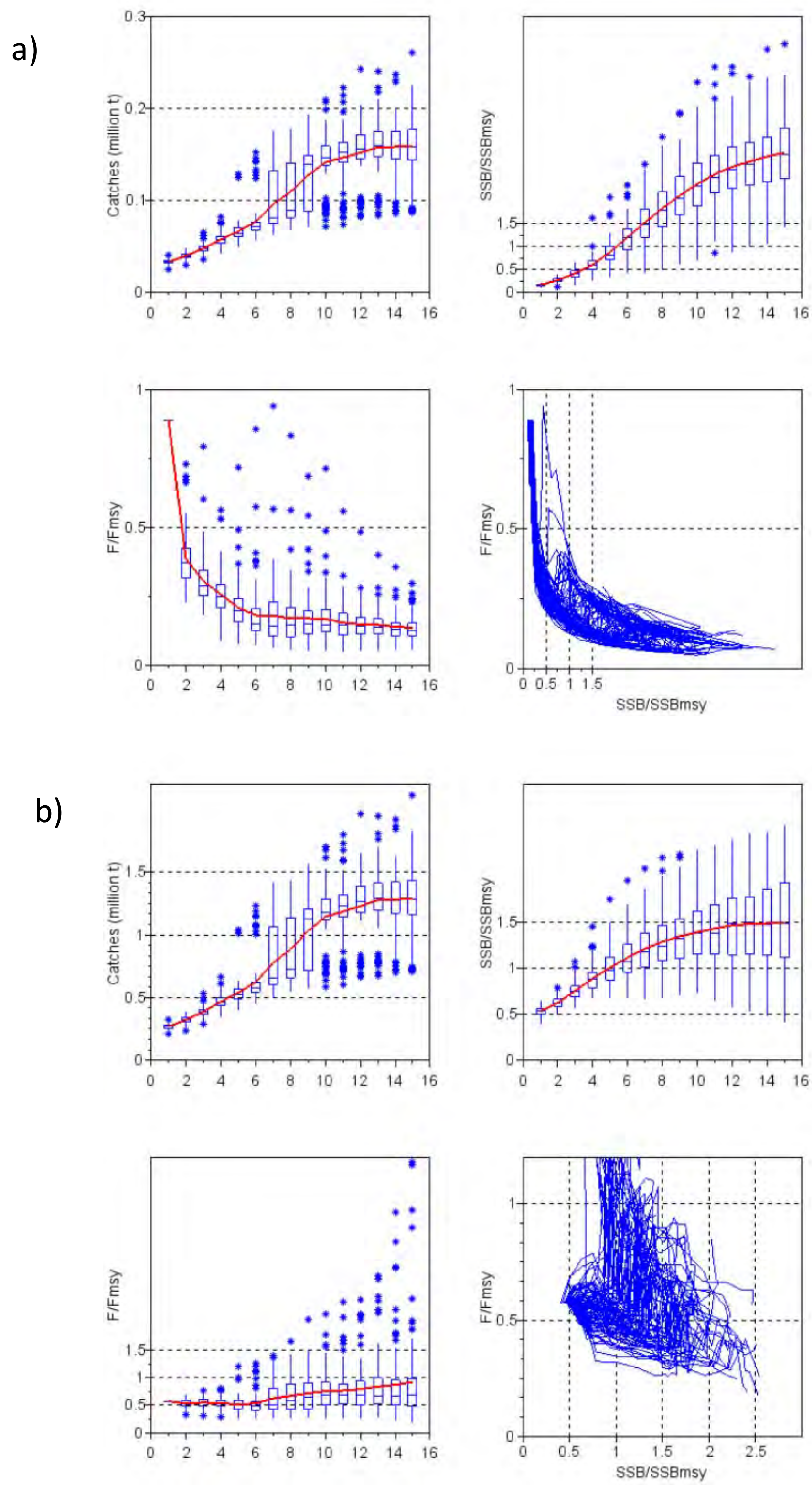


Figure 3. Box-plot and performance of the state variables of the two stocks based on the management of a single stock unit. The red line represents the average. a) northern

stock and b) southern stock. **Scenario # 1: Management a single stock when in fact there are two**.

