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Jack mackerel status in the South Eastern Pacific and exploitation management strategies

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Technical Report

Jack mackerel (*Trachurus murphyi*) status in the South Eastern Pacific and exploitation management strategies

**OCEANA-CAPES
PROJECT**

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SUMMARY

A stock assessment of the South Eastern Pacific (SEP) jack mackerel stock is conducted considering two hypotheses about stock structure and two scenarios for the steepness of the stock-recruitment function. An integrated statistical catch-at-age model was implemented considering the following fishery-dependent data: i) catches in the SEP from 1970 to 2014 grouped in four main fleets (North Chile, South Central Chile, Far North and Offshore trawl), ii) CPUE indices for South-central Chile, Far North, China, European Union and Russia, and iii) age- structures from north Chile, south central Chile, Offshores Trawl and length-structures for Far North. Independent-fishery data corresponded to biomass acoustic surveys for the North and South central Chile and Far North, spawning biomass estimates from the daily egg production method for central-south of Chile and age structures from Chilean surveys. Life history parameters such as somatic growth were taken from the most recent and updated parameters available from literature. Catches and age-structures of the Chilean fleets were updated with complete information up to 2014. We used the model developed by the Scientific Committee of the South Pacific Regional Fishery Management Organization (SPRFMO), an adopted in 2010 as an assessment method of the jack mackerel stock. The two hypotheses evaluated were: i) Jack mackerel is one single population in the South Eastern Pacific area (Model-1) and ii) Jack mackerel constitute two discrete populations one in the Peruvian and Ecuadorian waters, and one off Chile extending onto the high seas, (Model-2). We assessed Model-1 by optimizing the model keeping all the information available. Model-2 was evaluated by removing all data from the Far North fleet, CPUE and survey from Peru and related underpinning processes in the model. Testing both hypotheses lead to the conclusion that the biomass from Peru and Ecuador did not make a significant contribution to the spawning biomass of the jack mackerel stock in the South Pacific. All combinations of stock hypotheses and scenarios of h (h=0.80 and h=0.65) lead to the same diagnosis of stock status. Jack mackerel stock in South Eastern Pacific is overexploited and with some probability of being depleted (close to $Blim$). We explore robustness of the model using a retrospective analysis concluding that he model proposed is robust to estimate abundance in jack mackerel.

Projections of the abundance included the combination of two level of recruitments (1970-2012 and 2000-2012), two level of steepness (h=0.80 and h=0.65) and five level of fishing mortality (F) obtained from different multiplier of F in 2014. Constant fishing mortality was assumed as an exploitation strategy. We assessed the probabilities to reach the maximum sustainable yield (MSY) or the 80% of MSY under different combinations of recruitment, steepness and F. Results show that the selection of recruitment period for projections is the factor that mostly influences the recovery of abundance. Steepness plays a secondary role, by influencing the time or the probability required to accomplish the management strategies based on MSY. Using long periods of recruitment (1970-

2012) is misleading and overestimates the rebuilding capacity of the stock; thus the last period of recruitment (2000-2012) is recommended when simulating exploitation strategies. Harvesting at a 50% of fishing mortality estimated in 2014 has a 30% chance of reaching *Bmsy* at the end of the projection period (year 2034). Harvesting with any higher fishing mortality (>50%F), will reduce the chances below an 8% to reach *Bmsy* in 2034 and thus it is not recommendable as a sustainable management strategy. Finally, we present preliminary results of a population dynamic model for understanding the interaction between jack mackerel (*Trachurus murphyi*) and the fishery. This analysis suggests that jack mackerel and fishery dynamics are linked in a predator/prey like system of mutual causal second-order loop. In addition, recruitment dynamics appears to interact with density-dependent process and El Niño variability. This dynamics model shed light about population processes usually not considered in integrated stock assessments models and thus, it provides a promising and complementary tool in the analysis of fish dynamics. Thus, further work in this project involves the integration of these results of population dynamic models in the context of stock assessment and management framework.

CONTENTS

1. INTRODUCTION

Jack mackerel (*Trachurus murphyi*, Nichols 1920) is a transboundary fishery resource and widespread specie throughout the South Pacific (SP), along the coastal and oceanic waters adjacent to Ecuador, Peru, and Chile, and along the Subtropical Convergence Zone. This has been described as the "Jack mackerel belt" that goes from the coast of Chile to New Zealand within a 35ºS to 50ºS variable band across the South Pacific (JMSWG-Report, 2014).

Five population structure hypotheses have been proposed for jack mackerel in the South Pacific, however only two of them are considered in the recent stock assessment (JMSWG-Report, 2014). First, jack mackerel conforms only one single population in the South Eastern Pacific, and the second proposes that jack mackerel constitute two discrete populations in the South Pacific: one in the Peruvian waters and, one off Chile extending onto the high seas (Hintzen et al. 2014; JMSWG-Report, 2014), although only the single population hypothesis is considered for management purposes.

The biological aspects indicate that jack mackerel has a low individual growth rate. A recent age validation study for jack mackerel caught off the Chilean coast was conducted by Cerna et al. (2011). The result of the study confirms that the by counting microincrements of the first annual annulus, also supported by previous studies conducted by Castillo and Arrizaga (1987) and Gili et al (1995), von Bertalanffy growth parameters estimated by Cerna et al. (2011) were: L_∞= 72,7 cm, k=0,074 (year^{-1}) and t_0=-1,97 (year^{-1}). Differences in somatic growth have also been identified for the jack mackerel caught off the coast of Peru, with higher somatic growth rate compared to the jack mackerel caught off the coast of Chile. Growth parameters of jack mackerel caught off Peru corresponded to L_∞= 80,77 cm, k=0,16 (year^{-1}) and t_0=-0,356 (year^{-1}) (Dioses et al. 2015). Natural mortality for jack mackerel estimated using the empirical method in Pauly (1980) is M=0.23 (year^{-1}) for Chile and M=0.33 (year^{-1}), for Peru (JMSWG-Report, 2014).

Maturity at age also differs between Peru and Chile. The maturity at $L_{50\%}$ off Chile occurs at 22.7 cm (between 2-3 years old) meanwhile for Peru $L_{50\%}$ is estimated as 26.5 cm (near 4 years old) (Leal et al. 2012, Pereas et al. 2013 respectively). The main spawning period takes place between October and December, with a small spawning period reported between July and March (JMSWG-Report, 2014, Leal et al 2012).

The jack mackerel fishery in the South Eastern Pacific is shared by the fleets of Chile, Peru, Ecuador and by the distant water fleets from China, European Union, Faroe Islands, Korea, Japan, Russian Federation, Ukraine and Vanuatu operating outsize of the Exclusive Economic Zone (EEZ) (JMSWG-Report, 2014) off south central Chile.

Fisheries management of jack mackerel in the coastal states (Ecuador, Peru and Chile) started in the middle of 1990s. The total allowed catch was introduced in 1999 in Chile and in 1995 in Peru. In this last country there is a ban to use jack mackerel catches for fishmeal production. The jack mackerel fishery outsize of EEZ has been banned since 2010 to the entry of new fishing vessels, and since 2011 total allowable catch has been defined in the South Pacific Regional Fisheries Management Organization (SPRFMO) as tenure to control fishing mortality.

The international fishery management of the jack mackerel started in 2010, when the first stock assessment of the jack mackerel at the South Pacific scale was developed. These assessments have been developed in the context of SPRFMO where the management unit takes into account the jack mackerel fisheries from coastal states and distant water fleets.

The SPRFMO has established that non-government organization such as OCEANA can attend the Annual Commission and the Scientific Committee (SC) meetings (www.sprfmo.int/participation/). Latest catch recommendations for jack mackerel have been established with a strategy of constant fishing mortality at high risk of not recovering the spawning biomass by 2034. According to Canales (2015) jack mackerel stock is close to 50% of the maximum sustainable yield, and thus close to a status of collapse or depletion according to the criteria used by the New Chilean Fisheries Law. In order to assess the current state of the jack mackerel stock and its exploitation strategies, Oceana requested (CAPES) to elaborate a report to examine key parameters that guarantee the sustainability of the stock and provide recommendation for precautionary quota decisions in the future. This document contains the status of jack mackerel with complete information until 2014 and the analysis of its exploitation strategies.

2. GENERAL OBJECTIVE

The aim of this project is to assess the status and exploitation strategies of jack mackerel considering the two main hypotheses about its population structure in the South Eastern Pacific.

3. SPECIFIC OBJECTIVES

3.1 Abundance estimation of jack mackerel considering two stock hypotheses in the SEP.

3.2 Estimates the biological references points of jack mackerel in the SEP following the method proposed for Chilean fisheries.

3.3 Define the status of jack mackerel stock (s) in the SEP and analysis its equilibrium points.

3.4 Evaluate exploitation strategies and risk analyses of jack mackerel in the SEP

2. METHODS

2.1. Data

The data used in this study correspond to the last jack mackerel stock assessment conducted in October of 2014 by the Scientific Committee (SC) of the SPRFMO, as well as from Canales (2014). Some modifications were introduced according to the criteria of the Working Team that carried out the present study. The stock assessment considered information updated until 2014.

Fishery data

The catch data used in this assessment is summarized in **Fig. 1** and **Table 1 (**Annex 1 and 2 respectively**)**. The records include reported catches by the fishing fleets from coastal countries and distant water fleets in the SEP, which are grouped into four main fleets according to the criteria of gear and fishing areas as defined in JMSWG-Report (2014) (Northern Chile, South Chile, Far North and Offshore Trawl fleets). The catches by fleet used in the year 2014 were updated with the available information at July 2015 for the Chilean fisheries. For other fleets, the data are the same as in First Report of the Project. The total catch of jack mackerel in the year 2014 was 406.942 t in the SEP and within the range of the maximum of 460.000 t, proposed as TAC for the year 2014 by the Commission at SPMFRO.

CPUE time series (**Table 2,** Annex 2) used in this model include: i) Fleet 2: South-Central Chile CPUE from the purse seiner fleet (1983-2014), ii) Fleet 3: Far North CPUE (2002-2014), iii) Fleet 4: three different CPUE time series are used: China (2001-2013), European Union (EU) (2006-2011; 2013) and Russia (1987-1991; 2008-2009; 2011). This information is the same as in JMSWG-Report (2014).

Catch at age in **Tables 3, 4** and **5** (Annex 2) are available for the fleets of north and south central Chile and for the offshore trawl fleet. Length structures are only available for far north fleet (**Table 6,** Annex 2). Mean weights at age by fleet are presented on **Table 7** to **10** (Annex 2) and are available for all fleets. In the present report age structures for the fleets of north and south central Chile encompassed the whole year 2014.

Survey data

Biomass indices from acoustic surveys are available for north Chile (1984-1988; 1991; 2006-2014), south central Chile (1997-2009), far north Peru (1986-2009; 2011-2013) (**Table 11**, Annex 2). Spawning biomass estimated (**Table 11**, Annex 2) by the Daily Egg Production Method (DEPM) is available for south central of Chile (1999-2001; 2003-2008) (**Table 11**, Annex 2). Age structures from acoustic surveys are only available for the Chilean data and they are summarized in **Tables 12 to 14**. Note that although an acoustic survey was carried in early 2015 off Northern Chile, the information was not yet available and therefore not included in this assessment.

Biological parameters

In jack mackerel, age at first reproduction is estimated between 2-3 years (**Table 15**, Annex 2). Simulated age-at-length key used to fit length structures from Peruvian data, was computed using growth parameters in Cerna et al. (2011) with L_{∞}= 72,7 cm, k=0,074 (year^{-1}) and t_0=-1,97 (year^{-1}). Natural mortality is considered M=0.23 (year^{-1}) following JMSWG-Report (2014).

2.2. Stock assessment model

The model used to assess the jack mackerel in the SEP was requested to the Subsecretaría de Pesca de Chile (www.subpesca.cl), we also obtained information from SPRFMO reports (www.sprfmo.int) and from de Instituto de Fomento Pesquero reports (www.ifop.cl). The current model was developed by the SC at the SPRFMO, and was adopted as an assessment method for the Jack mackerel in the South Eastern Pacific in 2010 (JMSWG-Report, 2014).

The stock assessment model corresponded to an integrated statistical catch-at-age approach, implemented in AD Model Builder (ADMB) with different sources of information from the jack mackerel fisheries in the SEP area as well as fishery-independent information (surveys) covering the period from 1970 to 2014 (Canales 2014, JMSWG-Report, 2014).

The model consists of four main components: 1) the dynamics of the fish population (**Table 1**, Annex 3); 2) the fishery dynamics (**Table 1**, Annex 3), 3) observations models (**Table 2**, Annex 3), and 4) parameter estimation (**Table 3**, Annex 3).

Population and fishery dynamics

Population dynamic considers ages from 1 to 12+ years old, the recruitment is assumed to take place on the first of January of each year, and the spawning occurs instantaneously in the middle of November. The initial population is based on equilibrium condition in 1958, 12 years before the information start in 1970 (landings are available from 1970). Cohort dynamic considers exponential decay of the abundance affected only by natural mortality up to 1970 and thereafter from natural mortality and fishing. Natural mortality is assumed to be time and age invariant (**Table 1**, Annex 3).

Fishing mortality is modeled using the separability hypotheses based on an annual component, and the selectivity that describes the proportion of individuals at age removed by fishing. Selectivity is non-parametric, fishery-specific and time-variant. The catchability is assumed variable (changes in the fishing effort) modeled by a random walk (**Table 1**, Annex 3). Stochastic density-dependence relationship between recruitments and spawning biomass is modeled using the Beverton and Holt stock recruitment function (**Table 1**, Annex 3).

Observations model

Observations come from four datasets as follows. (1) The abundance indices (CPUE, acoustic survey and spawning biomass from DEPM), (2) total catches, (3) ages and (4) length structures from fishing operations, acoustic surveys and DEPM. The observation models for each dataset are described in **Table 2** (Annex 3). The observation models of the indices are obtained according to the fraction of year that they take place. Catches by year, age and fleet (**Table 2,** Annex 3) are all weighted by ageing error matrix based on Chilean age data (**Table 16**, Annex 2). **Table** 2 (Annex 3) shows the form of transition matrix to convert length distribution into age distribution, based on the von Bertalanffy growth parameters L_∞ and k.

Parameters estimation

The parameters of the model were estimated maximizing the log-likelihood of each dataset together with log probability density functions of the priors and smoothing penalties of selectivity. The list of parameters is summarized in **Table 3** (Annex 3).

The log-likelihood (**Table 3,** Annex 3) of indices (CPUE and surveys) and catches are assumed as lognormal distributed. Likewise, multinomial distribution is considered for the age and length frequencies. Constrain for the fishing mortality are assumed for the last year of the assessment due to effect of the presence of incomplete cohorts. Estimates of recruitment are conditioned to a stock-recruitment curve over the period 1977-2011.

The weight of each dataset (coefficients of variations and sample sizes) of each likelihood function was taken from JMSWG-Report, (2014) to maintain consistency. Thus, CV of the catches was cv=0.05 for the four fleets keeping the assumption of high precision of the catch data. Smoothness for selectivity (indexes) were all were kept as$\lambda = 100$, the S-R function fit was kept with a cv=0.7 and the recruitment regularity $\lambda = 1.4$. Sample size for the proportions at age of the Chilean acoustic survey were n=30, and DEPM n=20. **Table 4** (Annex 3) summarizes the weights used for abundance indices, smoothness for selectivity of the fleets and samples size of the proportions at age/length of each fleet.

Hypotheses - Stock Structure

We explored the trends and levels of the spawning biomasses for two hypotheses about the stock structure of jack mackerel in the SEP. Two hypotheses were evaluated as follows. H1: Jack mackerel is one single population in the South Eastern Pacific area, this hypothesis, hereafter Model-1, and H2: Jack mackerel constitute two discrete populations one in the Peruvian and Ecuadorian waters, and one off Chile extending onto the high seas, hereafter Model-2. We assessed both hypotheses by optimizing the stock assessment models, first keeping all the information (Model-1). Hypothesis H2 all the data and related underpinning processes in the model belonging to the Far North fleet (CPUE and survey from Peru) were removed from the assessment (Model-2). This means that only the portion of the jack mackerel population inhabiting off Chile and distributed in coastal waters and high sea is assessed. Results showed that when information from Peru were removed from the assessment, no significant differences in the trend and level of the spawning biomass were observed, and we concluded that the biomass from Peru did not make a significant addition to the spawning biomass of the jack mackerel stock in the SEP. Thus, the following analyses is based only in the H1 (Model-1), however we take into account two scenarios regarding the assumptions of the steepness of the stock-recruitment relationship of jack mackerel, this means h=0.65 (low resilience) y h=0.8 (high resilience).

Biological references points (BRP)

To estimate the biological reference points of jack mackerel we reviewed the methodological approach proposed by Payá et al. (2014) for Chilean Fisheries, Canales (2014) and JMSWG-Report (2014).

Payá et al. (2014) classified the jack mackerel fishery as a Tier 1a, which means there is enough information to apply an age- or length-structured assessment model which will provide usable estimates of the current abundance of the stock. This tier also implies that species-specific MSY can be estimated and therefore the steepness parameter (h) of Beverton and Holt stock-recruitment relationship can be estimated within the assessment model. Therefore, *Fmsy* (fishing mortality at maximum sustainable yield), *Bmsy* (spawning biomass at maximum sustainable yield), and *Blim* (spawning biomass at collapse or depletion limit) can be estimated with reliability. Canales (2015) discussed the status of jack mackerel based in two values of steepness implies high (h=0.8) and low (h=0.65) resilience to fishing exploitation. However, both assumptions lead to a similar status of jack mackerel.

Here, we used the stock assessment model to estimate BRPs and define the status of jack mackerel population. We analyzed two scenarios for steepness parameter, considered fixed h=0.8 and 0.65 following Canales 2015; JMSWG-Report, 2014. Although h could have been estimated within the stock assessment models, as proposed in Payá et al (2014), we decided to fix it in order to maintain consistency with previous assessments. Note that, when the steepness parameter (h) is known, BPRs as MSY, *Fmsy* and *Bmsy* can be directly derived from yield per recruit analysis. We computed these BRPs using a routine already implemented in the jack mackerel stock assessment model (JMSWG-Report, 2014). Notice that *Fmsy* and *Bmsy* are target management values according to the Chilean Fishing Law, but they are also used as management values at the SPRMFO. We also estimated *Blim* (spawning biomass limit) a half of *Bmsy* (*Blim*=*Bmsy*/2) following Payá et al. (2014). This reference point indicates a non-desirable state for jack mackerel spawning biomass, because beyond this point the risk of collapse is high.

To define population status we used the Kobe o Phase Diagram plot. This is a scatter plot of the ratio between annual estimates of spawning biomass (1970-2014) and the target spawning biomass (x-axis) and, the ratio of annual estimates of fishing mortality (1970-2014) and target fishing mortality (y-axis). In the diagram, we distinguish different areas following recommendations from Payá et al. (2014) for Chilean fisheries resources. Thus, we identified different areas: i) under-exploitation, where the actual point of the spawning biomass of jack mackerel is higher than the target biomass ($B/Bmsy > 1$), or lower if the criteria is fishing mortality ($F/Fmsy < 1$), ii) full-exploitation, a level in which the biological point has been reached or is close to *Bmsy* ($B/Bmsy \approx 1$), iii) over-exploitation, a level where the current or actual biomass is below the target biomass ($B/Bmsy < 1$), or higher if the fishing mortality is considered ($F/Fmsy > 1$), and iv) depleted or collapsed, where biomass is below the biomass of the biological limit point (*Blim*).

Harvest control rule (HCR)

During 2008 and 2012, the Science Group (SG) of SPFRMO made an important progress in estimating the status of jack mackerel stock. As a result of this work, the spawning biomass was diagnosed as depleted where its lowest level was reached in 2010. Thus SPRMFO proposed a rebuilding plan for the jack mackerel stock over the whole southeast Pacific Ocean (http://www.southpacificrfmo.org/2nd-commission-meeting/). The first management action was reduced the jack mackerel catches in 2011. Afterwards, a substantial decrease of the fishing mortality was estimated, however, the spawning biomass was still at 51% of *Bmsy* during 2013. The nearest objective of the management procedure was to ensure that the spawning biomass of jack mackerel will increase up to 80% of *Bmsy*. Notice that 80%*Bmsy* was set as a management objective for the SPRMFO which is different than the one established in the Chilean Fishing Law, which uses *Bmsy*.

Projections of population abundance of jack mackerel population were conducted following Canales (2015) and JMSWG-Report (2014). The starting point of the projection was the year 2015, and the population was projected forward until 2034. Recruitments were modeled using the Beverton & Holt function with two assumptions about steepness h=0.8 and 0.65 and two value of long-term recruitment or maximum recruitment (Rmed) as 1970-2012 and 2000-2012. The fishing strategy considered was fishing at a constant rate, and using five levels of F. The fishing mortality estimated in 2014 was multiplied by the following factors (multipliers): mf={0,0.25,0.5,0.75,1,1.25} creating five levels of fishing mortality for the projections of the spawning biomass. Thus, four scenarios for the projection of the jack mackerel stock and catches were proposed as follows:

- **Scenario 1**: Model-1, h=0.8, and mean recruitment (Rmed) computed from the period 1970-2012.
- **Scenario 2**: Model-1, h=0.8, and mean recruitment (Rmed) computed from the period 2000-2012.
- **Scenario 3**: Model-1, h=0.65, and mean recruitment (Rmed) computed from the

period 1970-2012.

- **Scenario 4**: Model-1, *h*=0.65, and mean recruitment (Rmed) computed from the period 2000-2012.

Note that each scenario simulated the jack mackerel abundance (stock) using the five level of fishing mortality described before.

3. ASSESSMENT RESULTS

3.1. Fitting model to data

A comparison of the fit in Model-1 in all indices used and for the two scenarios of steepness (h=0.80 and h=0.65) is shown in **Fig. 2** (Annex 1). Almost no differences were observed between the fits of both models. In general, the fits are better for CPUE series than the surveys biomass indices. Within the time series of CPUE, the model predictions were better for SC-Chile, China and EU. The fit of age structures for fleets and survey data for the two scenarios of the steepness of Model-1, as the same as the indices show little differences between the two scenarios of *h* (**Fig. 3** to **Fig. 9**, Annex 1).

3.2. Stock assessment

Abundance estimates and the associated uncertainty for each scenario of *h* are summarized in **Fig. 10**, **Fig. 11** (Annex 1) and **Table 17** (Annex 2). The comparison between scenarios (**Fig. 12**, Annex 1) showed almost no differences between *h* scenarios on the mean value of the spawning biomass time series. Between 1974 and 2002 the highest recruitment period is observed in both models. Since 2003, jack mackerel recruitments fluctuated with values below mean recruitment estimates over the period 1974 to 2002 in both models. The highest spawning biomass (SSB) in both models is estimated in 1988, as well as the second maximum in the year 2003. Since 2010, the spawning biomass had increased, although estimates are still on the range of its lowest values. This slight recovery is explained by higher recruitments observed between 2007 to 2009 and an important decrease of the fishing mortality experienced since 2011. This increase of recruitments is mainly caused by an increase in the last few years of the CPUE in Chile CS. Spawning biomass estimates in 2014 for the Model-1 with two scenarios of steepness reached almost 3.6 million tones (Model-1, *h*=0.8), and 3.4 million t Model-1, *h*=0.65. The fishing mortality of both scenarios followed the same trend. A significant decrease of the fishing mortality takes place from 2009 to 2011 as a consequence of a decrease of total landings in almost a half.

3.3. Retrospective analysis

Retrospective analysis in stock assessment, refers to the examination of the consistency among successive estimates of the same parameter obtained as new data are gathered. This analysis constitutes a useful tool to examine systematic patterns or inconsistency in state variables derived from integrated stock assessment models (Mohn, 1999). There are two types of retrospective analysis: historical and within-model. Historical retrospective analysis compare results of each final assessment with those conducted in previous years, and it is usually implemented to evaluate the effects of changing stock assessment methodologies. In contrast, within-model retrospective analysis uses the same data and assessment model to trim the most recent year's data in successive models runs. Thus, this analysis reproduces what would have been obtained annually if the current method had been used for past assessments. The within-model retrospective analysis is the most useful for determining internal inconsistency in the data, because the only change in different runs is the number of years in the model (Clark et al. 2012). We conducted a within-model retrospective analysis to evaluate consistency in the stock assessment proposed for jack mackerel. We used spawning biomass time series as a control variable dropping five years of the most recent data.