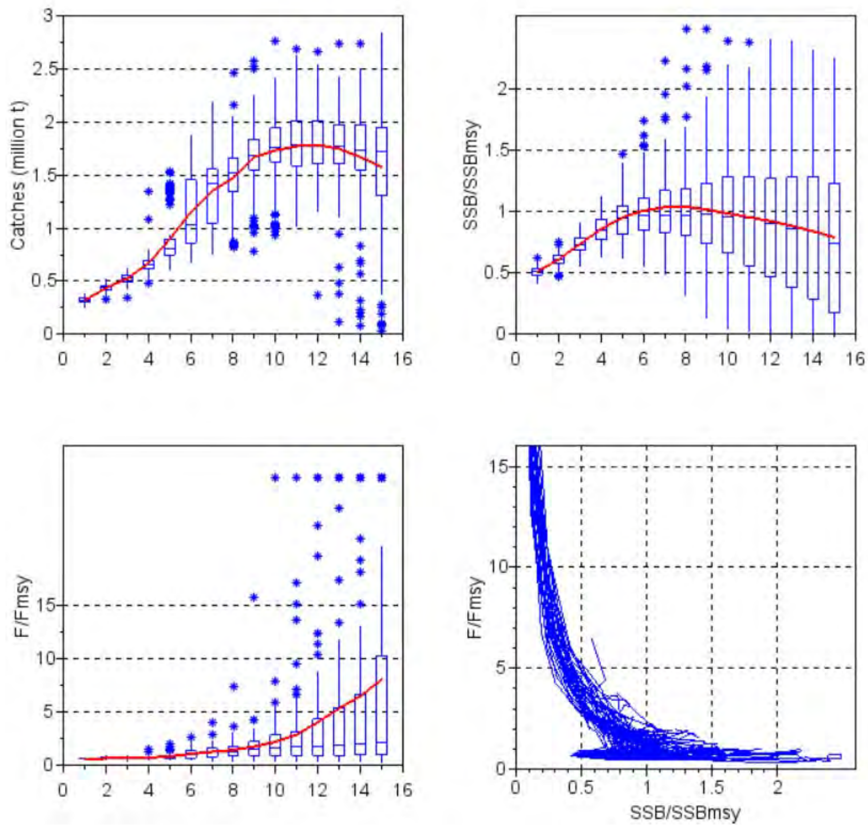
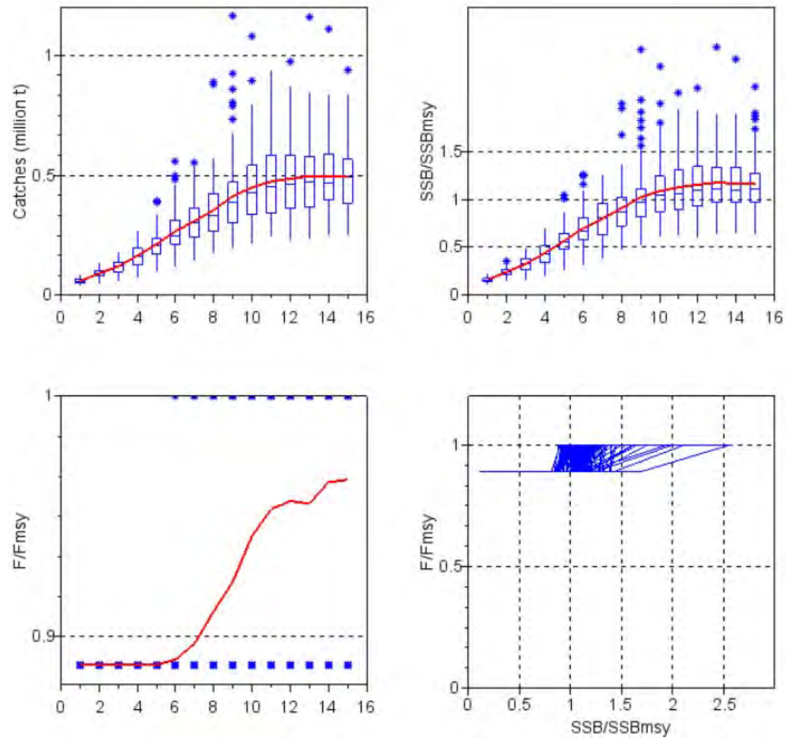


Figure 4. Box-plot and performance of the state variables of single stock in response to the management of two independent units stock. The red line represents the average. **Scenario # 2: Management two stocks when in fact there is only one.**

a)


Catches (million t)
SSB/SSBmsy
F/Fmsy
F/Fmsy
SSB/SSBmsy

b)