In **Fig. 13**, evaluations with previous data are labeled as "R-1" to "R-5" indicating the number of years that has been dropped from the last assessment. We can see that for the retrospective analysis in R-1 to R-4, an overestimated spawning biomass respect to the mean value of the most recent assessment (actual) is found. In addition, assessment considering the least data (R-5) showed an inverse behavior respect to the rest of retrospective analyses and provided estimates of spawning biomass smaller of what was predicted using the most recent assessment. Higher differences are shown only in the last few years of each assessment (R1 to R5). Spawning biomass estimates from R-1 to R-5 fall onto the 95% confidence intervals computed for the last year assessment (**Fig. 13**).

In **Fig. 14**, retrospective analysis is showed in terms of percent differences between the spawning biomass in each year to the terminal year estimates. Here, we see that the main difference is detected when dropping two years from the last assessment (R-2), which in percent differences reached about 30% of the spawning biomass estimated in 2010 with the last assessment. On the other hand, for the same year, retrospective analysis in R-5 produces estimates of spawning biomass that are 20% lower of what is estimated when using the last year assessment.

4. EXPLOITATION STATUS

Biological references points computed for Model-1, *h*=0.8 and Model-1, *h*=0.65 are shown in **Table 18** (Annex 2). Depletion of the unexploited biomass is slightly greater in the case when *h*=0.65. Spawning biomass in the year 2014 in Model-1, *h*=0.8 and Model-1, *h*=0.65 are near to *Blim* rather than *Bmsy* in both cases; however F in 2014 is below *Fmsy* (**Table 17**, Annex 2).

The status of jack mackerel stock in the SEP under the scenarios of Model-1, *h*=0.8 and Model-1, *h*=0.65 are shown in the **Fig. 15** and **Fig. 16** (Annex 1). Differences between trajectories of spawning biomass under both escenarios of *h* are small. Both diagrams show that during the 1970s, jack mackerel was underexploited, and during 1980s and 1990s the stock reached overexploitation with spawning biomass below maximum sustainable yield (B<*Bmsy*) and F > *Fmsy*). For a few years, during the year 2000 the stock seems to be near *Bmsy,* although always above *Fmsy*. From 2008 to 2012 the stock status is in depletion. Steepness scenarios change the perceived status in 2013. When using *h*=0.8 the status is overexploited, whereas with *h*=0.65 the population is in depletion. However, in 2014 both scenarios of steepness lead to overexploited condition (**Fig. 15** and **Fig. 16**).

Confidence intervals over the fishing mortality and spawning biomass estimates for the year 2014 in the scenarios *h*=0.8 suggest a 0.5 probability of being below B_{lim}, and thus, in a depleted condition (**Fig. 15**, Annex 1). In addition, confidence intervals of fishing mortality show there is a 10% chance of exceeding target fishing mortality level (F>*Fmsy*) (**Fig. 15**, Annex 1). Kobe plot for *h*=0.65 (**Fig. 16**, Annex 1) shows that spawning biomass (B) has a probability higher than 0.75 of being depleted where B<B*msy* and low a probability of F > *Fmsy*.

5. PROJECTIONS AND EXPLOITATION STRATEGIES

The scenario 1 (Model 1, *h*=0.80, Rmed=1970-2012) of spawning biomass projection (**Fig. 17**) showed that under all levels of constant fishing mortality the spawning biomass of jack mackerel would be higher than the spawning biomass in 2015 in the short (2016), medium (2024) and long term (2034). In addition, all these projections show that spawning biomass was higher than the B*msy* (**Table 18**) in short, medium and long term. Scenario 2 (Model 1, *h*=0.80, Rmed=2000-2012) (**Fig. 20**) shows different results than the scenario 1. At all levels of F>0, the spawning biomass tends to decrease in the long term (2034). The biggest decrease in biomass is observed when projection are set with F values 25% higher than F 2014. In this case, biomass in 2015 is below the level defined by *Bmsy* and thus, in an overexploited condition.

None of the F scenarios analyzed recovers the spawning biomass over *Bmsy.* The scenarios of Rmed used to project the abundance explains the differences observed in these two scenarios. The first scenario used Rmed, which was based in the years 1970 to 2012 (see recruitment time series, **Fig. 10**) and the second from 2000-2012. In the first case, maximum recruitment for the population growth is higher than in the second case. Thus, the first case has higher compensation as fishing mortality increases across different F scenarios projected.

In **Fig. 18** and **21** show the probability distribution to fall below 80%*Bmsy* (yellow area) and *Bmsy* (blue line) for scenarios 1 and 2, respectively. For scenario 2 (**Fig. 21**) in the short term (2016), the probability to be below the 80%*Bmsy* or *Bmsy* is higher than in scenario 1 (**Fig. 18**). In the medium term, scenario 1 has a lower chance to be below 80%*Bmsy* or *Bmsy* than scenario 2, and the same results are shown for long-term for all levels of F. On the other hand, **Fig. 19** and **22** show the probability of recovery of the spawning biomass of jack mackerel over *Bmsy.* In the short term (2016), the probability to recover the spawning biomass is lower in the scenario 2 (**Fig. 22**) than scenario 1 (**Fig. 19**). In the scenario 2, spawning biomass has a higher probability to recover the spawning biomass over *Bmsy* only when F=0. In the medium (2024) and long-term (2034) scenario 2 is worse, with the highest chances to recover the spawning biomass over *Bmsy* only if the F is half of F in 2014 (35% and 27% respectively) and above > 90% if F=0.

Scenarios 3 and 4 (**Fig. 23** and **26**) correspond to the projections of spawning biomass of jack mackerel with value of steepness of *h*=0.65. Scenario 3 (Model 1, *h*=0.65, Rmed=1970-2012) showed that at almost all levels of constant fishing mortality produced in the short, medium and long term spawning biomasses higher than the value in 2015 (**Fig. 23**). In all these projections (except at 125%F) spawning biomass is higher than B*msy* (**Table 18**) in the medium and long term. In cases where fishing mortality is equal to 25% or above the F estimates in 2014 (> 25%F), the spawning biomass does not recover over the *Bmsy* in the short, medium and long term. Scenario 4 (Model 1, *h*=0.65, Rmed=2000-2012) (**Fig. 26**) shows different results than scenario 3. At all levels of F, except when F=0, spawning biomass decreases below *Bmsy* (**Table 18**) in the medium and long term (2034). The highest decline takes place with the highest values of *F*, 125% of the estimates F in 2014 (125%F). Different Rmed used in the simulation explains the differences observed between scenarios 3-4, and 1-2. The first scenario used an Rmed based in the years 1970 to 2012 (see recruitment time series, **Fig. 11**), and the second from 2000-2012. Thus, scenario 3 sets a higher Rmed than the scenario 4. In addition, scenarios 3-4 show a slightly deeper decline than scenarios 1-2, due to the lower resilience set by the steepness value of *h*=0.65.

Probability distribution to fall below 80% of *Bmsy* (yellow area) and *Bmsy* (blue line) for the scenario 3 and 4, respectively are shown in **Fig. 24** and **27**. Scenario 4, short term (2016), shows that the probability to be below to 80%*Bmsy* or *Bmsy* is higher than in scenario 3. In the medium term, scenario 3 has a lower chance for the spawning biomass to fall below 80%*Bmsy* or *Bmsy* than scenario 4, in the medium and long term. **Fig. 25** and **28** show the probability to recover the spawning biomass of jack mackerel over *Bmsy,* in scenarios 3 and 4 respectively. In the short term (2016) the probability is lower for scenario 4 than scenario 3. Scenario 3 has the highest probability (0.12) to recover spawning biomass over *Bmsy* but only if F=0. In the medium term (2024) and long-term (2034) scenario 4 is worse than scenario 3. Scenario 3 in general has better chances to recover the spawning biomass over *Bmsy* than scenario 4. In scenario 4, the highest probability to recover the spawning biomass over *Bmsy,* in the medium and long term takes place only when F=0. Likewise 50%F has a probability to recover the spawning biomass above *Bmsy* of 0.07 in the short term (2016), 0.28 in a medium term (2024) and 0.22 in long term (2034).

Probabilities of the jack mackerel spawning biomass to recover over *Bmsy* or to fall below 80%*Bmsy* for each scenario and F level are summarized in **Table 19**. The table also contains the predicted catches of jack mackerel in the year 2016 and 2017. It is clear from the results in **Table 19** that the recovery of the spawning biomass of jack mackerel over *Bmsy* in the short term (2016), has the highest probability (>0.2) only if *h*=0.8 and Rmed= 1970-2012 and F=0. For all levels of F, the probability to recover biomass above *Bmsy* in the four scenarios is <0.2. In the medium term projection, the highest probability (> 0.5) to recover the spawning biomass above *Bmsy* occurs when Rmed is computed from the period 1970-2012, however the probability decreases (<0.35) if Rmed is computed from the period 2000-2012 and $F \neq 0$. In the medium term projection, 50%F increases the chances to recover the biomass above *Bmsy* between 28% and 35% depending on *h* value used on the projection. Long-term results are similar to medium term although, chances to recover the spawning biomass over *Bmsy* drop slightly more (< 27%) if fishing mortality is 50%F. Using Rmed for the period 2000-2012 and *h*=0.8 (scenario 2), TAC of jack mackerel 2016 takes a range between 357 to 768 thousands t depending on the level of F and risk of not accomplish the management rule proposed. When using *h*=0.65 this TAC range changes slightly between 353 to 759 thousand tones also depending on F and risk (**Table 19**).

Although, there are no strong differences between the range of TAC 2016 depending on the scenario of *h*, the higher impact of this parameter is reflected in the time and probability that the stock of jack mackerel will leave the overexploited area. As we can see in **Table 19**, the probability to recover the jack mackerel stock to the sustainable area (over the *Bmsy*) in the long term (2034) taking a *h*=0.8 varied between 0.002 to 0.266 when F>0. With a value of steepness of *h*=0.65, these probabilities became smaller, for instance increasing F over the value of F in 2014 will not recover the stock by 2034 (**Table 19**), and if F is kept equal to the value of F in 2014 the probability is 0.006 (*h*=0.65) and 0.016 (*h*=0.80) under the same scenario of Rmed.

6. DISCUSSION

Main results of this work indicate that jack mackerel stock in the South Eastern Pacific is overexploited and with some probability of being depleted (close to B_{lim}). We conducted a stock assessment considering two hypotheses regarding the stock structure of the jack mackerel in the South Pacific (Canales et al. 2015), and two scenarios of steepness (h). All these combinations between stock hypotheses and scenarios of h lead to the same diagnosis of stock status. Main differences between hypotheses and scenarios of h are related with the probability of depletion, which varies between 0.25 (one single stock) and 0.35 (two stock). In addition, based on the hypotheses of one single stock (Model-1), probability of depletion varies between 0.5 (h=0.80) and 0.75 when h=0.65. A similar conclusion is found in Canales (2015) who reported that jack mackerel is overexploited with spawning biomass near *Blim*, and thus, with probability of depletion.

The stock assessment presented in this report was conducted using updated information of the catches of Chilean fleets in 2014, based in the landings available up to July 2015. The complete catch at age structures of the North and Central south of Chile fleet observed in 2014 was also updated. The new information included in the assessment did not produce significant variation in the trend, level and status of jack mackerel. This robustness of the state variables to the incorporation of new information if expected in lengthy-data and age-structured stock assessment models like the one used here, because historical information has a high relative weight in the analysis. In addition, note that here, we use a different set of growth parameters than those reported in previous assessments in JMSWG-Report (2014) (k=0.16 year^{-1}, L_∞=74.4 *cm*). These parameters showed inconsistencies, because k estimates seem to be close to what is reported to the far north stock, while L_∞, is similar of what is reported in Chilean waters. k and L_∞, are highly correlated parameters and thus, consistency between their estimates is expected.

Growth parameters in this assessment are used to model a simulated age at length key to account for length structures observed on the far north fleet. Misspecification of growth parameters in age-structured stock assessment models that fit length structures usually result in biased estimations of fleet-specific selectivity-at-age, which are then propagated in a cascade effect to, biased abundance estimates, biological reference points and population status. Given the importance of growth parameters in this assessment, we used the latest revision of growth parameters available in this species from Cerna et al (2014). These parameters are as follows k=0.074 year^{-1} and L_∞=72.7 cm. Changes in growth parameters usually trigger a revision of natural mortality. However, in order to maintain consistency with previous assessments we kept M=0.23 year^{-1}. Nevertheless, using growth parameters in Cerna et al (2014), and using the M estimator in Pauly (1980) and temperatures from 15-20°C show a variation of M from 0.19 to 0.22, a value close to what is currently used in the assessment.

Comparing stock assessment outputs presented here with previous assessments in JMSWG-Report (2014) (comparison not shown here) we note that observed differences are mainly related with modifications of Chilean catches and age-structures and, secondarily with changes in growth parameters described above. In addition, results presented here for both hypotheses about stock structure were not significant (for details, see Canales et al. 2015). Thus, we conclude that magnitude of the Peruvian catches is small leading to a relative small estimate of abundance off shore Peru and thus making almost negligible to the contribution of this abundance to the mega scale stock of jack mackerel in the SEP.

We conducted a retrospective analysis based on the spawning biomass of jack mackerel to assess if there is a systematic over- or under-estimation of the last year of the assessment. Spawning biomass was overestimated in four of the retrospective analyses (R-1 to R-4), representing the most recent years. In the last analysis R-5 this pattern is inverted and biomass observed is underestimated. We conclude that abundance estimates in jack mackerel are highly influenced by the CPUE index from Center-South (CS) off Chile. The retrospective pattern found in jack mackerel appears to be random and thus, only caused by the addition of new data, because changes in historical spawning biomass estimates from R-1 to R-5 are small and falling into the confidence intervals computed in the last assessment. The amount of percent differences reported here for jack mackerel is small in comparison with other species (see Legault 2009) and this kind of patterns in retrospective analysis are probably of little concern (Clark et al. 2012). Retrospective analyses should be considered for further investigations where "one-way" pattern is observed. This means that as data is added, the recent estimates of the spawning biomass changed for each of the years considered in the analysis. Nevertheless, this is not the case for the assessment presented here for jack mackerel and thus, we conclude that the present assessment provides a robust estimation of abundance.

Scenarios of projections included the combination of two levels of h and two levels of Rmed. Here, we conclude that Rmed has an important impact in the projections and predicted recovery of the spawning biomass over *Bmsy or 80%Bmsy.* Instead, the level of h chosen has less relevance on the projections, which may seem a bit confusing giving the importance of in MSY-based management approaches (Mangel et al 2013). Here, projections of abundance are based on the Beverton-Holt function parameterized in terms of Rmed and h. Rmed is used to compute the unexploited recruitment (R_0), which defines the asymptotic level of the Beverton-Holt function. Thus, the period over Rmed computed has a direct effect on defining the upper limit of "ceiling" that simulated recruitments can reach on abundance projections. On the other hand, *h* defines the slope of the Beverton-Holt function and thus, this gives an idea on how fast the asymptotic recruitment is reached when simulating projections. Here, Rmed is computed over two periods, 1970-2012 and 2000-2012. It is important to notice that the period 2000-2012 was selected based on JMSWG-Report (2014). When using the longest period of recruitment (1970-2012), Rmed gives higher values of what is observed in the last two decades period (2000-2012). Higher value of Rmed using the longest period is highly influenced by extreme high values of recruitments estimated in 1984 and 1985. Last period of recruitments are lower and thus more precautionary and will give a better idea of the current level of recruitments, which may be more likely to occur during the horizon of projections. On the other hand, the impact of the two different scenarios of steepness (*h*=0.8 and *h*=0.65) is negligible in comparison with changes in Rmed, although it affects the probability of reaching *Bmsy* in a certain period of time. For the same Rmed, the uses of higher values of resilience (h=0.8) increase the probability to reach *Bmsy*, in comparison with low resilience scenarios (*h*=0.65). Thus, *h* has a secondary importance on the projections and it is mainly associated with the probability of accomplished management decision based on MSY. In the current stock assessment, steepness value is treated as fixed parameter and sensitivity analysis is conducted using two levels of *h*. Levels of *h* chosen here seem to be according of what we would expected in species with life histories such as jack mackerel (Payá et al 2014). Projections using multipliers of the fishing mortality estimated for 2014 have high probability of accomplish the management rule proposed only in case of high Rmed is considered in the longest period. However, the Rmed for the period 1970-2012 does not represent the recruitment level for the most recent years and is likely to overestimate recruitment in the short and medium term projections. Therefore, the use of Rmed for the longest period may be misleading and overestimate the rebuilding capacity of the jack mackerel stock. Thus using Rmed from the period 2000-2012 is more appropriate to represent the current productive capacity of the stock. The choice of this scenario will imply that harvesting at 50% of fishing mortality estimates in 2014 has a chance of 30% to accomplish *Bmsy* at the end of the projection period (year 2034). Harvesting with any higher F (> 50%F), will reduce the chances below an 8% to reach *Bmsy* in 2034 and thus it is not recommendable as a sustainable management strategy. At the current exploitation status presented here for jack mackerel, according to the precautionary approach FAO guidelines state, it is fundamental to take this recommendation into account in order to ensure the sustainability of the stock. This means when a course of action has to be chosen (e.g catch limits), negative impacts need to be avoided or minimized and management decisions should ensure a low risk in order drive the stock to desirable levels of abundance. The acceptance of the precautionary approach usually involve the adoption of harvest rules that only allows 10% of risk of not accomplish the management objective.

Thus, even reducing fishing mortality to be applied at only half of what was estimated for 2015, the chances of reaching *Bmsy* by 2034 are only 30%, a relative large risk in the light of a precautionary approach. In order to reach 10% of risk, fishing mortality and related catches need to be reduced even more of what is presented in **Table 19**, for those scenarios considering Rmed (2000-2012) and a multiplier of 50% of the fishing mortality in 2014.

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ANNEX 1: FIGURES

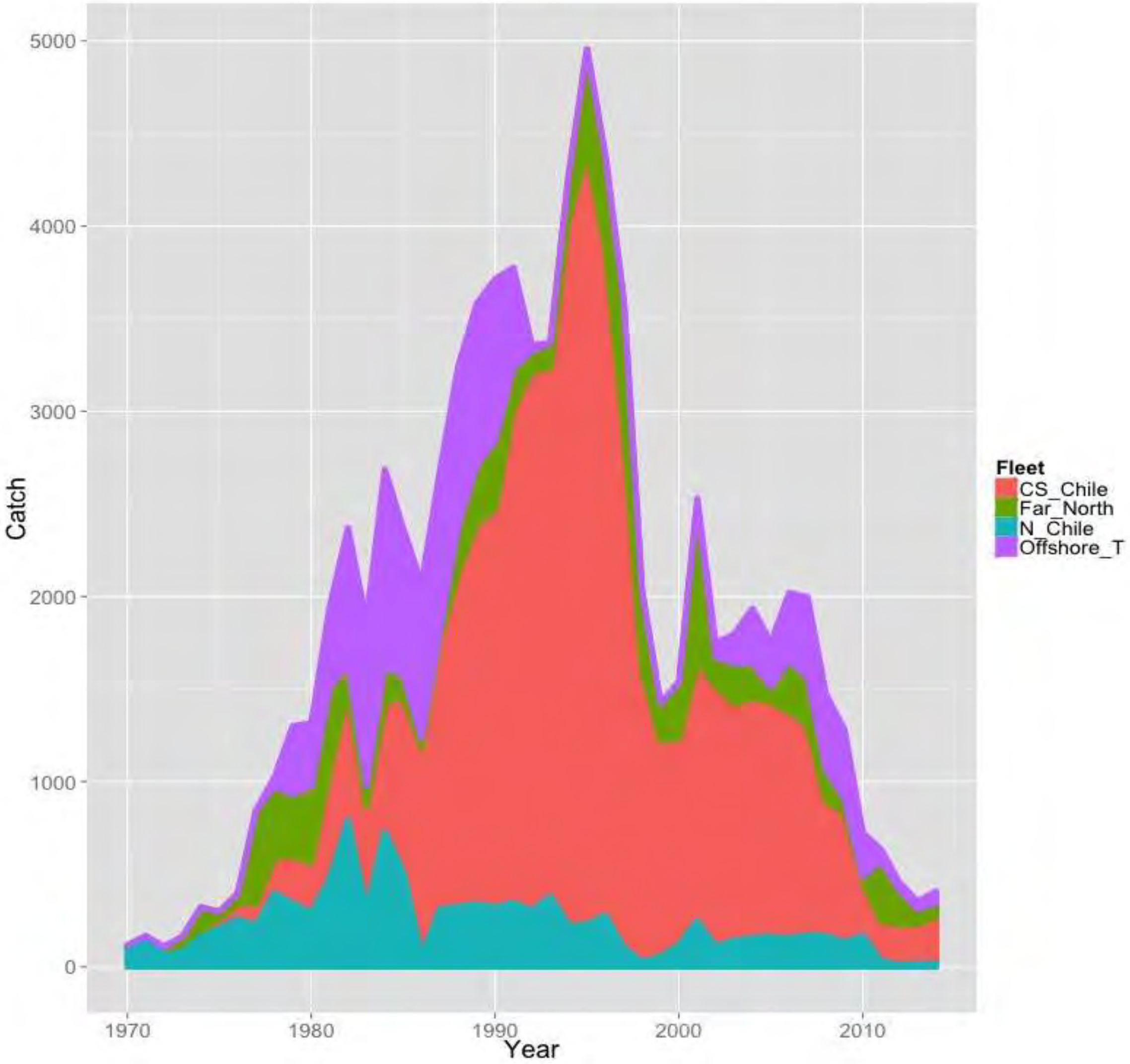

Fig 1. Catches (x10^3 metric ton) of jack mackerel at the Southern-eastern Pacific 1970-2014. (Fleet 1: Northern Chile, Fleet 2: Central-south Chile, Fleet 3: Far North - Peru, Fleet 4: Offshore Trawl).

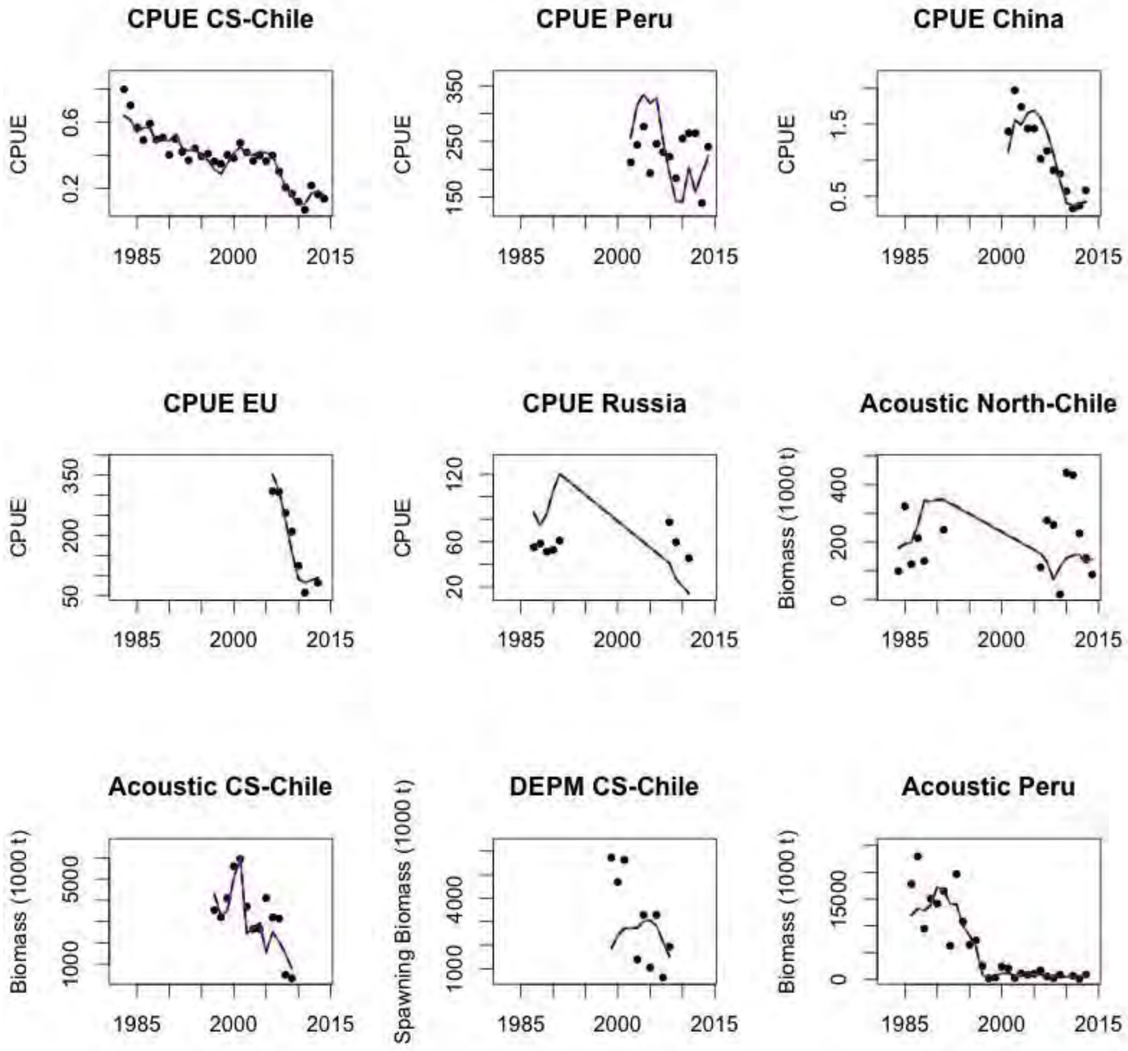

Fig. 2. Comparison of the Model-1 of two scenarios of steepness, h=0.8 and h=0.65. Black dots: observed values, red solid line: predicted values Model-1, and h=0.8; blue dotted line: predicted values Model-1, h=0.65 (CS: central south, EU: European Union, DEMP: Daily Egg Production Method).

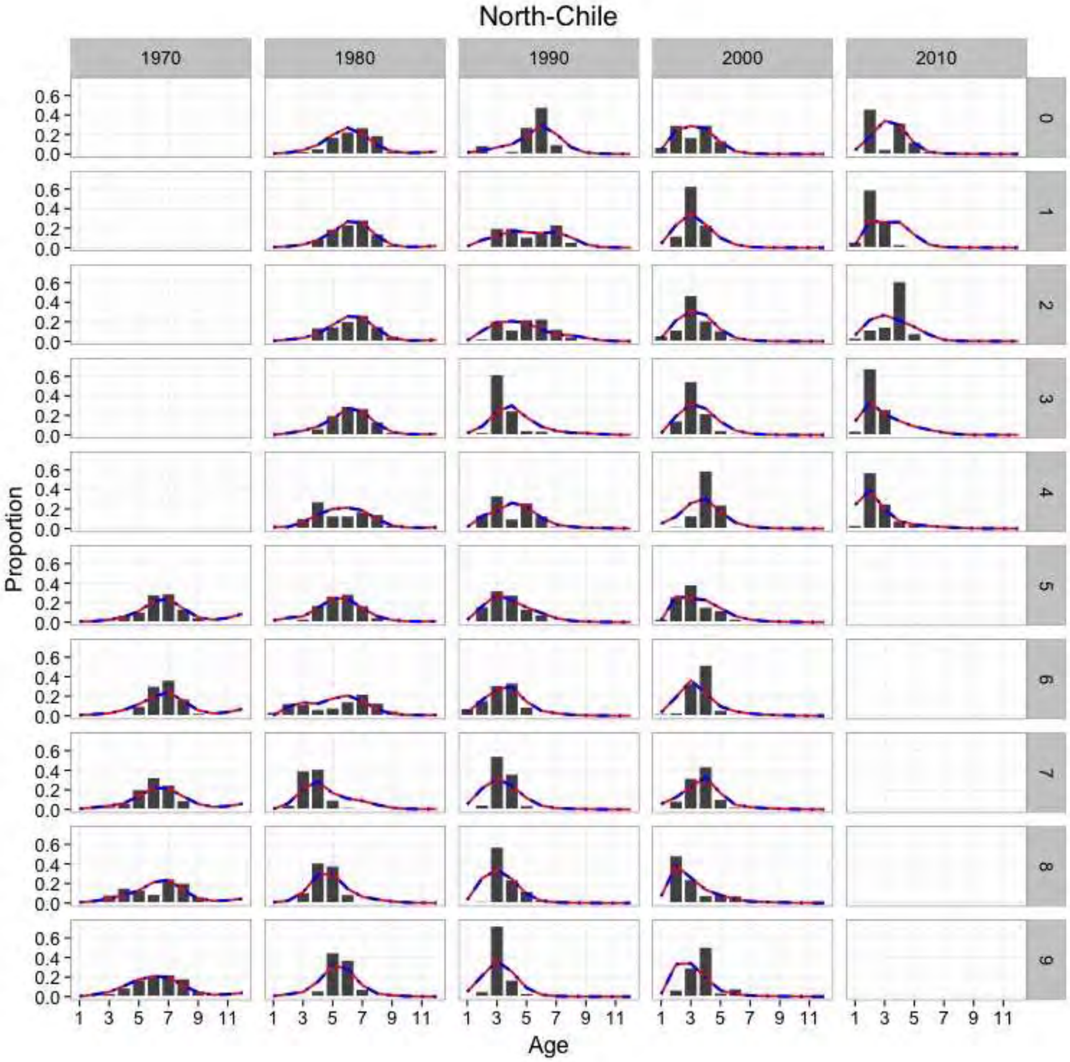

Fig. 3. Comparison fit catch at age of the North Chilean fleet (Fleet 1). Two scenarios of steepness, h=0.8 and h=0.65 (Model-1). Grey bars: observed values, red solid line: predicted values Model-1, and h=0.8; blue dotted line: predicted values Model-1, h=0.65.

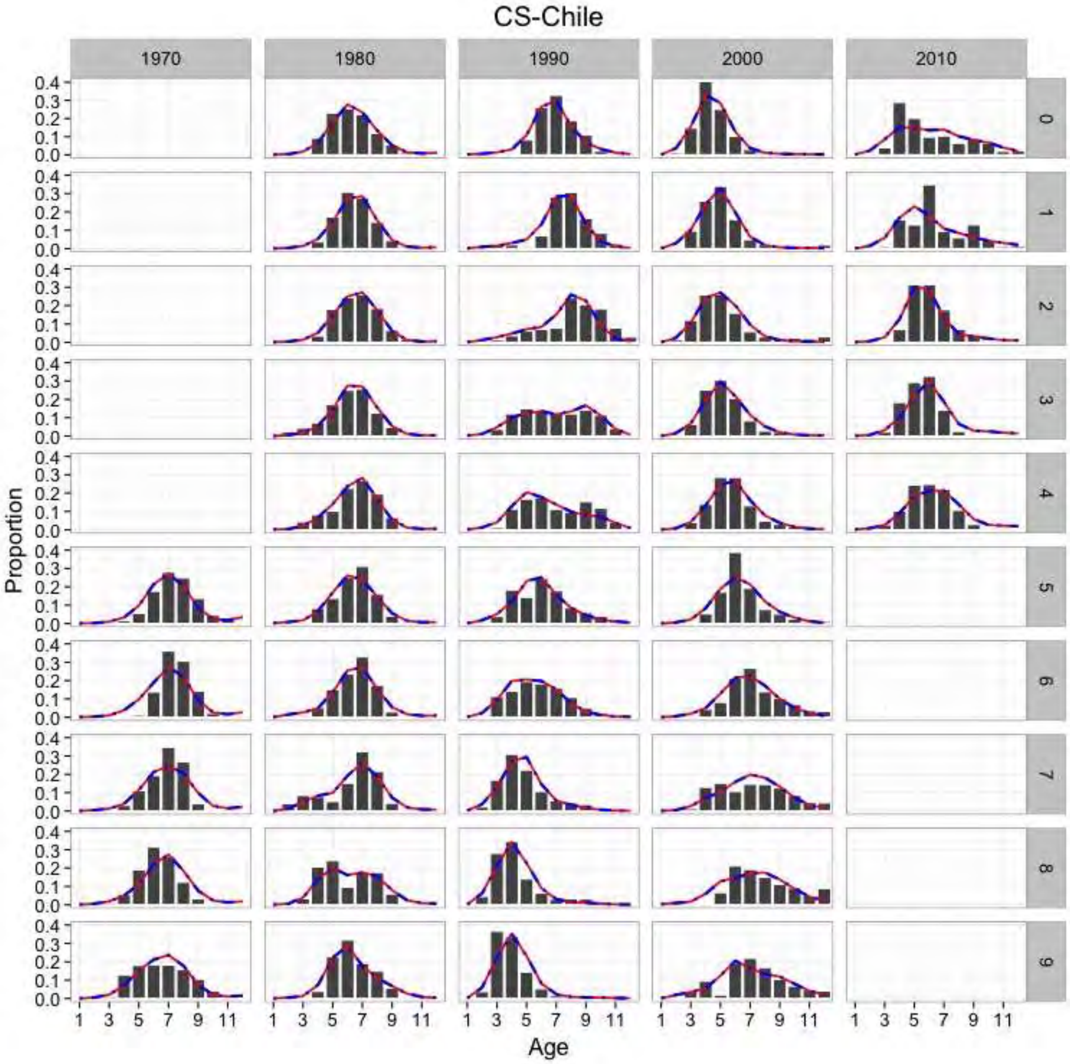

Fig. 4. Comparison fit catch at age of the central-south Chilean fleet (Fleet 2). Two scenarios of steepness, *h*=0.8 and *h*=0.65 (Model-1). Grey bars: observed values, red solid line: predicted values Model-1, and *h*=0.8; blue dotted line: predicted values Model-1, *h*=0.65.

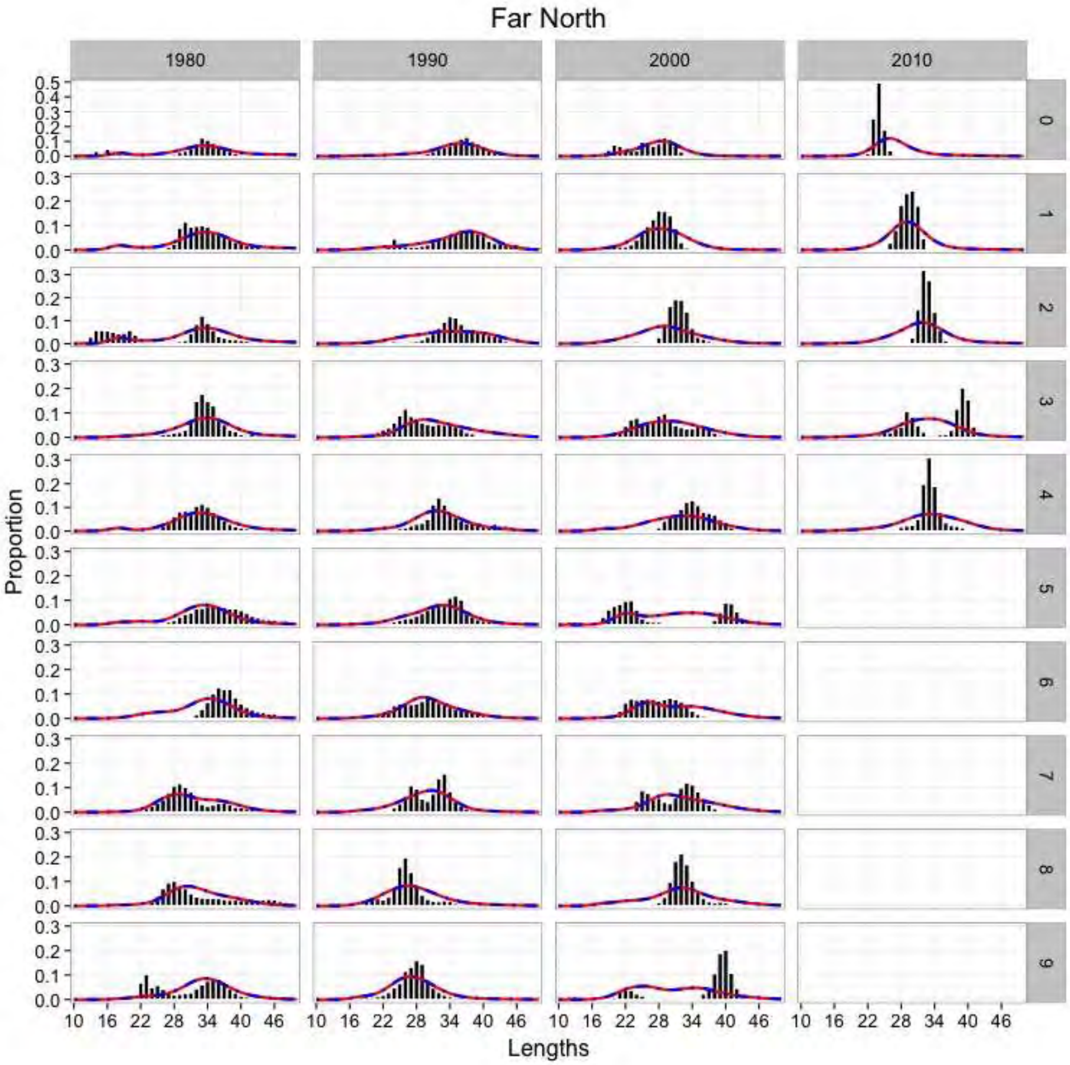

Fig. 5. Comparison fit catch at age of the Far North (Fleet 3). Two scenarios of steepness, *h*=0.8 and *h*=0.65 (Model-1). Grey bars: observed values, red solid line: predicted values Model-1, and *h*=0.8; blue dotted line: predicted values Model-1, *h*=0.65.

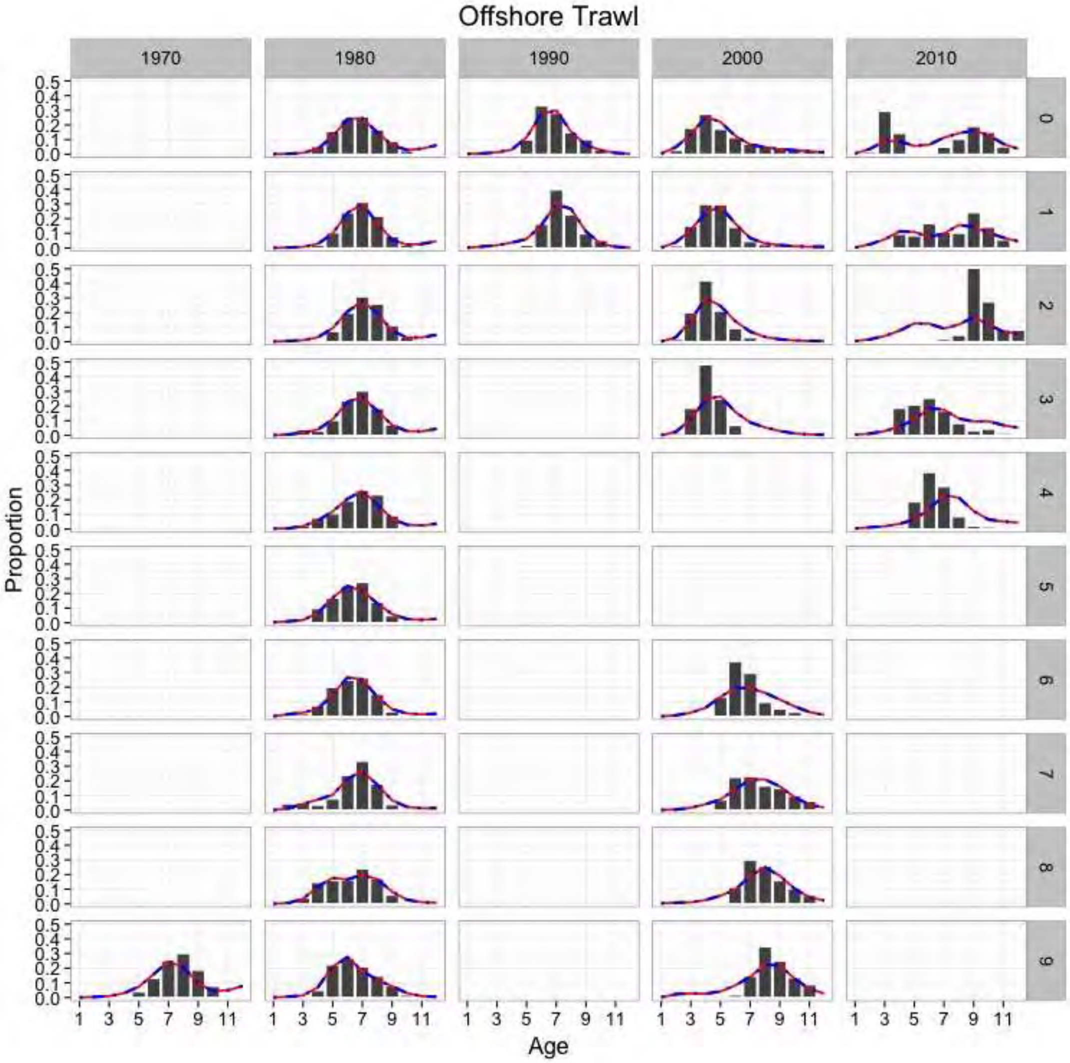

Fig. 6. Comparison fit catch at age of the Offshore Trawl (Fleet 4). Two scenarios of steepness, h=0.8 and h=0.65 (Model-1). Grey bars: observed values, red solid line: predicted values Model-1, and h=0.8; blue dotted line: predicted values Model-1, h=0.65.

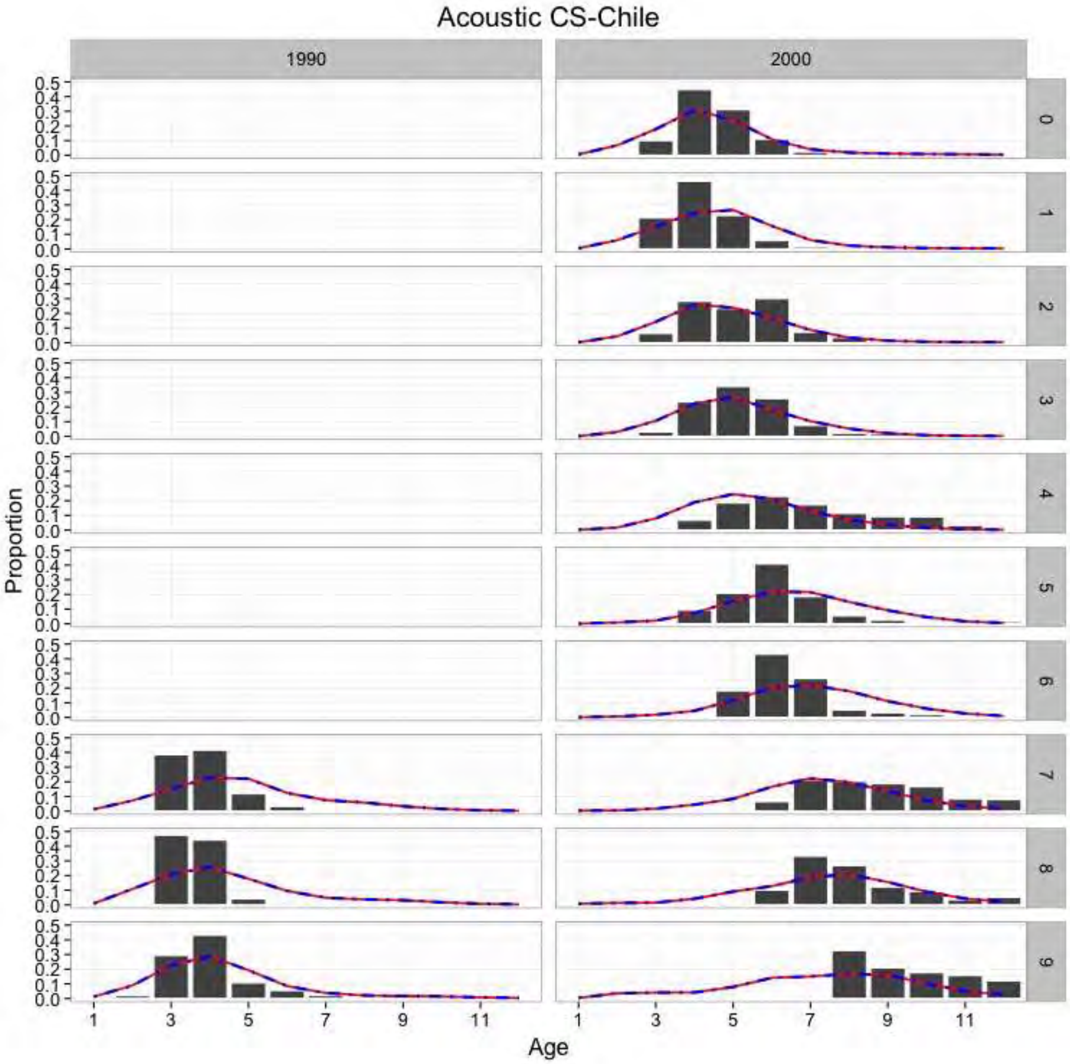

Fig. 7. Comparison fit catch at age of the Acoustic survey - central South Chile. Two scenarios of steepness, *h*=0.8 and *h*=0.65 (Model-1). Grey bars: observed values, red solid line: predicted values Model-1, and *h*=0.8; blue dotted line: predicted values Model-1, *h*=0.65.

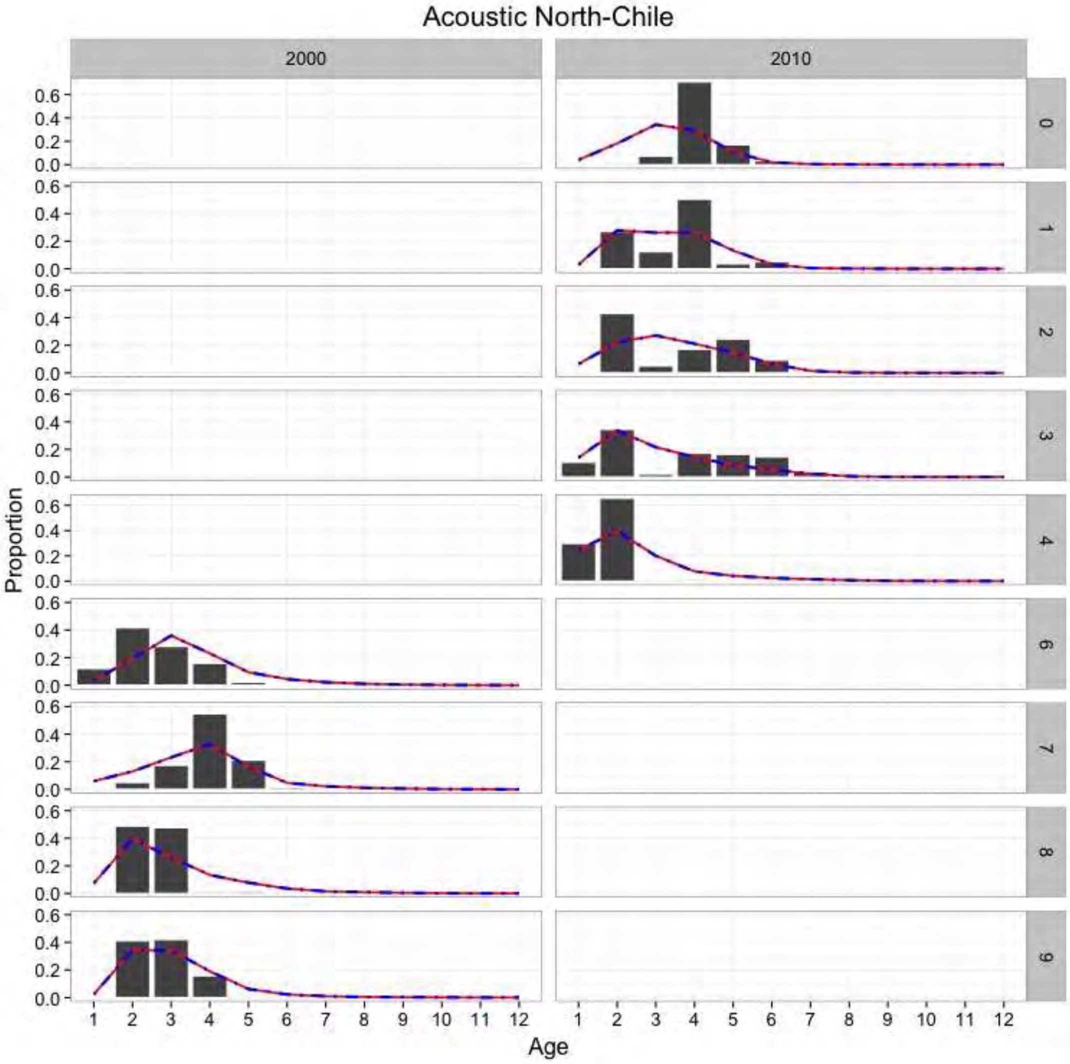

Fig. 8. Comparison fit catch at age of the Acoustic survey – North - Chile. Two scenarios of steepness, *h*=0.8 and *h*=0.65 (Model-1). Grey bars: observed values, red solid line: predicted values Model-1, and *h*=0.8; blue dotted line: predicted values Model-1, *h*=0.65.