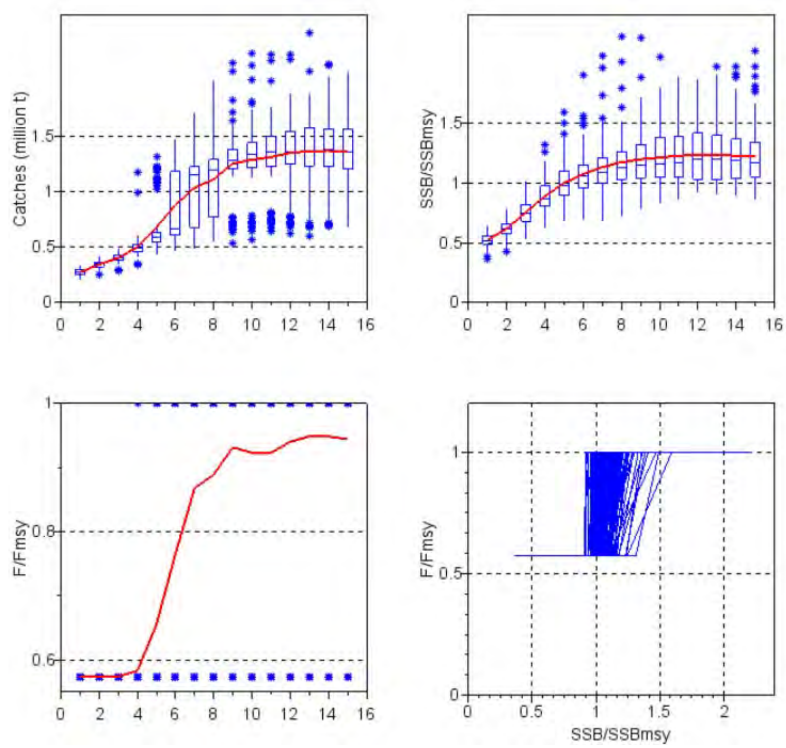

Catches (million t)
SSB/SSBmsy
F/Fmsy
F/Fmsy
SSB/SSBmsy

Figure 5. Box-plot and performance of the state variables of two independent stocks based on the management of a harvest rule. The red line represents the average. **Scenario # 2: Management two stocks when in fact there is only one.**

4. Conclusions

Simulation analysis allowed the explicit evaluation of fishing management risks when population structure of jack mackerel is not well known. Under the assumption that population estimates of each scenario of stock assessment represent reality, different projection analysis of stock under uncertainty conditions were conducted and overfishing (if F>Fmsy) and overexploitation (if SSB<SSBmsy) risks were measured.

Under the current fishing management scenario, based on the hypothesis of a single stock unit and an empirical harvest rule, the risk of generating overfishing or overexploitation in the two possible independent stock units was determined to be low and the recovery of their respective biomass above SSBmsy occurs before 10 years. In the other case, if fishing management is sustained on the assumption of two stock units when in fact there is only one, results showed that the perception of a suitable fishing management of each unit separately does not necessarily assure the safety of the single stock. Under these conditions, the risk of overfishing and overexploitation of the true single stock in the long term is high, reaching levels of 0.80 and 0.64 respectively.

This is explained since the sum of ABCs of each stock unit generates catches that are not related to the magnitude of the single stock, thus increasing fishing mortality significantly above its referent Fmsy. As a result of this, once SSBmsy of local stocks is reached, the sum of MSY separately (northern MSY = 509 thousand t + southern MSY = 1.38 million t) surpasses the MSY of the single stock (MSY = 1.6 million t) (Figure 6), generating a declining trend of its population, increasing fishing mortality and with that the risk of overfishing and overexploitation.

Differences obtained in this analysis regarding the work of Hintzen et al (2014) are probably because, in such work, the projection of the single stock was conducted under the assumption of change of regime (low productivity), producing lower biomass and thus the reference value SSBmsy is never reached if it has been calculated based on the historical performance of recruitments (Ro).

3. References

Hintzen, N.T., T. Brunel, A-C Dragon & P. Lehodey, 2014. Evaluating the consequences of different assumptions on population and management structure on the sustainable exploitation of Chilean Jack Mackerel (*Trachurus murphyi*). SC-02-JM-08. 2nd Meeting of the Scientific Committee, Honolulu, Hawaii, USA: 16 pp.