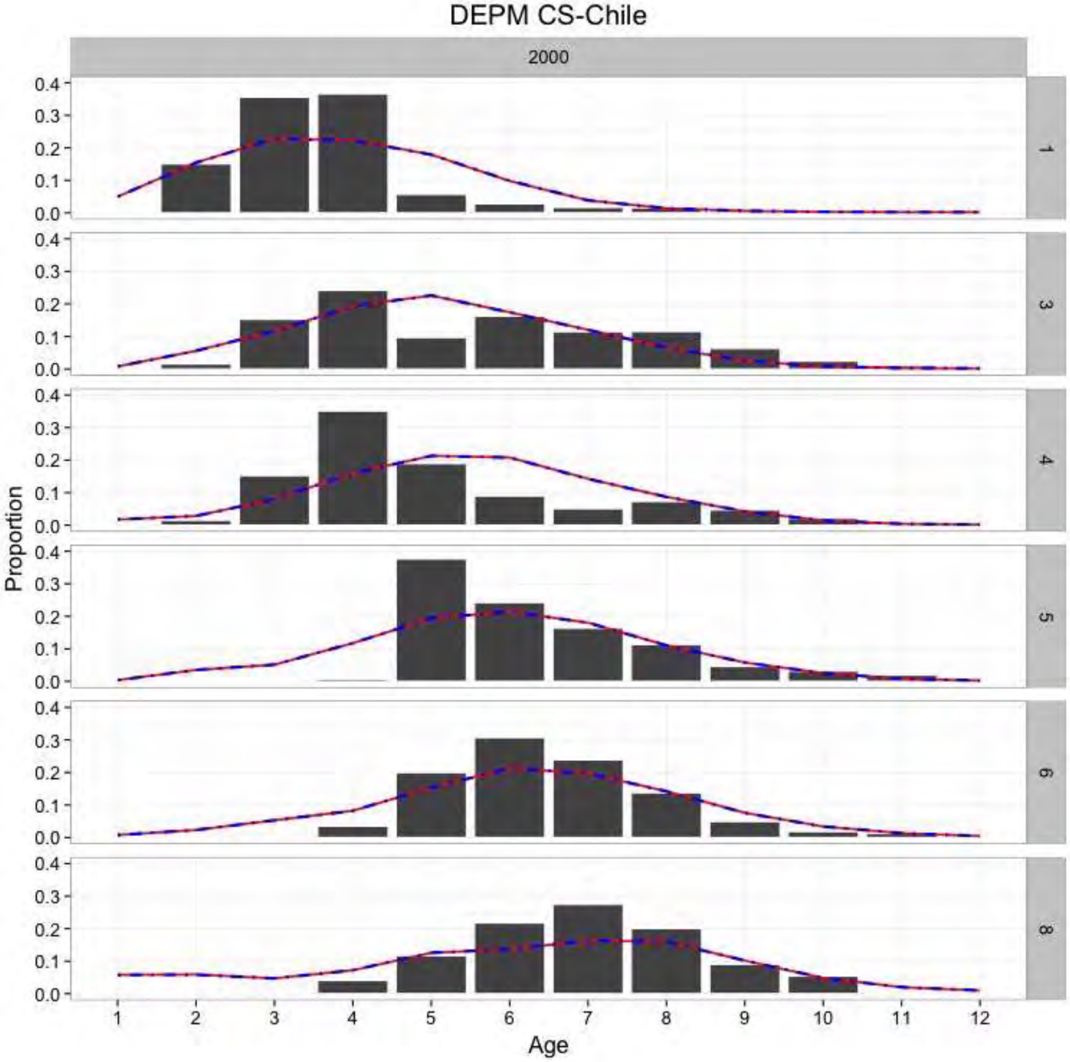

Fig. 9. Comparison fit catch at age of the DEPM – Central south Chile. Two scenarios of steepness, h=0.8 and h=0.65 (Model-1). Grey bars: observed values, red solid line: predicted values Model-1, and h=0.8; blue dotted line: predicted values Model-1, h=0.65.

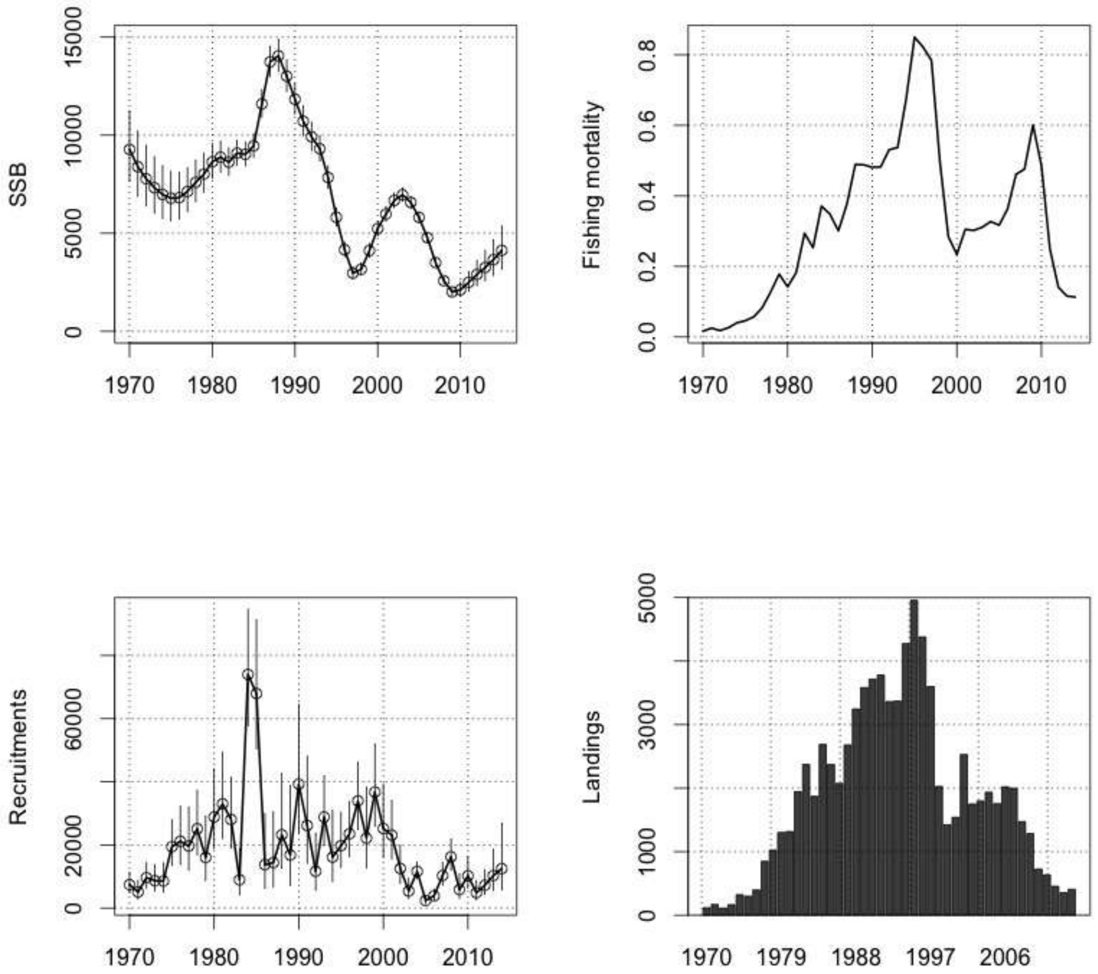

Fig. 10. Summary estimates of the population of jack mackerel 1970-2014. Model-1, *h*=0.8. Spawning biomass (SSB): 1000 t, Fishing mortality: year $^{-1}$, Recruitments: 10^9 number and Landings: 1000 t.

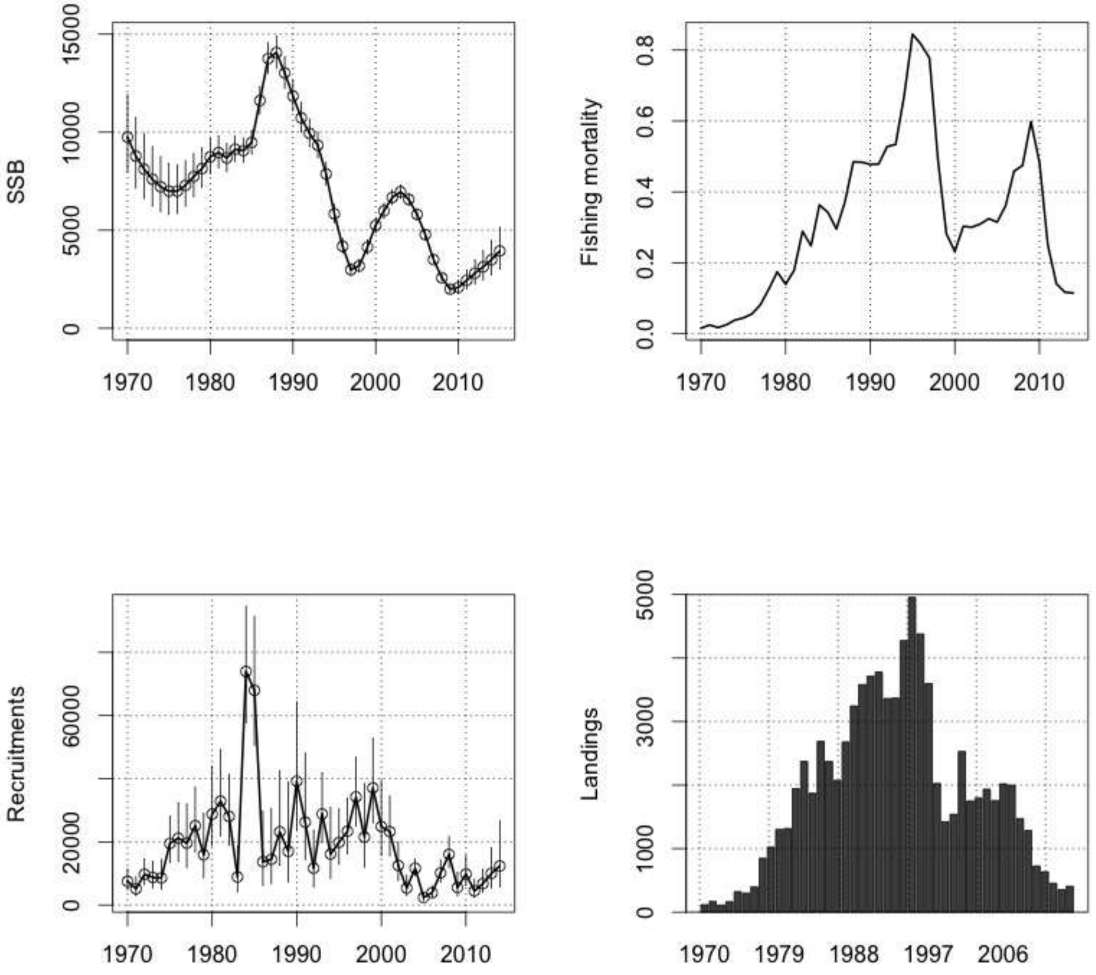

Fig. 11. Summary estimates of the population of jack mackerel 1970-2014. Model-1, *h*=0.65. Spawning biomass (SSB): 1000 t, Fishing mortality: year $^{-1}$, Recruitments: 10^9 number and Landings: 1000 t.

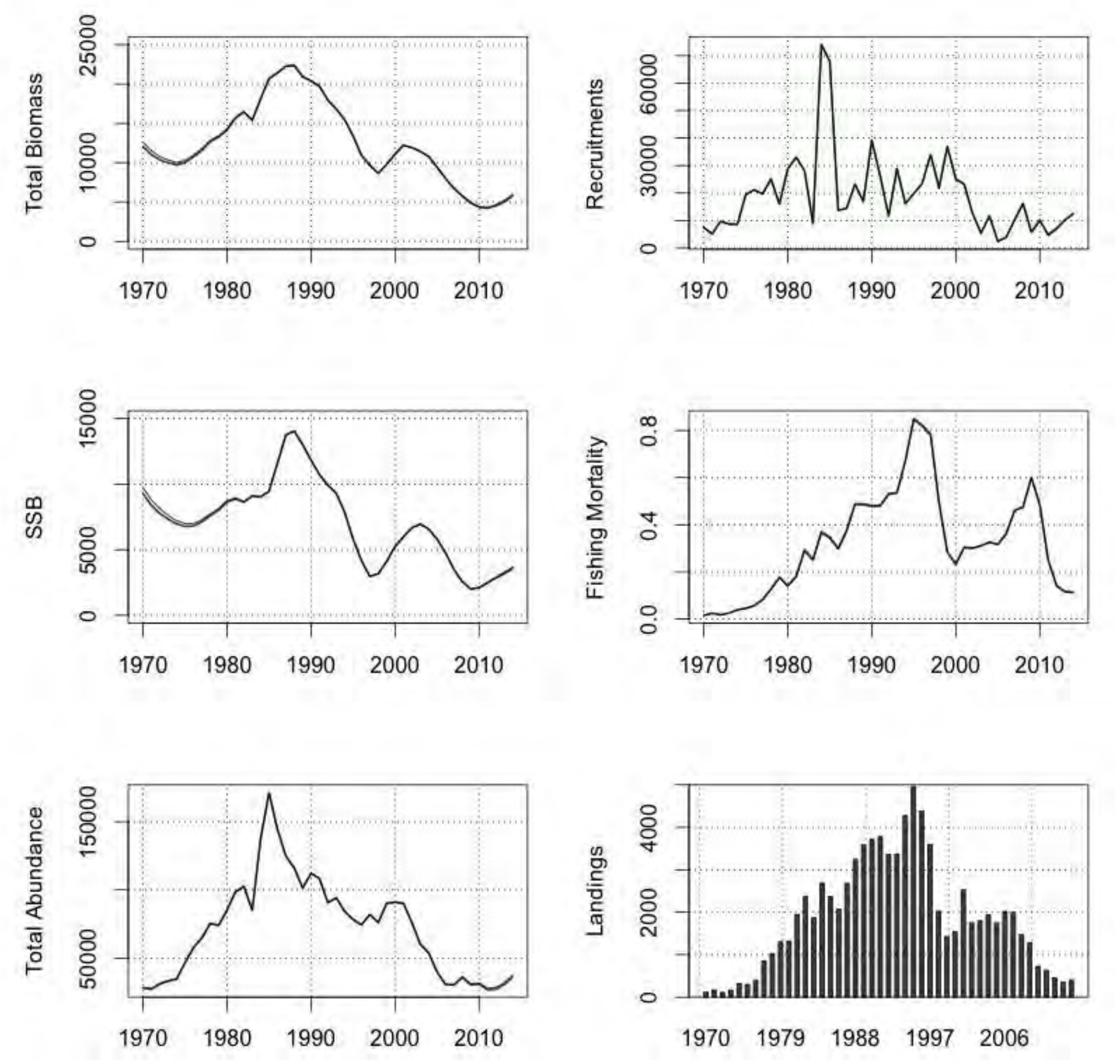

Fig. 12. Comparison of population estimates of Jack mackerel from Model 1, *h*=0.8 (dark green line) and Model-1, *h*=0.65 (black line) (1970 to 2014). Total Biomass: 1000 t, Spawning biomass (SSB): 1000 t, Total Abundance: 10^9 number, Recruitments: 10^9 number, Fishing mortality: year $^{-1}$, and Landings: 1000 t.

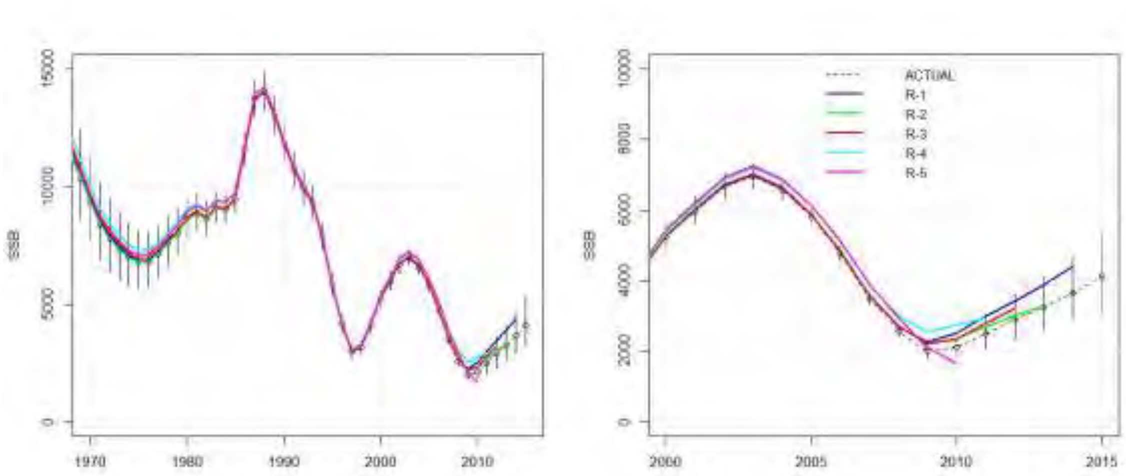

Fig. 13. Retrospective analysis in Jack mackerel stock assessment. Absolute changes in spawning biomass. Vertical lines represent the 95% confidence internals for the last year assessment.

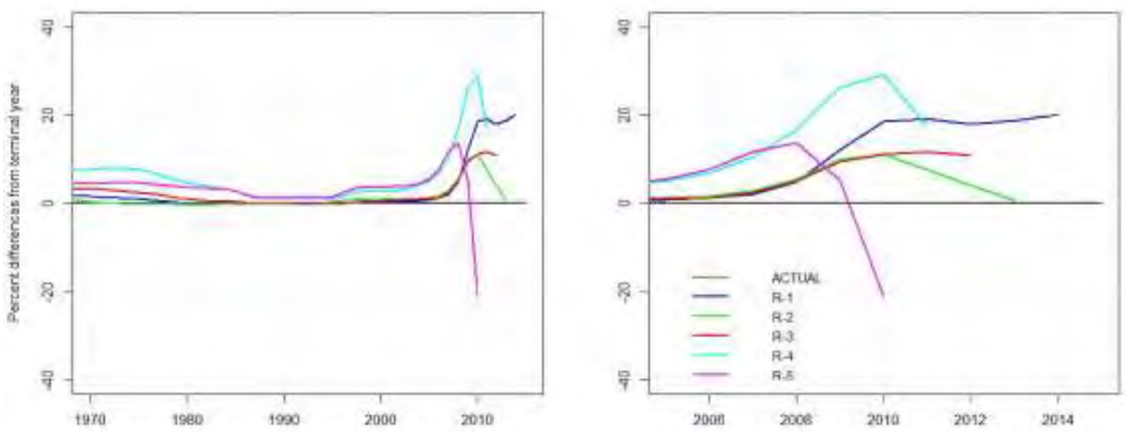

Fig. 14. Retrospective analysis in Jack mackerel stock assessment. Relative differences of spawning biomass in each year to the terminal year estimates.

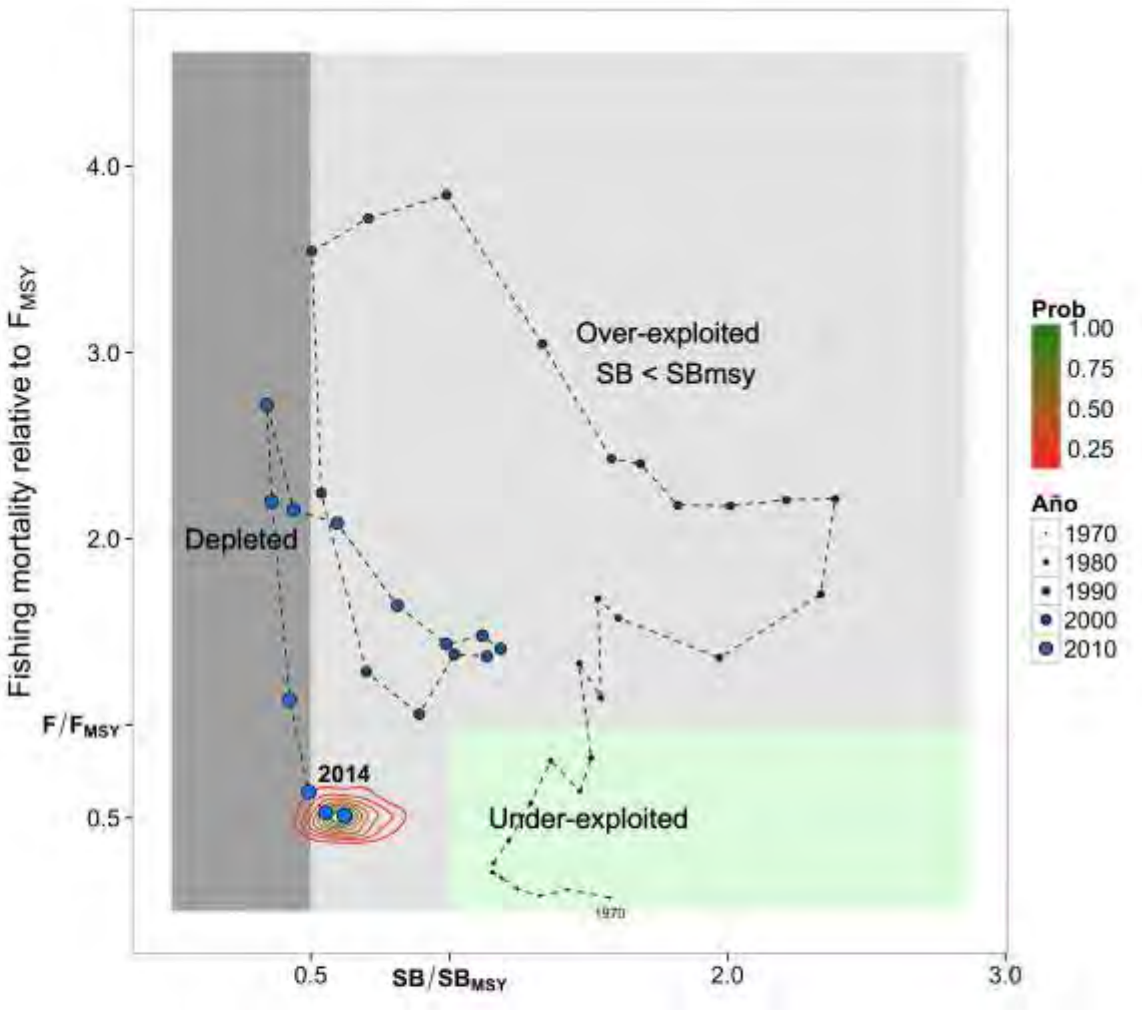

Fig. 15. Kobe diagram of the Jack mackerel Status (Model 1, *h*=0.8). Lines show the confidence region (90%) for spawning biomass and fishing mortality on year 2014. SB=spawning biomass (Dark grey area: depleted condition, light grey area: over-exploited condition, light green area: under-exploited condition of the stock).

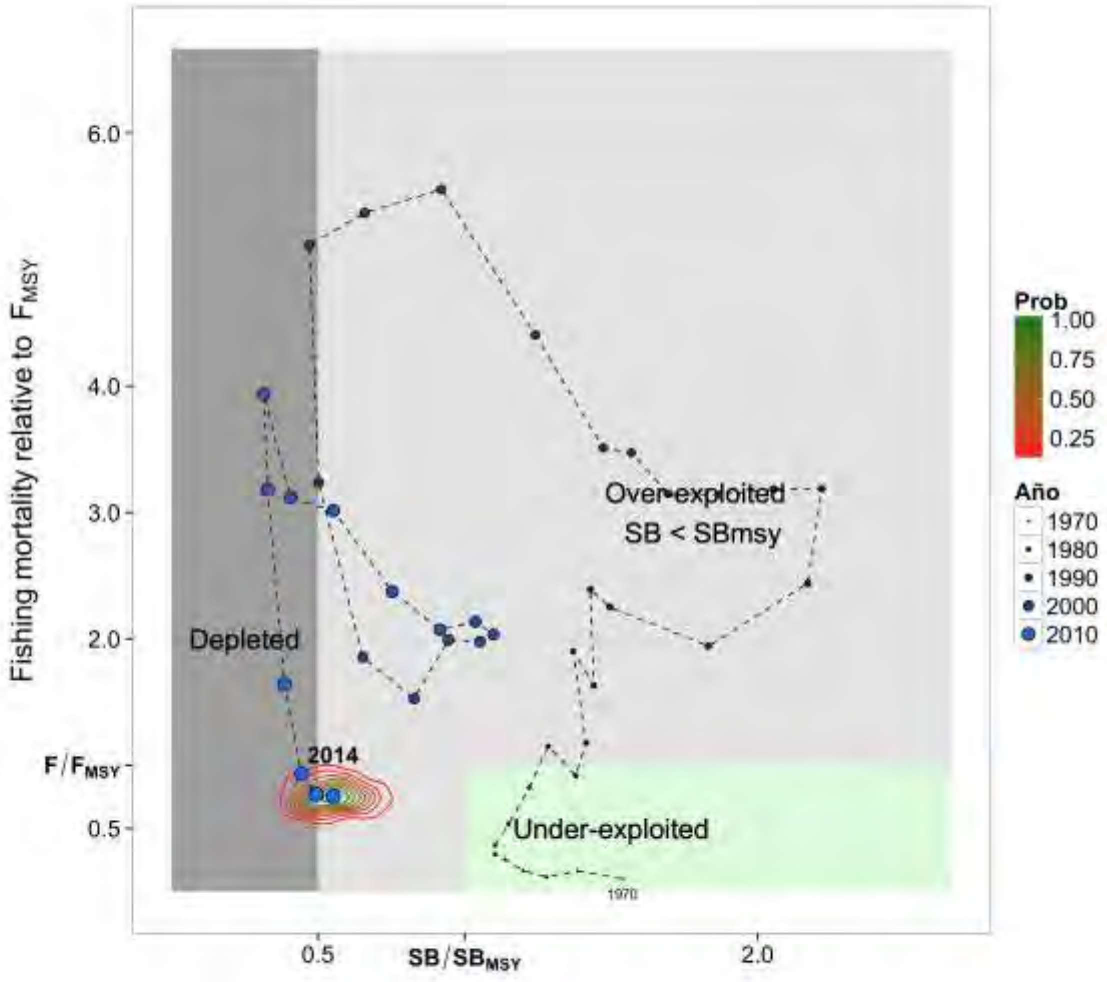

Fig. 16. Kobe diagram of Jack mackerel Status (Model 1, *h*=0.65). Lines show the confidence region (90%) for spawning biomass and fishing mortality on year 2014. SB=spawning biomass. (Dark grey area: depleted condition, light grey area: over-exploited condition, light green area: under-exploited condition of the stock).

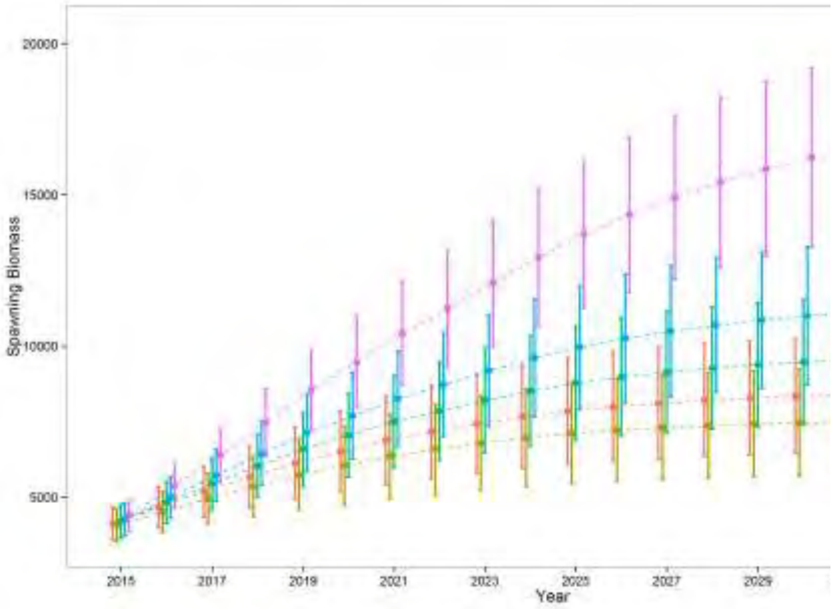

Fig. 17. Scenario 1: Projection of spawning biomass of jack mackerel 2015-2034 (Model 1, *h*=0.80, Rmed=1970-2012). F constant= fishing mortality (F) is equal to the value in 2014; 125%*F= fishing mortality is increased in a 25%; 50%*F= fishing mortality is reduced in a 50%; 75%*F= fishing mortality (F) is reduced in a 75%, and M= natural mortality operates and F=0.

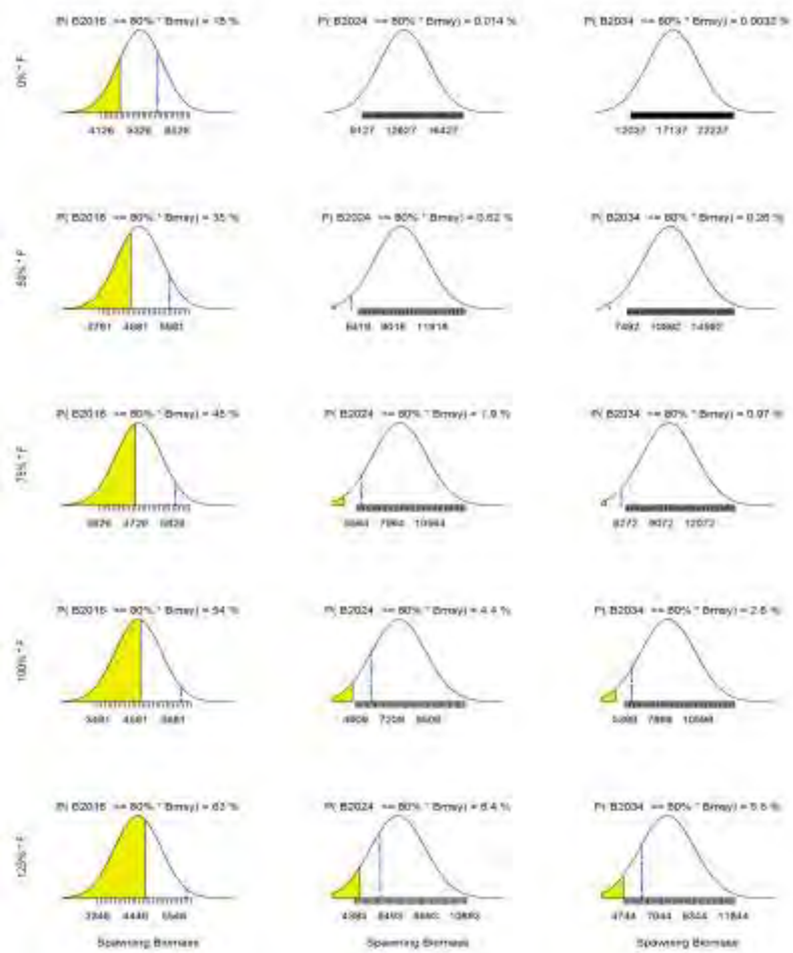

Fig. 18. Scenario 1: Probability distribution of the spawning biomass (Model 1, *h*=0.80, Rmed=1970-2012) in the years 2016, 2024 and 2034 (Vertical). The yellow color indicates the probability of the spawning biomass to fall below the 80%B*msy* and the blue line below the B*msy*. Horizontal: 0%*F = F=0; 50%*F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%; 100%*F= F was kept equal to the value estimated in 2014. 125%*F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the risk (%) to be below 80%B*msy* for each year and level of F.

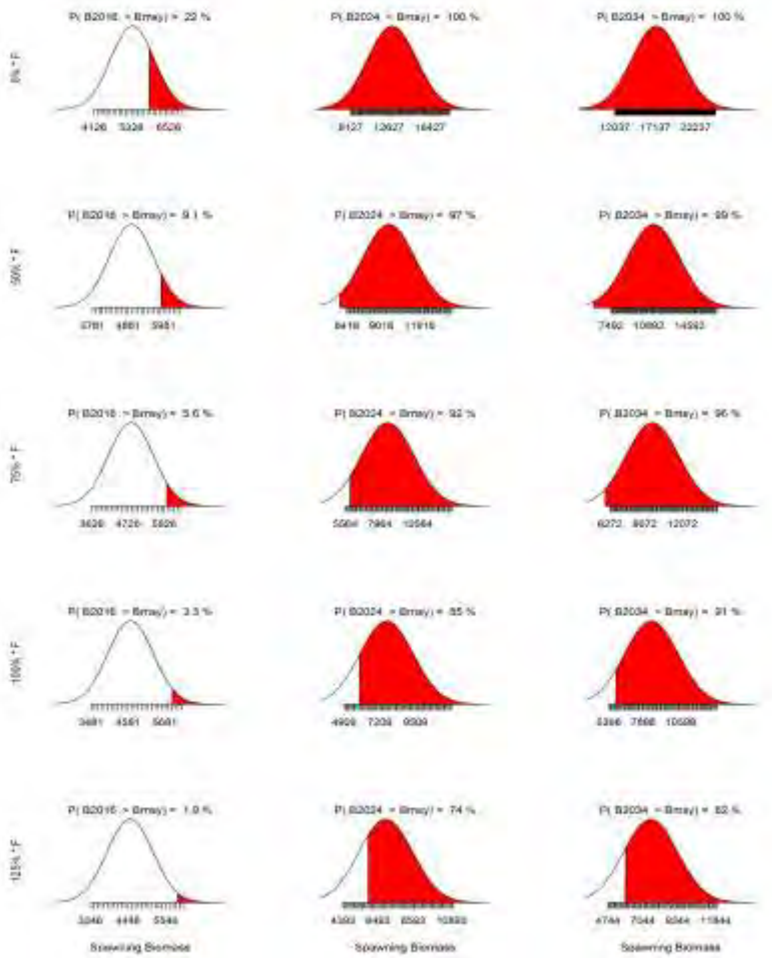

Fig. 19. Scenario 1: Probability distribution of the spawning biomass (Model 1, *h*=0.80, Rmed=1970-2012) in the years 2016, 2024 and 2034 (Vertical). The red color indicates the probability of the spawning biomass to recover over B*msy*. Horizontal: 0%*F = F=0; 50%*F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%; 100%*F= F was kept equal to the value estimated in 2014. 125%*F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the probability (%) to be located over B*msy* for each year and level of F.

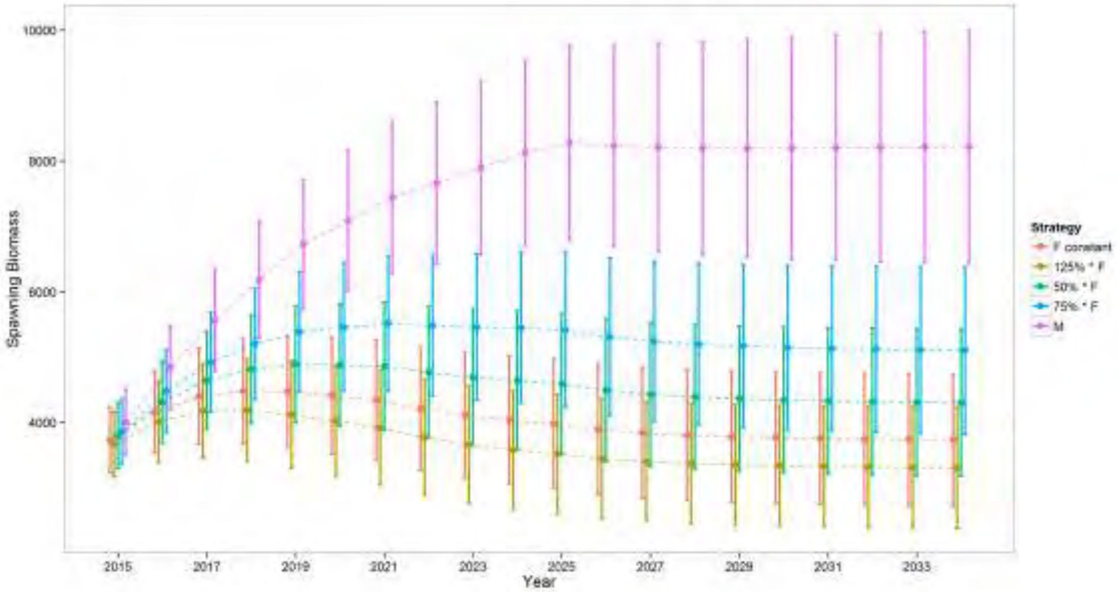

Fig. 20. Scenario 2: Projection of spawning biomass of jack mackerel 2015-2034 (Model 1, *h*=0.80, Rmed=2000-2012). F constant= fishing mortality (F) is equal to the value in 2014; 125%*F= F in 2014 is increased in a 25%; 50%*F= F in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%, and M= natural mortality operates and F=0.

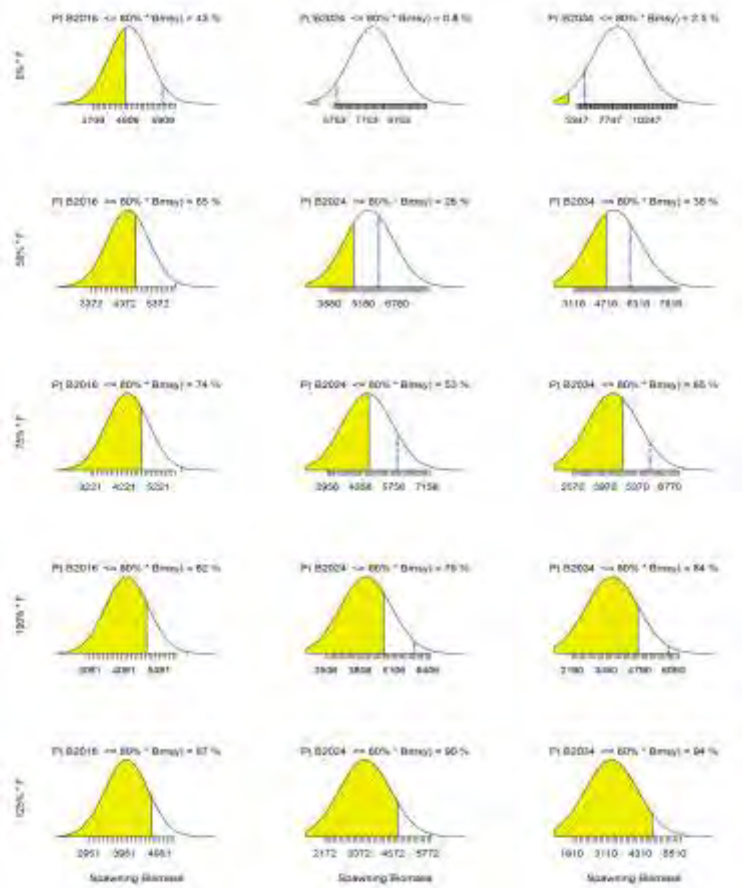

Fig. 21. Scenario 2: Probability distribution of the spawning biomass (Model 1, *h*=0.80, Rmed=2000-2012) in the years 2016, 2024 and 2034 (Vertical). The yellow color indicates the probability of the spawning biomass to fall below the 80%B*msy* and the blue line to fall below the B*msy*. Horizontal: 0%*F = F=0; 50%*F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%; 100%*F= F was kept equal to the value estimated in 2014. 125%*F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the risk (%) to be below 80%B*msy* in each year and level of F.

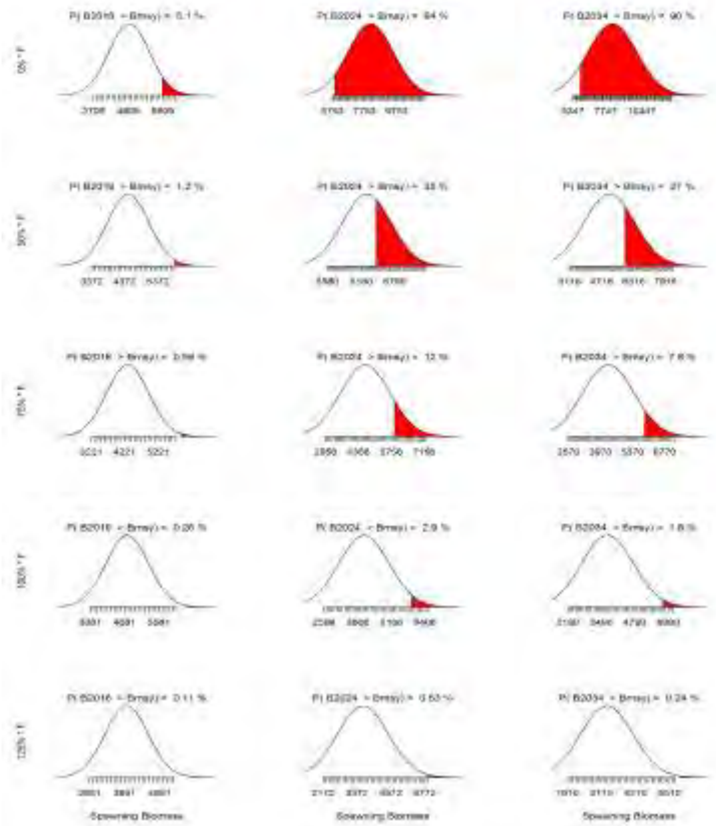

Fig. 22. Scenario 2: Probability distribution of the spawning biomass (Model 1, *h*=0.80, Rmed=2000-2012) in the years 2016, 2024 and 2034 (Vertical). The red color indicates the probability of the spawning biomass to recover over B*msy*. Horizontal: 0%*F = F=0; 50%*F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%; 100%*F= F was kept equal to the value estimated in 2014. 125%*F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the risk (%) to be located over B*msy* in each year and level of F.

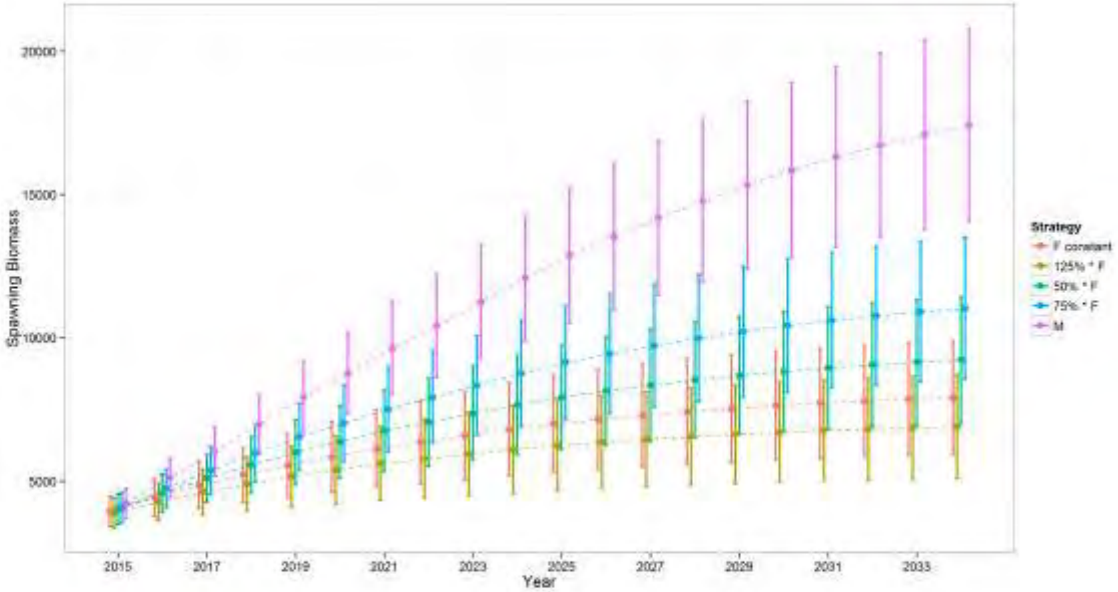

Fig. 23. Scenario 3: Projection of spawning biomass of jack mackerel 2015-2034 (Model 1, *h*=0.65, Rmed=1970-2012). F constant= fishing mortality (F) is equal to the value in 2014; 125%*F= F in 2014 is amplified in a 25%; 50%*F= F in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%, and M= natural mortality operates and F=0.

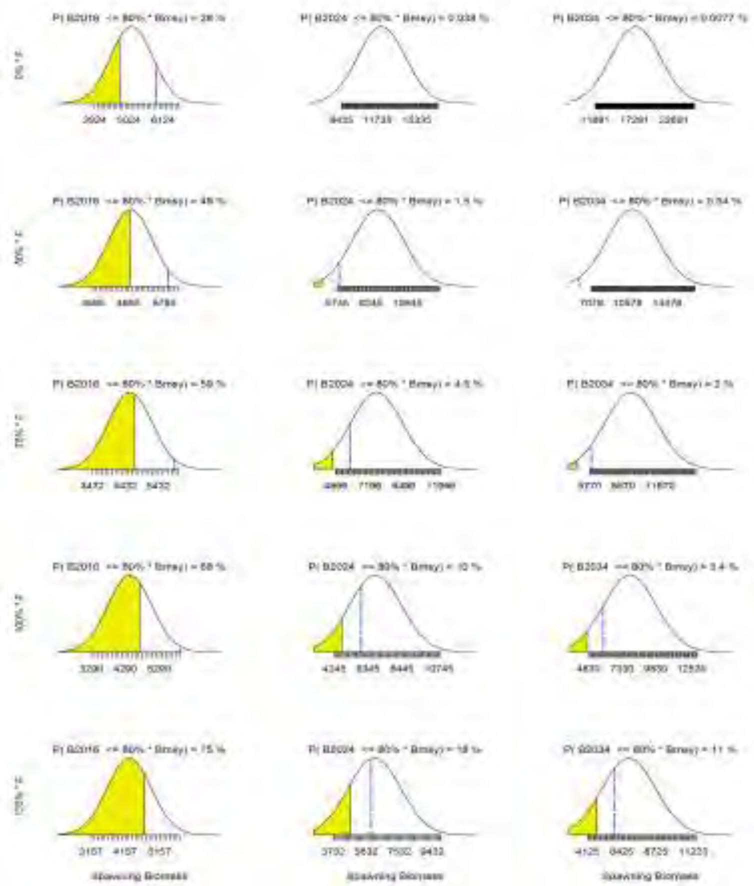

Fig. 24. Scenario 3: Probability distribution of the spawning biomass (Model 1, *h*=0.65, Rmed=1970-2012) in the years 2016, 2024 and 2034 (Vertical). The yellow color indicates the probability of the spawning biomass to be located below the 80%B*msy* and the blue line to be located below the B*msy*. Horizontal: 0%∗F = F=0; 50%∗F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%∗F= F in 2014 is reduced in a 75%; 100%∗F= F was kept equal to the value estimated in 2014. 125%∗F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the risk (%) to be below 80%B*msy* in each year and level of F.