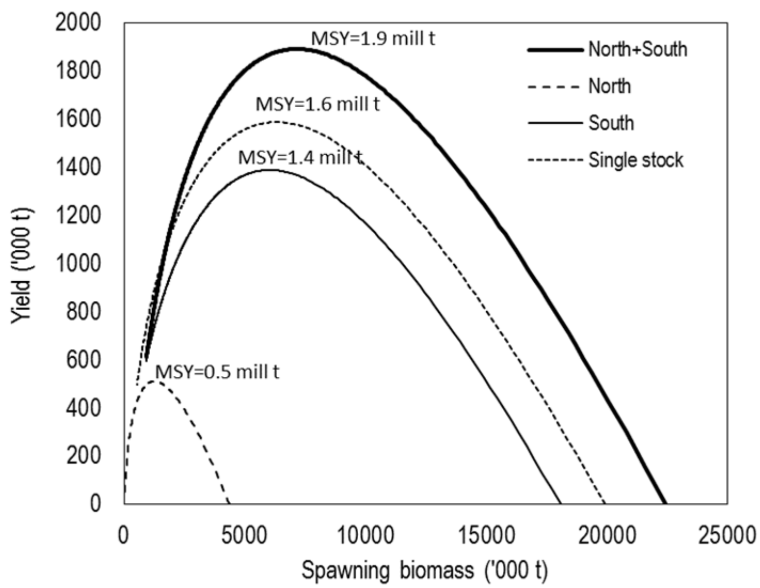


Figure 6. Equilibrium production curves of jack mackerel for different population structure hypothesis

Annex 1. Population parameters for each jack mackerel stock

<u>Single stock</u>

ages=1:12;
Wtt=[0.051 0.0884 0.134 0.195 0.2612 0.328 0.4184 0.5344 0.6814 0.8426 1.0705 1.4589];// Weight
Ot=[0.072 0.312 0.725 0.939 0.989 0.998 1.000 1.000 1.000 1.000 1.000 1.000]; // maturity
dt=9.5/12;
Mt=0.23;

R0t=exp(l9.68583859734);*// Ro*
B0t=19912.4;
Brmst=6313;
Frmst=0.185;

h=0.8;*// Steepness*
alphaSRt=B0t*(1-(h-0.2)/(0.8*h))/R0t;
betaSRt=(5*h-1)/(4*h*R0t);

Ft=[0.0106 0.0351 0.0439 0.0290 0.0619 0.0859 0.0934 0.1123 0.1925 0.2452 0.2452 0.2452]; *// F last year*
Not=[11680.8 6910.78 5819.79 2405.94 1846.26 2891.09 702.592 747.25 273.39 96.3901 77.63 58.27]; *// N last year*
esNot=[4485 1918 1035 483 398 536 199 180 67 26 20 16];// Standard error

<u>Northern stock</u>

ages=1:8;
Wtn=[0.038 0.146 0.324 0.555 0.819 1.1 1.384 1.66]; // Weight
On=[0 0.37 0.98 1 1 1 1 1]; // maturity
dtn=9.5/12;
Mn=0.33;

R0n=exp(8.16085108760);*// Ro*
B0n=4358.48;*//Bo*
Brmsn=1262;*//Bmsy*
Frmsn=0.228;*//Fmsy*

h=0.8;*// Steepness*
alphaSRn=B0n*(1-(h-0.2)/(0.8*h))/R0n;
betaSRn=(5*h-1)/(4*h*R0n);

Fn=[0.00424739 0.0365448 0.263261 0.263261 0.263261 0.263261 0.263261 0.263261]; *// F last year*
Non=[1326.16 773.658 692.629 62.096 25.1015 1.93402 0.271719 0.369697]; *// N last year*
esNon=[639 339 122 20 12 1 0.1 0.1]; // Standard error

Southern stock

ages=1:12;
Wts=[0.051 0.0884 0.134 0.195 0.2612 0.328 0.4184 0.5344 0.6814 0.8426 1.0705 1.4589]; // Weight
Os=[0.072 0.312 0.725 0.939 0.989 0.998 1.000 1.000 1.000 1.000 1.000 1.000]; // maturity
dt=9.5/12;
Ms=0.23;

R0s=exp(9.5887);
B0s=18069.5;
Brmss=6038;
Frmss=0.179;

h=0.8;*// Steepness*
alphaSRs=B0s*(1-(h-0.2)/(0.8*h))/R0s;
betaSRs=(5*h-1)/(4*h*R0s);

Fs=[0.004571 0.0273008 0.0165657 0.0222522 0.0614335 0.0910403 0.0874654 0.0997209 0.179977 0.214418 0.214418 0.214418]; *//*
Nos=[18391.4 8146.02 3938.15 2835.1 2355.72 3023.89 1047.94 898.46 135.115 47.0911 76.4547 73.7534];
esNos=[7177 2445 1165 758 734 805 325 230 42 16 20 20]; // Standard error