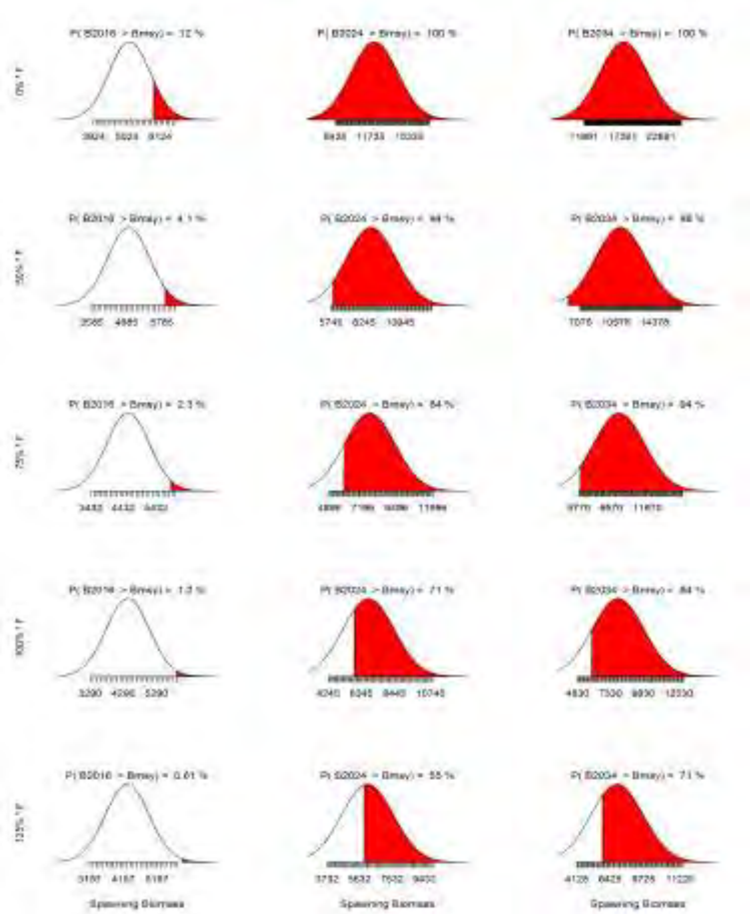

Fig. 25. Scenario 3: Probability distribution of the spawning biomass (Model 1, *h*=0.65, Rmed=1970-2012) in the years 2016, 2024 and 2034 (Vertical). The red color indicates the probability of the spawning biomass to be above of B*msy.* Horizontal: 0%*F = F=0; 50%*F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%; 100%*F= F was kept equal to the value estimated in 2014. 125%*F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the risk (%) to be located over B*msy* in each year and level of F.

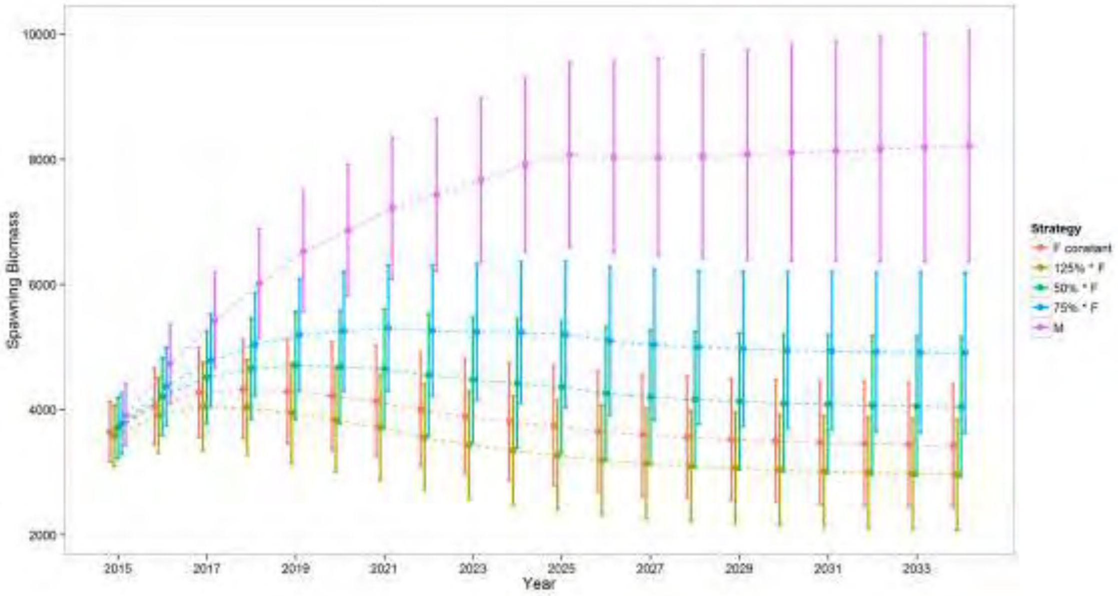

Fig. 26. Scenario 4: Projection of spawning biomass of jack mackerel 2015-2034 (Model 1, *h*=0.65, Rmed=2000-2012). F constant= fishing mortality (F) is equal to the value in 2014; 125%*F= F in 2014 was amplified in a 25%; 50%*F= F in 2014 is reduced in 50%; 75%*F= F in 2014 is reduced in 75%, and M= natural mortality operates and F=0.

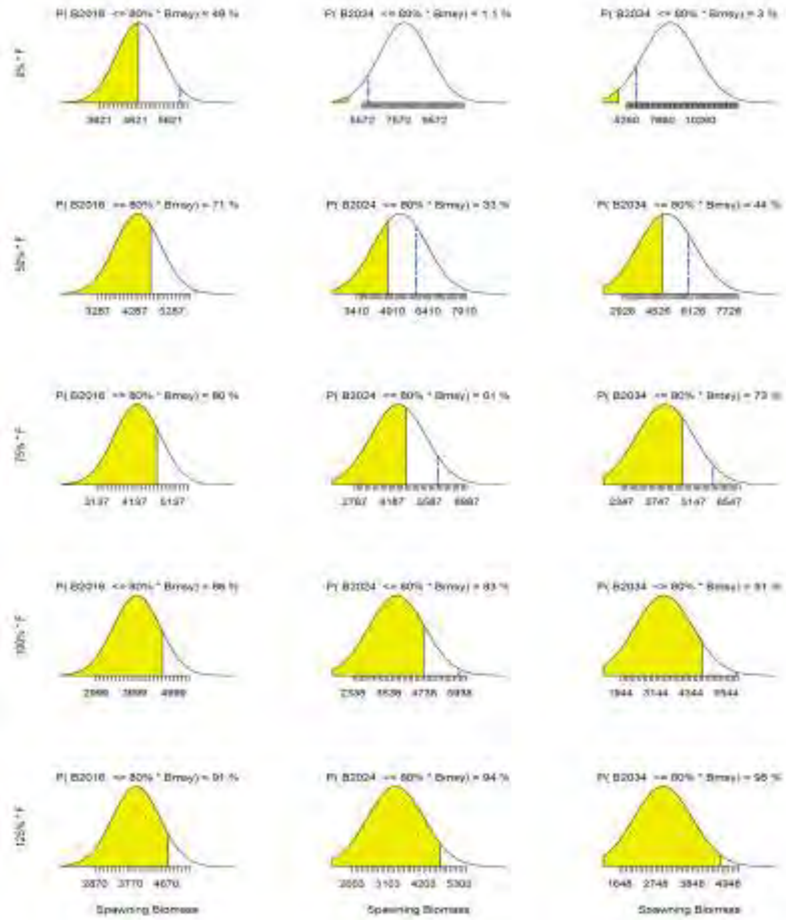

Fig. 27. Scenario 4: Probability distribution of the spawning biomass (Model 1, *h*=0.65, Rmed=2000-2012) in the years 2016, 2024 and 2034 (Vertical). The yellow color indicates the probability of the spawning biomass to be located below the 80%B*msy* and the blue line to be located below the B*msy*. Horizontal: 0%∗F = F=0; 50%∗F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%∗F= F in 2014 is reduced in a 75%; 100%∗F= F was kept equal to the value estimated in 2014. 125%∗F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the risk (%) to be below 80%B*msy* in each year and level of F.

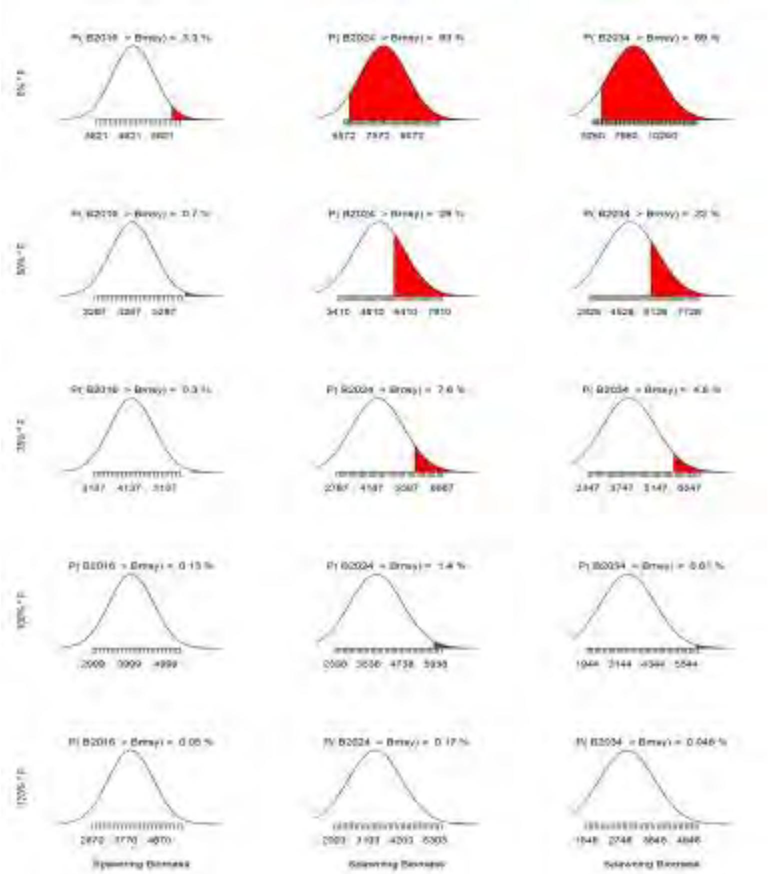

Fig. 28. Scenario 4: Probability distribution of the spawning biomass (Model 1, *h*=0.65, Rmed=2000-2012) in the years 2016, 2024 and 2034 (Vertical). The red color indicates the probability of the spawning biomass to be above of B*msy*. Horizontal: 0%*F = F=0; 50%*F = fishing mortality (F) value in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%; 100%*F= F was kept equal to the value estimated in 2014. 125%*F= F in 2014 is increased in a 25%. X-axis corresponds to the spawning biomass (x10^3 t). Notice that each title in each graph contains the risk (%) to be located over B*msy* in each year and level of F.

ANNEX 2: TABLES

Table 1. Input catch data (1000 t) of Jack mackerel from the South-Eastern Pacific. (Fleet 1: Northern Chile, Fleet 2: Central-south Chile, Fleet 3: Far North - Peru, Fleet 4: Offshore Trawl).

Year	Fleet 1	Fleet 2	Fleet 3	Fleet 4
1970	101.685	10.309	4.711	0.000
1971	143.454	14.988	9.189	0.000
1972	64.457	22.546	18.782	5.500
1973	83.204	38.391	42.781	0.000
1974	164.762	28.750	129.211	0.000
1975	207.327	53.878	37.899	0.000
1976	257.698	84.571	54.154	0.035
1977	226.234	114.572	504.992	2.273
1978	398.414	188.267	386.793	51.290
1979	344.051	253.460	333.810	370.290
1980	288.809	273.453	414.299	339.802
1981	474.817	586.092	445.638	438.123
1982	789.912	704.771	143.724	733.204
1983	301.934	563.338	110.690	894.300
1984	727.000	699.301	200.674	1,059.927
1985	511.150	945.839	114.622	799.323
1986	55.210	1,129.107	51.029	837.502
1987	313.310	1,456.727	46.304	863.423
1988	325.462	1,812.793	244.229	863.215
1989	338.600	2,051.517	316.247	875.821
1990	323.089	2,148.786	370.823	872.059
1991	346.245	2,674.267	213.447	543.659
1992	304.243	2,907.817	111.682	37.932
1993	379.467	2,856.777	133.354	0.000
1994	222.254	3,819.193	233.346	0.000
1995	230.177	4,174.016	550.993	0.000
1996	278.439	3,604.887	495.518	0.000
1997	104.198	2,812.866	680.053	0.000
1998	30.273	1,582.639	412.846	0.000
1999	55.654	1,164.035	203.751	0.007
2000	118.734	1,115.565	303.700	2.318
2001	248.097	1,401.836	857.744	20.090
2002	108.727	1,410.266	154.823	76.261
2003	143.277	1,278.019	217.734	158.199
2004	158.656	1,292.943	187.369	295.443
2005	165.626	1,264.808	80.663	243.576
2006	155.256	1,224.685	277.568	362.627
2007	172.701	1,130.083	255.360	438.831
2008	167.258	728.850	169.537	406.986
2009	134.022	700.905	76.629	371.918
2010	169.012	295.796	22.172	239.593
2011	30.825	216.470	326.394	60.891
2012	13.256	214.204	187.396	39.918
2013	16.361	214.999	80.586	41.177
2014	18.230	254.280	74.530	62.720

Table 2. CPUE time series used in the stock assessment of jack mackerel. (Fleet 2: Central-south Chile, Fleet 3: Far North - Peru, Fleet 4: Offshore Trawl).

Year	Fleet 2 - Chile	Fleet 3 - Peru	Fleet 4 - China	Fleet 4 - EU	Fleet 4 - RUSSIA
1983	0.797				
1984	0.700				
1985	0.568				
1986	0.491				
1987	0.590				55.020
1988	0.493				58.240
1989	0.506				51.060
1990	0.401				52.570
1991	0.497				60.990
1992	0.419				
1993	0.368				
1994	0.441				
1995	0.392				
1996	0.408				
1997	0.362				
1998	0.347				
1999	0.401				
2000	0.382				
2001	0.473		1.400		
2002	0.416	212.7	1.97		
2003	0.365	244.1	1.740		
2004	0.397	276.6	1.44		
2005	0.363	193.2	1.44		
2006	0.398	245.9	1.02	310	
2007	0.302	231.0	1.13	308	
2008	0.204	222.6	0.86	256	77.419
2009	0.167	184.1	0.81	209	59.563
2010	0.120	255.4	0.57	124	
2011	0.069	264.9	0.33	57	45.213
2012	0.217	264.7	0.37		
2013	0.162	139.3	0.58	81	
2014	0.135	240.4			

Table 3. Catch age-structure Fleet 1 (North Chile) 1975 – 2014 (numbers 10^9).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0	4,073	13,776	44,143	60,659	166,146	171,002	81,053	29,641	8,253	4,552	1,070
1976	0	27	1,676	10,342	62,211	190,616	229,530	109,553	17,356	4,612	104	0
1977	122	12,767	20,036	48,155	149,760	239,459	184,136	68,069	10,018	155	0	0
1978	0	5,910	92,821	171,908	149,947	99,992	274,829	227,407	75,025	11,649	99	0
1979	0	0	40,320	104,406	202,313	247,236	261,704	212,251	72,124	7,503	87	0
1980	0	5,663	19,209	39,611	120,365	158,767	188,736	133,955	25,201	792	0	0
1981	0	0	17,592	107,026	226,852	272,757	332,572	167,387	32,014	4,135	31	0
1982	0	1,674	29,021	332,623	362,536	484,944	639,872	367,034	127,157	21,795	225	0
1983	0	102	1,966	49,812	151,839	222,327	205,704	103,468	21,178	556	27	0
1984	0	4,148	232,259	599,923	284,517	284,809	377,052	318,705	67,881	4,009	0	0
1985	0	886	53,397	255,301	400,091	427,340	252,577	73,876	12,239	1,256	0	0
1986	4,646	15,143	14,153	8,069	9,791	17,324	26,790	15,727	6,358	1,078	0	0
1987	940	69,685	612,169	638,980	149,771	36,285	27,361	8,978	428	431	16	0
1988	0	3,652	130,324	489,772	452,240	105,585	5,445	647	14	0	0	0
1989	0	7,901	4,867	43,820	326,596	271,953	55,735	9,161	2,786	295	47	0
1990	6,262	77,422	5,668	27,866	236,685	412,335	84,292	8,079	388	94	3	0
1991	21	17,154	218,253	217,953	121,225	180,648	259,236	64,615	5,402	5,551	1,113	542
1992	1,787	30,253	252,037	142,917	268,721	274,311	149,879	60,020	8,877	790	39	0
1993	2,413	66,476	1,485,903	597,010	115,335	99,352	19,235	7,088	2,161	730	123	77
1994	431	139,526	339,253	101,904	266,129	131,505	23,152	3,211	1,618	68	0	0
1995	2,315	170,501	345,192	296,965	146,207	84,328	17,213	801	82	0	0	0
1996	131,844	269,877	533,140	572,880	155,446	30,636	7,068	63	68	0	0	0
1997	191	26,244	307,207	204,870	23,575	694	72	0	0	0	0	0
1998	0	3,406	89,297	37,875	18,933	5,847	285	1	0	0	0	0
1999	38	24,289	319,634	75,711	15,598	5,394	392	7	0	0	0	0
2000	57,122	235,887	136,283	236,690	110,317	15,424	39	0	0	0	0	0
2001	1,568	256,795	1,326,138	491,732	25,070	1,848	0	0	0	0	0	0
2002	48,483	98,920	391,463	176,981	92,150	18,789	4,497	276	26	0	0	0
2003	7,504	158,188	604,518	242,543	53,916	21,616	9,440	1,894	295	0	0	0
2004	747	17,164	103,070	464,915	191,312	7,389	275	0	0	0	0	0
2005	43,804	324,087	476,065	193,396	151,443	43,843	5,150	0	0	0	0	0
2006	27,386	38,392	390,068	607,711	68,098	25,256	8,161	1,256	49	0	0	0
2007	681	93,552	346,671	475,258	113,550	27,460	17,712	7,169	1,191	165	165	66
2008	14,499	712,726	359,139	117,862	138,886	110,359	12,931	844	191	41	0	0
2009	569	58,921	250,894	432,581	34,649	70,639	3,089	78	0	0	0	0
2010	4	524,298	57,658	360,130	140,820	36,448	9,825	1,044	506	146	0	0
2011	20,901	199,846	94,185	11,650	3,387	5,921	383	0	0	0	0	0
2012	2,080,455	6,700,598	8,465,934	34,863,481	4,648,381	106,332	0	0	0	0	0	0
2013	5,232,401	86,320,606	33,345,959	861,630	357,301	415,201	245,386	34,652	14,421	0	0	0
2014	3,726,116	61,365,991	27,398,847	8,823,215	4,763,121	790,779	35,958	6,085	0	0	0	0

Table 4. Catch age-structure of the Fleet 2 (Central South Chile) 1975 – 2014 (numbers 10^9).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1975	0	0	355	633	2,259	7,108	11,305	10,032	5,551	1,867	999	190
1976	0	1,272	364	353	1,550	17,545	45,885	38,920	18,306	2,707	37	0
1977	1	223	462	5,493	19,717	34,341	61,594	47,567	7,128	684	70	4
1978	0	595	4,226	20,574	70,250	115,605	96,857	45,404	12,171	1,330	0	0
1979	0	20	13,439	147,552	206,176	210,012	208,192	180,490	120,831	48,163	4,206	904
1980	2,152	3,996	8,314	128,820	322,829	356,395	311,998	166,713	78,325	17,706	686	995
1981	0	2,419	8,973	83,655	392,031	696,981	627,159	326,988	99,193	23,220	3,581	800
1982	1,324	4,221	8,889	118,067	618,244	826,235	877,968	626,789	224,844	57,471	10,391	13,914
1983	1,624	98,937	191,076	314,984	749,070	1,084,641	1,113,032	548,218	207,964	30,697	3,760	1,259
1984	98	7,977	190,091	357,918	447,250	985,396	1,175,198	851,961	292,315	38,931	7,977	394
1985	53	889	39,763	372,792	621,888	1,131,123	1,405,139	725,890	182,303	21,926	2,839	2,111
1986	7,703	32,892	50,408	254,334	720,436	1,125,301	1,563,727	833,125	141,461	12,640	1,048	651
1987	8,538	240,224	509,673	459,902	311,739	907,439	1,929,691	1,290,613	257,500	39,754	3,890	922
1988	442	23,756	228,313	1,415,721	1,662,909	665,913	1,203,766	1,215,469	405,628	50,539	6,623	114
1989	0	5,570	34,610	283,575	1,634,407	2,293,278	1,376,907	1,070,507	406,813	64,106	1,490	0
1990	248	5,228	1,826	31,608	506,751	1,598,666	2,003,162	1,148,443	668,436	128,313	8,666	130
1991	54	30,081	134,146	122,717	56,100	419,889	1,682,863	1,831,750	982,207	504,943	158,725	46,297
1992	0	0	71,389	186,534	321,697	367,160	405,356	1,258,212	1,072,392	952,609	406,683	151,907
1993	0	11,391	231,606	759,545	940,331	854,977	790,767	758,606	893,719	721,295	259,075	41,588
1994	0	21,702	87,328	808,441	1,200,387	1,266,242	802,876	692,317	1,102,792	853,702	284,938	26,970
1995	760	9,375	365,691	1,727,987	1,350,915	2,318,999	1,687,597	807,698	562,790	385,464	170,813	31,602
1996	3,354	48,674	835,128	1,041,899	1,421,658	1,327,055	1,172,716	792,734	374,612	171,145	70,209	20,378
1997	7,893	191,472	1,428,562	2,627,586	1,898,630	906,334	488,229	377,039	302,621	132,121	75,881	42,083
1998	25,251	242,671	1,516,538	1,864,189	763,106	345,371	165,969	178,113	173,183	79,161	32,019	13,170
1999	2,407	190,107	1,825,090	1,676,166	718,361	267,024	76,733	34,947	59,069	54,516	34,827	28,903
2000	780	46,357	597,816	1,633,359	1,015,296	412,689	115,221	42,928	47,268	58,944	37,371	31,373
2001	3	32,966	361,663	970,229	1,270,037	594,890	184,069	82,580	61,986	57,150	47,079	76,019
2002	3,553	44,875	395,001	846,794	853,666	522,140	191,428	97,160	80,106	76,745	63,094	99,435
2003	5	16,651	232,038	908,724	1,101,223	740,572	303,108	100,321	77,824	61,641	37,835	38,325
2004	0	1,617	128,611	449,306	920,244	917,951	422,033	156,434	98,973	58,716	27,757	30,207
2005	14,398	15,576	14,953	145,195	460,828	1,047,649	518,471	208,577	141,084	66,743	28,283	32,878
2006	401	4,986	11,959	82,227	150,385	390,459	490,794	255,963	191,215	127,571	67,970	60,057
2007	0	260	26,043	250,100	293,211	206,428	282,545	280,026	242,885	165,923	92,414	86,474
2008	6,542	23,768	1,806	6,768	74,663	237,017	215,953	168,781	124,776	104,046	55,045	100,625
2009	0	1,581	43,860	108,580	22,418	222,409	250,865	193,736	120,657	77,999	55,350	47,561
2010	0	1,799	24,389	176,203	122,711	59,484	63,728	38,970	55,112	40,186	12,155	13,967
2011	0	29	3,626	55,109	45,036	121,204	33,101	20,726	45,281	16,068	3,724	4,334
2012	0	0	0	33,833	151,629	151,544	85,613	34,624	20,360	3,061	842	834
2013	2,000	40,778	12,467,295	101,991,694	162,856,221	181,274,927	78,563,279	14,567,793	2,215,252	980,360	171,018	459,068
2014	149,950	1,068,084	12,787,928	46,238,563	109,660,285	111,079,109	99,304,853	48,000,998	13,232,481	4,157,327	1,653,121	1,232,270

Table 5. Catch age-structure of the Fleet 4 (Offshore Trawl) (numbers 10^9).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1975												
1976												
1977												
1978												
1979	0	0	49	1905	20679	69124	1E+05	2E+05	97437	40291	3780	904
1980	0	3842	4615	38803	1E+05	2E+05	2E+05	1E+05	64819	17129	686	995
1981	0	239	2919	18545	99141	2E+05	3E+05	2E+05	75791	19940	3221	800
1982	0	2756	1078	9883	1E+05	3E+05	5E+05	4E+05	2E+05	45982	10106	13829
1983	0	55448	99493	73750	3E+05	6E+05	8E+05	5E+05	2E+05	28049	3760	1259
1984	0	2428	53471	2E+05	2E+05	4E+05	6E+05	5E+05	2E+05	26780	7176	394
1985	0	539	20116	2E+05	3E+05	5E+05	6E+05	3E+05	96589	16896	2661	1840
1986	0	27483	33424	1E+05	4E+05	5E+05	5E+05	3E+05	62152	6636	748	651
1987	0	93104	1E+05	73668	2E+05	5E+05	7E+05	4E+05	79536	18316	2974	878
1988	0	12902	89058	3E+05	3E+05	4E+05	5E+05	4E+05	1E+05	23035	5183	114
1989	0	265	12357	1E+05	5E+05	6E+05	4E+05	3E+05	2E+05	35858	1293	0
1990	0	536	316	10917	2E+05	6E+05	5E+05	3E+05	2E+05	56477	5452	130
1991	0	3175	4982	9073	21237	2E+05	4E+05	2E+05	1E+05	57856	22617	9811
1992												
1993												
1994												
1995												
1996												
1997												
1998												
1999												
2000	6306	137881	9E+05	1E+06	9E+05	6E+05	4E+05	3E+05	3E+05	2E+05	1E+05	0
2001	0	934657	9E+06	2E+07	2E+07	9E+06	3E+06	1E+06	1E+06	6E+05	3E+05	0
2002	4000081	5531716	7E+07	1E+08	7E+07	3E+07	9E+06	4E+06	3E+06	1E+06	4E+05	0
2003	0	6341275	9E+07	2E+08	1E+08	3E+07	3E+06	3E+05	12549	0	0	0
2004												
2005												
2006	0	0	16612	4E+06	5E+07	1E+08	1E+08	4E+07	2E+07	1E+07	5E+06	0
2007	0	0	78923	4E+06	3E+07	1E+08	1E+08	8E+07	7E+07	5E+07	3E+07	0
2008	0	26553	1E+05	1E+05	4E+06	4E+07	1E+08	1E+08	6E+07	4E+07	2E+07	0
2009	0	1333996	2E+06	2E+06	7E+05	6E+06	5E+07	1E+08	9E+07	5E+07	3E+07	0
2010	0	3782200	8E+07	4E+07	1E+06	1E+06	1E+07	3E+07	5E+07	4E+07	1E+07	0
2011	0	858	2E+05	2E+06	1E+06	3E+06	2E+06	2E+06	4E+06	2E+06	9E+05	0
2012	0	0	0	0	0	40	598	1601	18477	10000	3052	2932
2013	0	1	1044	18799	21113	25626	16848	8282	3278	4366	1374	1040
2014	0	0	0	1326	18534	38572	28875	8395	2064	1421	570	159

Table 6. Catch length-structure of the Fleet 3 (Far North Peru) 1980 – 2014 (numbers 10^9).

Year	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1975																																									
1976																																									
1977																																									
1978																																									
1979																																									
1980	44	59	71	59	126	67	184	105	67	50	0	0	0	33	46	25	9	9	50	101	134	209	318	471	419	343	251	184	134	84	50	33	33	29	17	9	9	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	14	28	101	129	105	109	112	105	87	78	62	50	36	34	22	20	17	8	3	1	0	0	0	0
1982	0	23	91	272	545	545	523	477	409	432	545	364	68	23	0	0	0	0	45	91	136	409	795	1136	840	545	296	227	181	159	136	113	23	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	114	137	182	206	297	707	1426	1711	1426	1254	707	502	297	228	114	69	137	69	22	46	22	0	0	0	0
1984	0	0	0	0	0	8	16	8	4	0	4	8	41	90	160	340	872	1743	2472	3355	3441	3270	4325	4657	4153	3245	2545	1731	1166	777	585	401	274	258	209	147	217	147	123	45	0
1985	0	0	0	0	0	0	0	3	6	8	16	16	19	19	22	31	62	136	215	399	535	615	818	848	949	987	888	906	822	821	725	585	439	353	277	259	242	179	199	150	0
1986	3	8	18	13	13	27	39	29	14	17	24	36	51	63	64	67	57	37	23	17	30	53	165	397	691	1066	1337	1260	1255	896	637	478	369	287	257	207	195	141	140	109	0
1987	2	6	8	10	6	21	52	61	43	44	74	95	106	169	254	395	533	830	1110	1215	1071	861	537	337	249	308	376	408	335	213	200	160	130	92	61	44	19	10	7	8	0
1988	0	0	0	0	0	0	0	4	22	60	73	95	186	354	739	1663	2985	3961	4250	3615	2985	2134	1559	1378	1309	1304	1266	1136	981	1019	972	1149	1058	1045	1088	1145	1045	747	596	354	0
1989	0	0	0	0	0	0	0	0	0	7	179	365	3204	4837	2294	2723	1988	1212	877	1009	1157	1309	2110	2874	3570	3979	3959	2848	2080	1295	705	498	386	297	260	251	260	237	191	185	0
1990	0	0	0	0	0	0	0	0	0	0	22	45	90	90	127	187	247	284	486	860	1533	2326	3373	4548	5221	6769	8579	9410	7353	6119	4473	3194	2409	1855	1279	808	554	292	202	90	0
1991	0	0	0	3	0	13	62	112	85	102	131	99	118	927	2308	1107	686	628	658	813	1134	1749	2249	2786	2851	3441	4354	4262	3939	3496	2993	1877	1405	1469	1237	1167	1130	864	687	616	504
1992	0	0	0	0	0	0	0	0	0	19	103	306	166	124	162	131	116	136	164	273	471	698	1108	1555	1948	1862	1393	1054	979	866	812	597	532	401	168	104	79	64	63	76	0
1993	0	3	20	16	3	0	3	26	66	201	497	691	1036	1266	1963	2943	3798	2821	2430	1934	1726	1605	1809	1670	1684	1506	1154	658	480	224	164	155	122	128	43	30	7	3	0	3	0
1994	4	4	0	4	4	11	7	0	4	29	72	133	176	240	341	452	625	958	1253	1450	2175	4824	6041	4810	3331	2495	1920	1407	1472	1088	1141	962	1267	908	965	815	510	445	298	334	194
1995	0	0	0	22	73	103	125	95	51	44	103	396	792	1041	1459	2236	3043	3263	4326	5635	7159	9177	10307	10768	13407	14406	12580	6838	4115	2602	2003	1675	1201	789	761	594	501	488	232	119	154
1996	0	0	0	0	6	44	200	194	237	712	1437	1469	1462	2550	3834	4445	4353	4211	4457	5153	6419	6045	4674	4311	3460	2887	2815	2487	2268	1352	849	549	319	211	76	44	12	12	6	0	0
1997	0	0	0	0	0	0	0	0	5	14	57	109	166	332	916	1832	3506	5749	5052	2855	2347	3963	7246	8255	4460	2297	1380	737	506	371	234	163	103	65	38	24	10	5	0	5	0
1998	0	0	0	5	65	207	109	71	283	1301	1927	1600	1339	1937	3940	8593	10727	7402	4272	2444	1453	1012	936	1176	980	555	425	343	261	234	174	147	109	98	87	60	49	27	27	16	0
1999	0	0	0	0	21	80	80	101	155	174	140	186	270	457	762	1035	1838	2102	2532	2300	1279	755	464	284	183	127	120	57	64	106	43	27	27	21	15	17	3	17	3	5	0
2000	0	0	0	4	7	7	7	18	178	1495	2766	2473	1856	1341	1339	3492	2839	2483	3039	4523	4097	2703	1151	387	119	31	11	4	4	4	7	0	4	0	0	0	0	0	0	0	0
2001	0	0	16	33	33	16	41	188	459	942	1500	1344	1304	2041	4038	6242	9220	11965	15404	15088	13405	8369	2959	850	239	97	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002	8	15	33	71	81	101	71	47	35	45	40	57	93	123	140	68	61	120	449	1426	2689	3181	3146	2300	1102	462	337	183	93	28	8	2	0	0	0	0	0	0	0	0	0
2003	0	0	0	0	2	2	8	31	61	159	278	453	905	1419	1555	1173	1063	1254	1732	1911	1399	961	795	687	697	937	972	640	348	154	63	18	4	2	2	0	0	0	0	0	0
2004	8	15	47	51	45	40	55	48	19	5	1	0	1	1	1	1	5	38	196	577	879	1015	1269	1665	1779	1478	1086	1040	946	657	350	206	103	45	22	8	3	1	0	0	0
2005	9	71	220	226	151	93	65	95	581	1147	1409	1553	1803	1846	1130	471	263	200	198	123	97	71	47	34	7	11	22	78	329	942	1676	1618	994	499	314	163	84	28	9	0	0
2006	0	0	0	0	0	0	0	0	40	392	1200	2432	5056	6408	5992	6200	6424	6304	5784	6176	6664	6224	5448	3928	2464	1296	712	392	216	120	56	24	16	0	0	8	8	8	8	0	0
2007	0	0	0	0	34	52	52	155	258	206	189	275	430	1324	7738	15184	13224	8976	9853	6895	5984	10145	16972	20704	19190	14358	9853	5399	2528	1135	447	258	103	17	0	0	0	0	0	0	0
2008	0	0	2	4	13	22	11	4	2	4	11	22	20	31	74	120	142	179	316	763	2120	3978	4641	3688	2233	1213	652	375	277	338	275	166	74	24	7	2	2	0	0	0	0
2009	169	161	227	227	54	21	0	0	0	27	182	729	822	756	467	314	114	74	138	149	85	43	64	91	89	145	460	1034	2137	3803	4100	2182	915	299	95	31	0	0	0	0	0
2010	0	0	0	0	0	0	0	0	0	0	17	0	17	231	451	162	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	53	53	53	53	0	0	0	0	0	53	0	106	4377	18221	52278	119239	150535	157464	117077	30214	425	53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	2	15	32	27	14	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	2	2	4	4	11	8	5	2	0	1	1	1	3	12	20	15	4	1	0	0	0	0	0	0	0	0
2014	0	0	0	0	4328	15869	25967	25967	7213	2885	1443	2885	7213	17311	14426	14426	142819	725636	2234612	3062673	3391589	6820687	26946617	42294605	25791082	10924928	4763517	3166541	2781363	1905695	773242	323146	24524	12984	0	0	0	0	1443	0	0

Table 7. Mean body mass (kg) at age over time assumed for Fleet 1 (North Chile).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1971	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1972	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1973	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1974	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1975	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1976	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1977	0.05	0.089	0.129	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115
1978	0.05	0.105	0.124	0.163	0.204	0.314	0.369	0.405	0.434	0.453	0.59	1.115
1979	0.05	0.108	0.163	0.179	0.217	0.274	0.37	0.42	0.474	0.629	0.633	1.115
1980	0.05	0.069	0.118	0.21	0.256	0.324	0.41	0.451	0.511	0.998	0.88	1.115
1981	0.05	0.094	0.139	0.214	0.269	0.331	0.412	0.481	0.58	0.661	1.112	1.115
1982	0.071	0.093	0.168	0.202	0.248	0.305	0.356	0.411	0.446	0.471	0.719	1.115
1983	0.084	0.099	0.119	0.221	0.264	0.314	0.377	0.429	0.475	0.528	0.54	1.115
1984	0.05	0.164	0.186	0.217	0.273	0.345	0.394	0.437	0.497	0.568	0.786	1.115
1985	0.05	0.167	0.173	0.224	0.271	0.34	0.401	0.465	0.536	0.582	0.726	1.115
1986	0.096	0.099	0.143	0.222	0.289	0.332	0.418	0.497	0.55	0.869	0.88	1.115
1987	0.092	0.121	0.146	0.189	0.233	0.336	0.427	0.477	0.513	0.65	0.803	1.115
1988	0.05	0.11	0.167	0.197	0.23	0.298	0.472	0.545	0.586	0.6095	0.88	1.115
1989	0.05	0.123	0.167	0.23	0.27	0.31	0.379	0.491	0.541	0.569	0.713	1.115
1990	0.069	0.099	0.16	0.248	0.29	0.338	0.409	0.533	0.651	0.677	0.756	1.115
1991	0.049	0.121	0.143	0.201	0.277	0.366	0.408	0.478	0.637	0.72	0.794	0.883
1992	0.069	0.092	0.127	0.201	0.268	0.3	0.373	0.444	0.512	0.595	0.681	0.786
1993	0.021	0.116	0.152	0.205	0.298	0.364	0.422	0.489	0.528	0.596	0.774	0.889
1994	0.059	0.097	0.107	0.235	0.291	0.33	0.387	0.459	0.565	0.748	0.798	0.898
1995	0.069	0.101	0.137	0.186	0.263	0.321	0.357	0.434	0.561	0.668	0.88	1.115
1996	0.067	0	0.14	0.17	0.229	0.295	0.367	0.507	0.657	0.639	0.88	1.115
1997	0.029	0.063	0.125	0.177	0.246	0.357	0.503	0.615	0.584	0.728	0.88	1.115
1998	0	0.082	0.104	0.195	0.249	0.29	0.39	0.475	0.634	0.728	0.88	1.115
1999	0.071	0.074	0.089	0.147	0.27	0.315	0.446	0.722	0.584	0.728	0.88	1.115
2000	0.043	0.054	0.138	0.191	0.225	0.251	0.372	0.488	0.584	0.728	0.88	1.115
2001	0.066	0.093	0.112	0.133	0.204	0.286	0.421	0.488	0.584	0.728	0.88	1.115
2002	0.029	0.059	0.092	0.172	0.238	0.327	0.398	0.416	0.628	0.728	0.88	1.115
2003	0.036	0.082	0.102	0.141	0.227	0.309	0.416	0.464	0.534	0.728	0.88	1.115
2004	0.037	0.078	0.164	0.186	0.203	0.257	0.342	0.488	0.584	0.728	0.88	1.115
2005	0.029	0.076	0.111	0.175	0.222	0.268	0.281	0.488	0.584	0.728	0.88	1.115
2006	0.032	0.074	0.114	0.132	0.204	0.374	0.442	0.506	0.606	0.728	0.88	1.115
2007	0.087	0.075	0.122	0.158	0.222	0.296	0.404	0.514	0.614	0.723	0.723	1.115
2008	0.042	0.047	0.066	0.187	0.243	0.291	0.388	0.563	0.616	0.748	0.88	1.115
2009	0.015	0.047	0.106	0.138	0.239	0.285	0.335	0.526	0.584	0.728	0.88	1.115
2010	0.013	0.048	0.101	0.172	0.233	0.301	0.397	0.493	0.639	0.772	0.88	1.115
2011	0.019	0.065	0.095	0.167	0.276	0.314	0.398	0.488	0.584	0.728	0.88	1.115
2012	0.016	0.048	0.088	0.202	0.235	0.269	0.396	0.488	0.584	0.728	0.88	1.115
2013	0.038	0.052	0.069	0.151	0.255	0.43	0.495	0.664	0.525	0.687	0.821	1.086
2014	0.018	0.04	0.082	0.189	0.248	0.313	0.396	0.488	0.584	0.728	0.88	1.115

Table 8. Mean body mass (kg) at age over time assumed for Fleet 2 (Central South Chile).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1971	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1972	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1973	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1974	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1975	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1976	0.052	0.078	0.155	0.214	0.275	0.336	0.394	0.472	0.632	0.714	0.898	1.538
1977	0.055	0.092	0.109	0.236	0.275	0.314	0.375	0.456	0.521	0.732	0.651	1.137
1978	0.052	0.084	0.104	0.147	0.211	0.327	0.394	0.449	0.514	0.583	0.631	1.538
1979	0.052	0.108	0.16	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.026	0.06	0.132	0.231	0.272	0.35	0.447	0.519	0.716	0.82	1.073	1.854
1981	0.052	0.095	0.149	0.242	0.294	0.34	0.407	0.503	0.637	0.765	1.184	1.9
1982	0.055	0.085	0.166	0.207	0.269	0.323	0.378	0.472	0.536	0.644	0.987	1.185
1983	0.07	0.099	0.122	0.23	0.273	0.32	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.035	0.135	0.154	0.185	0.266	0.33	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.058	0.148	0.181	0.223	0.27	0.339	0.398	0.473	0.573	0.796	1.376	1.647
1986	0.073	0.075	0.172	0.247	0.286	0.346	0.427	0.518	0.64	0.844	1.351	2.11
1987	0.076	0.117	0.14	0.191	0.27	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.1	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.75	1.012	1.372
1989	0.052	0.103	0.22	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.88	1.538
1990	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.97	1.598
1991	0.037	0.106	0.132	0.186	0.271	0.381	0.451	0.542	0.667	0.787	0.901	1.053
1992	0.063	0.083	0.118	0.177	0.239	0.275	0.409	0.524	0.594	0.709	0.851	1.046
1993	0.011	0.089	0.121	0.181	0.246	0.32	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.041	0.084	0.112	0.224	0.27	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.07	0.098	0.145	0.192	0.27	0.34	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.061	0.092	0.151	0.191	0.28	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.104	0.106	0.146	0.201	0.26	0.355	0.495	0.683	0.884	1.088	1.467	1.647
1998	0.084	0.128	0.138	0.178	0.248	0.34	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.09	0.109	0.134	0.174	0.25	0.331	0.465	0.742	1.021	1.258	1.376	1.776
2000	0.043	0.064	0.163	0.196	0.255	0.346	0.466	0.756	0.999	1.141	1.228	1.563
2001	0.066	0.098	0.122	0.179	0.258	0.325	0.461	0.614	0.828	1.074	1.36	1.671
2002	0.031	0.074	0.13	0.2	0.257	0.329	0.445	0.645	0.883	1.102	1.321	1.649
2003	0.036	0.086	0.117	0.186	0.245	0.307	0.4	0.564	0.768	1.005	1.209	1.537
2004	0.034	0.08	0.158	0.193	0.247	0.307	0.387	0.528	0.7	0.897	1.087	1.541
2005	0.029	0.075	0.113	0.196	0.259	0.318	0.399	0.517	0.641	0.767	0.918	1.296
2006	0.033	0.076	0.116	0.141	0.261	0.35	0.419	0.516	0.631	0.752	0.924	1.263
2007	0.086	0.074	0.121	0.172	0.226	0.331	0.431	0.51	0.621	0.756	0.903	1.177
2008	0.036	0.048	0.069	0.186	0.254	0.312	0.416	0.515	0.605	0.719	0.861	1.148
2009	0.014	0.045	0.109	0.142	0.253	0.33	0.411	0.532	0.625	0.764	0.886	1.144
2010	0.014	0.052	0.101	0.175	0.237	0.313	0.415	0.539	0.649	0.787	0.964	1.473
2011	0.019	0.067	0.101	0.19	0.287	0.353	0.466	0.613	0.774	0.923	1.173	1.514
2012	0.007	0.014	0.082	0.202	0.264	0.353	0.476	0.558	0.711	0.912	1.146	1.6
2013	0.054	0.158	0.251	0.26	0.318	0.385	0.45	0.553	0.705	0.829	1.117	1.977
2014	0.052	0.093	0.182	0.247	0.375	0.485	0.534	0.682	1.094	1.281	1.302	1.656

Table 9. Mean body mass (kg) at age over time assumed for Fleet 3 (Far North).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.045	0.171	0.377	0.642	0.945	1.265	1.587	1.9	2.196	2.47	2.721	2.946
1971	0.045	0.171	0.377	0.643	0.946	1.266	1.588	1.902	2.198	2.472	2.723	2.949
1972	0.03	0.13	0.306	0.548	0.835	1.148	1.47	1.789	2.095	2.382	2.647	2.887
1973	0.037	0.147	0.33	0.568	0.842	1.134	1.43	1.718	1.991	2.246	2.478	2.688
1974	0.038	0.147	0.326	0.558	0.825	1.108	1.393	1.671	1.934	2.178	2.402	2.603
1975	0.034	0.136	0.31	0.54	0.808	1.095	1.387	1.674	1.946	2.201	2.434	2.645
1976	0.044	0.16	0.34	0.567	0.822	1.087	1.351	1.606	1.845	2.065	2.266	2.446
1977	0.032	0.13	0.294	0.51	0.76	1.028	1.3	1.566	1.818	2.054	2.27	2.465
1978	0.032	0.129	0.295	0.516	0.774	1.05	1.332	1.608	1.872	2.117	2.343	2.547
1979	0.036	0.138	0.304	0.518	0.762	1.02	1.28	1.532	1.77	1.991	2.193	2.375
1980	0.036	0.136	0.298	0.506	0.743	0.994	1.245	1.49	1.721	1.934	2.13	2.306
1981	0.041	0.148	0.314	0.524	0.758	1.003	1.247	1.481	1.702	1.905	2.089	2.255
1982	0.039	0.144	0.309	0.519	0.755	1.002	1.249	1.488	1.712	1.92	2.108	2.278
1983	0.042	0.138	0.28	0.451	0.638	0.828	1.014	1.191	1.356	1.507	1.643	1.764
1984	0.044	0.156	0.328	0.541	0.778	1.024	1.267	1.501	1.719	1.921	2.103	2.267
1985	0.04	0.149	0.322	0.541	0.789	1.048	1.308	1.558	1.794	2.012	2.211	2.389
1986	0.042	0.151	0.323	0.539	0.781	1.033	1.285	1.527	1.755	1.965	2.156	2.327
1987	0.034	0.132	0.294	0.504	0.745	1.001	1.26	1.512	1.751	1.973	2.176	2.359
1988	0.038	0.145	0.315	0.533	0.78	1.041	1.302	1.554	1.793	2.013	2.215	2.396
1989	0.044	0.158	0.337	0.561	0.812	1.074	1.334	1.585	1.821	2.038	2.236	2.413
1990	0.042	0.15	0.32	0.532	0.769	1.017	1.263	1.499	1.722	1.927	2.113	2.28
1991	0.039	0.142	0.305	0.511	0.743	0.985	1.227	1.461	1.68	1.883	2.068	2.234
1992	0.04	0.148	0.318	0.534	0.776	1.031	1.286	1.531	1.763	1.976	2.171	2.346
1993	0.039	0.147	0.323	0.549	0.807	1.08	1.354	1.62	1.871	2.104	2.317	2.508
1994	0.036	0.147	0.335	0.584	0.874	1.186	1.503	1.813	2.109	2.385	2.638	2.867
1995	0.038	0.146	0.318	0.54	0.792	1.058	1.325	1.583	1.827	2.053	2.26	2.446
1996	0.038	0.145	0.317	0.537	0.788	1.053	1.318	1.576	1.82	2.045	2.251	2.436
1997	0.045	0.152	0.312	0.506	0.72	0.94	1.155	1.361	1.553	1.729	1.889	2.031
1998	0.04	0.14	0.294	0.483	0.693	0.911	1.126	1.333	1.526	1.703	1.864	2.008
1999	0.037	0.146	0.324	0.557	0.824	1.107	1.394	1.673	1.938	2.183	2.408	2.611
2000	0.035	0.145	0.336	0.592	0.893	1.218	1.55	1.877	2.189	2.481	2.75	2.994
2001	0.033	0.139	0.324	0.572	0.864	1.18	1.504	1.822	2.127	2.412	2.674	2.912
2002	0.036	0.145	0.33	0.576	0.861	1.167	1.478	1.783	2.074	2.344	2.593	2.817
2003	0.04	0.154	0.341	0.584	0.862	1.157	1.454	1.743	2.017	2.272	2.504	2.714
2004	0.038	0.149	0.333	0.574	0.852	1.148	1.447	1.74	2.017	2.275	2.511	2.724
2005	0.037	0.15	0.341	0.595	0.89	1.206	1.527	1.842	2.142	2.422	2.678	2.911
2006	0.038	0.152	0.347	0.606	0.907	1.23	1.558	1.88	2.187	2.473	2.735	2.973
2007	0.038	0.149	0.335	0.579	0.861	1.161	1.465	1.762	2.044	2.306	2.546	2.763
2008	0.036	0.146	0.334	0.585	0.876	1.19	1.51	1.823	2.122	2.4	2.656	2.888
2009	0.038	0.15	0.337	0.582	0.865	1.167	1.474	1.773	2.057	2.321	2.563	2.782
2010	0.039	0.15	0.332	0.567	0.837	1.123	1.411	1.691	1.956	2.203	2.428	2.631
2011	0.031	0.143	0.351	0.644	1	1.395	1.806	2.217	2.614	2.99	3.337	3.655
2012	0.032	0.145	0.349	0.632	0.971	1.344	1.731	2.115	2.485	2.834	3.156	3.449
2013	0.032	0.145	0.349	0.632	0.971	1.344	1.731	2.115	2.485	2.834	3.156	3.449
2014	0.032	0.145	0.349	0.632	0.971	1.344	1.731	2.115	2.485	2.834	3.156	3.449

Table 10. Mean body mass (kg) at age over time assumed for Fleet 4 (Offshore Trawl).

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1970	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1971	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1972	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1973	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1974	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1975	0.052	0.093	0.131	0.178	0.262	0.294	0.34	0.396	0.549	0.738	0.984	1.093
1976	0.052	0.078	0.155	0.214	0.275	0.336	0.394	0.472	0.632	0.714	0.898	1.538
1977	0.055	0.092	0.109	0.236	0.275	0.314	0.375	0.456	0.521	0.732	0.651	1.137
1978	0.052	0.084	0.104	0.147	0.211	0.327	0.394	0.449	0.514	0.583	0.631	1.538
1979	0.052	0.108	0.16	0.199	0.241	0.301	0.388	0.466	0.588	0.871	1.265	1.972
1980	0.026	0.06	0.132	0.231	0.272	0.35	0.447	0.519	0.716	0.82	1.073	1.854
1981	0.052	0.095	0.149	0.242	0.294	0.34	0.407	0.503	0.637	0.765	1.184	1.9
1982	0.055	0.085	0.166	0.207	0.269	0.323	0.378	0.472	0.536	0.644	0.987	1.185
1983	0.07	0.099	0.122	0.23	0.273	0.32	0.374	0.461	0.596	0.709	1.196	1.769
1984	0.035	0.135	0.154	0.185	0.266	0.33	0.383	0.449	0.577	0.685	1.012	1.846
1985	0.058	0.148	0.181	0.223	0.27	0.339	0.398	0.473	0.573	0.796	1.376	1.647
1986	0.073	0.075	0.172	0.247	0.286	0.346	0.427	0.518	0.64	0.844	1.351	2.11
1987	0.076	0.117	0.14	0.191	0.27	0.357	0.434	0.503	0.577	0.689	1.089	1.979
1988	0.1	0.124	0.159	0.197	0.233	0.342	0.444	0.512	0.588	0.75	1.012	1.372
1989	0.052	0.103	0.22	0.241	0.278	0.339	0.467	0.585	0.702	0.779	0.88	1.538
1990	0.064	0.091	0.153	0.264	0.309	0.373	0.461	0.582	0.694	0.835	0.97	1.598
1991	0.037	0.106	0.132	0.186	0.271	0.381	0.451	0.542	0.667	0.787	0.901	1.053
1992	0.063	0.083	0.118	0.177	0.239	0.275	0.409	0.524	0.594	0.709	0.851	1.046
1993	0.011	0.089	0.121	0.181	0.246	0.32	0.408	0.579	0.719	0.853	0.965	1.174
1994	0.041	0.084	0.112	0.224	0.27	0.336	0.462	0.643	0.808	0.868	1.058	1.421
1995	0.07	0.098	0.145	0.192	0.27	0.34	0.429	0.577	0.807	0.965	1.115	1.367
1996	0.061	0.092	0.151	0.191	0.28	0.352	0.524	0.683	0.945	1.216	1.426	1.477
1997	0.104	0.106	0.146	0.201	0.26	0.355	0.495	0.683	0.884	1.088	1.467	1.647
1998	0.084	0.128	0.138	0.178	0.248	0.34	0.545	0.806	1.035	1.246	1.412	1.655
1999	0.09	0.109	0.134	0.174	0.25	0.331	0.465	0.742	1.021	1.258	1.376	1.776
2000	0.043	0.064	0.163	0.196	0.255	0.346	0.466	0.756	0.999	1.141	1.228	1.563
2001	0.066	0.098	0.122	0.179	0.258	0.325	0.461	0.614	0.828	1.074	1.36	1.671
2002	0.031	0.074	0.13	0.2	0.257	0.329	0.445	0.645	0.883	1.102	1.321	1.649
2003	0.036	0.086	0.117	0.186	0.245	0.307	0.4	0.564	0.768	1.005	1.209	1.537
2004	0.034	0.08	0.158	0.193	0.247	0.307	0.387	0.528	0.7	0.897	1.087	1.541
2005	0.029	0.075	0.113	0.196	0.259	0.318	0.399	0.517	0.641	0.767	0.918	1.296
2006	0.033	0.076	0.116	0.141	0.261	0.35	0.419	0.516	0.631	0.752	0.924	1.263
2007	0.086	0.074	0.121	0.172	0.226	0.331	0.431	0.51	0.621	0.756	0.903	1.177
2008	0.036	0.048	0.069	0.186	0.254	0.312	0.416	0.515	0.605	0.719	0.861	1.148
2009	0.014	0.045	0.109	0.142	0.253	0.33	0.411	0.532	0.625	0.764	0.886	1.144
2010	0.014	0.052	0.101	0.175	0.237	0.313	0.415	0.539	0.649	0.787	0.964	1.473
2011	0.019	0.067	0.101	0.19	0.287	0.353	0.466	0.613	0.774	0.923	1.173	1.514
2012	0.007	0.014	0.082	0.202	0.264	0.353	0.476	0.558	0.711	0.912	1.146	1.6
2013	0.052	0.125	0.268	0.263	0.31	0.362	0.431	0.507	0.678	0.726	0.936	1.143
2014	0.026	0.069	0.150	0.218	0.287	0.356	0.458	0.559	0.721	0.854	1.085	1.419

Table 11. Survey biomass time series (1000 t).

Year	Biomass (North Chile)	Biomass (Central south Chile)	Spawning Biomass DEPM (Central south Chile)	Biomass (Peru)
1983				
1984	99			
1985	324			
1986	123			17811
1987	213			22955
1988	134			9459
1989				15034
1990				14139
1991	242			16486
1992				6266
1993				19659
1994				10768
1995				6429
1996				7271
1997		3530		2561
1998		3200		190
1999		4100	5724	342
2000		5600	4688	2373
2001		5950	5627	2052
2002		3700		248
2003		2640	1388	1118
2004		2640	3287	864
2005		4110	1043	1025
2006	112	3192	3283	1678
2007	275	3140	626	522
2008	259	487	1935	223
2009	18	328		849
2010	440			
2011	432			678
2012	230			94
2013	144			890
2014	87			

Table 12. Acoustic biomass age-structured (numbers, x10^9). (2006-2014). North Chile.

Year	1	2	3	4	5	6	7	8	9	10	11	12+
2006	116822	403538	272612	154651	21715	0	0	0	0	0	0	0
2007	273	69043	241335	755691	292140	19746	2980	0	0	0	0	0
2008	14998	2E+06	2E+06	41648	45795	16174	145	0	0	0	0	0
2009	0	54510	55714	20943	392	721	129	0	0	0	0	0
2010	0	10321	175262	2E+06	401742	79272	20972	0	0	0	0	0
2011	0	764206	350733	1E+06	103679	144140	37702	2300	0	0	0	0
2012	721	538523	63430	214664	307532	116579	9419	779	0	0	0	0
2013	83292	269344	16908	134710	128512	114395	29374	4131	0	0	0	0
2014	473762	1E+06	14319	20965	5207	19510	12090	0	0	0	0	0

Table 13. Acoustic biomass age-structure (numbers, x10^9). (1997-2009). Central South Chile.

Year	1	2	3	4	5	6	7	8	9	10	11	12+
1997	74	265	7857	8492	2422	668	131	115	128	75	76	95
1998	3	119	10599	9851	912	236	142	241	166	24	4	6
1999	0	365	5368	7891	1963	1014	377	194	500	357	212	63
2000	0	0	2529	11296	7864	2787	567	113	42	20	16	20
2001	0	280	6596	14354	7124	1792	428	241	177	103	44	7
2002	0	1	498	2217	1833	2363	565	280	80	21	7	2
2003	0	1	276	2132	3089	2343	680	200	156	115	54	41
2004	0	0	120	662	1833	2277	1709	1128	910	893	320	62
2005	0	0	0	1210	2670	5250	2377	701	320	64	82	188
2006	0	0	0	12	1799	4266	2625	511	322	188	110	70
2007	0	0	0	0	1	339	1113	1058	976	869	439	411
2008	0	0	0	0	0	96	317	256	117	87	34	49
2009	0	0	0	0	0	0	7	265	169	143	127	98

Table 14. Biomass age-structured (numbers, x10^9). DEPM (Daily Egg Production Method). Central south Chile.

Year	1	2	3	4	5	6	7	8	9	10	11	12+
2001	0	3787	8944	9208	1436	700	420	401	182	58	14	9
2003	0	54	529	837	336	563	398	400	219	84	35	6
2004	0	122	1217	2801	1511	719	405	584	376	168	66	9
2005	0	0	0	21	1115	718	485	336	136	94	57	0
2006	0	0	6	216	1232	1892	1473	849	304	114	78	0
2008	0	0	0	146	419	778	982	716	323	194	9	9

Table 15. Jack mackerel sexual maturity at age used in the stock assessment. Central south Chile.

Age	Proportion
1	0.07
2	0.31
3	0.72
4	0.93
5	0.98
6	0.99
7	1
8	1
9	1
10	1
11	1
12	1

Table 16. Ageing error matrix of Jack mackerel based on Chilean age studies

Age	1	2	3	4	5	6	7	8	9	10	11	12+
1	1	0	0	0	0	0	0	0	0	0	0	0
2	0	0.76	0.22	0.02	0	0	0	0	0	0	0	0
3	0	0.24	0.51	0.23	0.02	0	0	0	0	0	0	0
4	0	0.02	0.23	0.5	0.23	0.02	0	0	0	0	0	0
5	0	0	0.02	0.23	0.49	0.23	0.02	0	0	0	0	0
6	0	0	0	0.03	0.23	0.48	0.23	0.03	0	0	0	0
7	0	0	0	0	0.03	0.24	0.46	0.24	0.03	0	0	0
8	0	0	0	0	0	0.03	0.24	0.45	0.24	0.03	0	0
9	0	0	0	0	0	0	0.04	0.24	0.44	0.24	0.04	0
10	0	0	0	0	0	0	0	0.04	0.24	0.43	0.24	0.04
11	0	0	0	0	0	0	0	0	0.04	0.24	0.42	0.29
12+	0	0	0	0	0	0	0	0	0	0.05	0.24	0.71

Table 17. Jack mackerel population estimates. Spawning biomass (SSB, 1000 t), recruitment (R, number 10^9) and fishing mortality (F, year^{-1}).

	Model-1, *h*=0.8			Model-2, *h*=0.65		
Year	**SSB**	**R**	**F**	**SSB**	**R**	**F**
1970	9276.2	7428.6	0.02	9749.1	7535.8	0.02
1971	8391.5	5093.5	0.03	8784.7	5142.8	0.02
1972	7782.0	9630.5	0.02	8113.2	9725.6	0.02
1973	7323.8	8670.8	0.03	7605.5	8718.6	0.03
1974	6975.6	8555.9	0.04	7217.9	8569.9	0.04
1975	6785.9	19424.6	0.05	6995.9	19485.7	0.04
1976	6811.3	21163.4	0.06	6994.4	21186.4	0.06
1977	7130.7	19648.5	0.08	7291.3	19588.7	0.08
1978	7596.7	25119.6	0.13	7737.8	25101.7	0.13
1979	8022.1	16014.8	0.18	8144.8	15904.7	0.17
1980	8640.4	28858.8	0.14	8744.0	28779.2	0.14
1981	8879.2	33003.1	0.18	8963.0	32919.1	0.18
1982	8625.0	28072.6	0.29	8688.6	28048.6	0.29
1983	9085.6	8958.9	0.25	9132.7	8892.8	0.25
1984	9023.2	73993.1	0.37	9056.8	73962.4	0.36
1985	9455.6	67944.0	0.35	9477.9	68002.8	0.34
1986	11594.7	13740.7	0.30	11611.7	13675.1	0.30
1987	13742.6	14412.3	0.38	13757.5	14486.3	0.37
1988	14050.9	23201.4	0.49	14063.4	23179.7	0.48
1989	13012.0	16807.5	0.49	13024.4	17001.7	0.48
1990	11831.6	39265.4	0.48	11846.3	39197.9	0.48
1991	10714.0	26152.1	0.48	10733.5	26255.8	0.48
1992	9922.8	11647.8	0.53	9945.5	11654.0	0.53
1993	9308.7	28829.8	0.54	9333.7	28846.9	0.53
1994	7843.7	16163.1	0.67	7869.4	16143.4	0.67
1995	5816.0	19783.2	0.85	5840.9	19840.6	0.84
1996	4158.6	23518.0	0.82	4182.4	23406.1	0.82
1997	2962.6	33925.9	0.78	2985.9	34224.0	0.78
1998	3160.1	22154.8	0.50	3183.2	21515.1	0.49
1999	4115.8	36747.5	0.28	4138.9	37093.3	0.28
2000	5236.3	25201.1	0.23	5249.6	24863.0	0.23
2001	5979.7	23098.6	0.31	5987.5	23234.3	0.30
2002	6671.1	12542.2	0.30	6674.4	12502.5	0.30
2003	6959.9	5396.1	0.31	6962.2	5359.8	0.31
2004	6572.2	11621.0	0.33	6574.2	11653.0	0.32
2005	5806.2	2403.0	0.32	5808.4	2389.4	0.32
2006	4773.1	3899.3	0.36	4775.8	3887.4	0.36
2007	3499.0	10293.8	0.46	3501.9	10151.9	0.46
2008	2575.6	16245.2	0.48	2575.1	16046.8	0.47
2009	2007.9	5860.2	0.60	1998.0	5525.0	0.60
2010	2114.6	10230.3	0.49	2088.0	9801.2	0.48
2011	2498.6	4874.9	0.25	2446.6	4468.2	0.25
2012	2898.5	7233.3	0.14	2814.5	6776.7	0.14
2013	3255.4	10281.2	0.12	3135.8	9980.7	0.12
2014	3652.4	12507.7	0.11	3497.7	12370.9	0.11

Table 18. Biological References Points of Jack mackerel, based on Model-1, *h*=0.8 and *h*=0.65. *Fmsy*= fishing mortality at the maximum sustainable yield (MSY), *Bmsy*= spawning biomass at the MSY, *Blim*= spawning biomass limit, *Bo*=virginal spawning biomass, *Bmsy/Bo*=depletion level of the spawning biomass.

BRP	Model-1, *h*=0.8	Model-1, *h*=0.65
Fmsy	0.221 (year^{-1})	0.152 (year^{-1})
Bmsy	5.8 million t	6.9 million t
Blim	2.9 million t	3.4 million t
Bmsy/Bo	32%	35%

Table 19. Summary of the results of the short (2016), medium (2024) and long term (2034) predictions of the spawning biomass (*B*) of jack mackerel and catches 2016 and 2017 for each scenario of steepness (*h*) and recruitment. The risk is presented in term of the probability that the spawning biomass in 2016 (B2016), 2024 (B2024) and 2034 (B2034) is lower or equal than 80%*Bmsy* (or 0.8*Bmsy*), and higher than *Bmsy*. 0%*F = F=0; 50%*F = F in 2014 is reduced in a 50%; 75%*F= F in 2014 is reduced in a 75%; 100%*F= F is equal to the value in 2014. 125%*F= F in 2014 is amplified in a 25%.

Multipler F	B2016	P(B2016<=0.8*Bmsy)	P(B2016>Bmsy)	B2024	P(B2024<=0.8*Bmsy)	P(B2024>Bmsy)	B2034	P(B2034<=0.8*Bmsy)	P(B2034>Bmsy)	Catch 2016	Catch 2017
Steepness *h*=0.8; recruitment 1970-2012											
0% * F	5,355	0.182	0.218	12,918	0.000	0.999	17,263	0.000	1.000	0	0
50% * F	4,981	0.352	0.091	9,593	0.006	0.971	11,314	0.003	0.989	367.740	441.922
75% * F	4,811	0.447	0.056	8,503	0.019	0.923	9,672	0.010	0.962	525.908	612.902
100% * F	4,652	0.540	0.033	7,645	0.044	0.846	8,472	0.026	0.908	669.107	757.345
125% * F	4,502	0.627	0.019	6,954	0.084	0.743	7,558	0.056	0.824	798.761	879.359
Steepness *h*=0.8; recruitment 2000-2012											
0% * F	4,840	0.426	0.051	8,127	0.008	0.942	8,218	0.025	0.903	0	0
50% * F	4,474	0.650	0.012	5,449	0.264	0.348	5,101	0.383	0.266	357.026	425.002
75% * F	4,309	0.743	0.006	4,643	0.529	0.118	4,301	0.645	0.078	508.921	586.622
100% * F	4,155	0.817	0.003	4,041	0.756	0.029	3,731	0.836	0.016	645.436	721.604
125% * F	4,010	0.875	0.001	3,579	0.896	0.005	3,304	0.938	0.002	768.116	834.299
Steepness *h*=0.65; recruitment 1970-2012											
0% * F	5,111	0.426	0.122	12,084	0.008	0.998	17,422	0.025	1.000	0	0
50% * F	4,743	0.650	0.041	8,760	0.264	0.937	11,025	0.383	0.981	360.348	430.353
75% * F	4,576	0.743	0.023	7,664	0.529	0.845	9,229	0.645	0.935	514.917	596.196
100% * F	4,419	0.817	0.012	6,799	0.756	0.710	7,907	0.836	0.845	654.591	735.901
125% * F	4,272	0.875	0.006	6,101	0.896	0.553	6,895	0.938	0.710	780.798	853.543
Steepness *h*=0.65; recruitment 2000-2012											
0% * F	4,731	0.426	0.033	7,909	0.008	0.925	8,207	0.025	0.894	0	0
50% * F	4,367	0.650	0.007	5,231	0.264	0.277	4,902	0.383	0.219	353.668	419.744
75% * F	4,204	0.743	0.003	4,420	0.529	0.076	4,041	0.645	0.048	503.893	578.975
100% * F	4,050	0.817	0.001	3,812	0.756	0.014	3,424	0.836	0.006	638.756	711.730
125% * F	3,907	0.875	0.001	3,344	0.896	0.002	2,961	0.938	0.000	759.807	822.356

ANNEX 3: STOCK ASSESSMENT MODEL

Table 1. Population and fishery dynamics equations. Year index i ={1970,.., 2014}, age index: j ={1, 12$^+$}, length index: l ={10,11,….,50}.

Equation	Symbol/Constrains	Description
$N_{i,j=1} = e^{\mu_R+\varepsilon_i}$	$\varepsilon_i, \sum_{i=1958}^{2014} \varepsilon_i = 0$	Year effect and individuals at age 1 and *i*=1958 ,…, 2014
	μ_R	Mean survival in recruitment effect
$N_{1970,j} = e^{\mu_R+\varepsilon_{1970}}$	*j*=1	Initial numbers at age
$N_{1970,j} = e^{\mu_R+\varepsilon_{1971-j}} \prod_{j=1}^{j} e^{-M}$	1< *j* < *11*	
$N_{1970,12} = N_{1970,11}\left(1-e^{-M}\right)^{-1}$	*j*=12+	
$N_{i,1} = e^{\mu_R+\varepsilon_i}$	*j*=1	Years *i* >1970
$N_{i,j} = N_{i-1,j-1} e^{-Z_{i-1,j-1}}$		
$N_{i,12^+} = N_{i-1,11}\, e^{-Z_{i-1,10}} + N_{i-1,12}\, e^{-Z_{i-1,11}}$	1< *j* < *11*	
$Z_{i,j} = \sum_f F_{i,j}^f + M$		Total mortality
M	Fixed	Natural mortality
$F_{i,j}^f = e^{\mu^f+\eta_j^f+\phi_i}$		Instantaneous Fishing mortality
μ^f		Mean fishing effect
$\eta^f{}_j, \sum_{j=1958}^{2014} \eta^f{}_j = 0$	$S_{ij}^f = e^{\eta_j^f}$; $j \leq maxage$ $S_{ij}^f = e^{\eta_{maxage}^f}$; $j > maxage$	Age effect of fishing (regularized). In year time variation allowed
$\eta_{i,j}^f = \eta_{i-1,j}^f$	$i \neq$ change year	Years where selectivity is constant over time
$\phi_i, \sum_{i=1970}^{2014} \phi_i = 0$		Annual effect of fishing mortality in year *i*
$B_i = \sum_{j=2}^{12} N_{ij} e^{-\frac{10,5}{12} Z_{ij}} W_{ij} p_j$	B_i	Spawning biomass (spawning occurs at mid of November)
	$p_{j=}$proportion of females mature at age *j* $W_{ij=}$mean weight in the year *i* and age *j*	
$\tilde{R}_{i,j=1} = \dfrac{\alpha\beta}{\beta + B_{j-1}}$	$\widetilde{R}$	Recruitment at age *j*=1 (Beverton and Holt equation)
$\alpha = \dfrac{4hR_0}{5h-1}$; $\beta = \dfrac{B_0(1-h)}{5h-1}$	R_0	Unfished recruitment
h	Fixed	Steepness
$B_0 = R_0\varphi$		Unfished biomass
$\varphi = \sum_{j=1}^{12} e^{-M(j-1)} W_j\, p_j + \dfrac{e^{-12M} W_{12} p_{12}}{1-e^{-M}}$		

Table 2. Observations models for the survey or CPUE indexes, total catch, and proportion of individuals caught at age or length by survey and the fleets.

Equation	Symbol/Constrains	Description
$\hat{I}_i^s = q^s \sum_{j=1}^{12} N_{i,j}\, W_{i,j} S_j^s e^{-\Delta^s Z_{i,j}}$	$\hat{I}_i^s$	Abundance index ($\hat{I}_i^s$) by year *i* and survey *s*. Δ^s represents the fraction of the year when the survey takes place.
	q^s= survey catchability coefficient	*s* represents acoustic biomass, DEPM biomass or CPUE
$q_i^s = e^{\mu^s}$		Index catchability *q*, of the survey *s* or fleet *f*
	μ^s, μ^f	Mean effect
$S_j^s = e^{\eta_j^s}$; $j \leq maxage$ $S_j^s = e^{\eta_{maxage}^s}$; $j > maxage$	$\eta^s{}_j$, $\sum_{j=1958}^{2014} \eta^s{}_j = 0$	Age effect
$\hat{C}_{i,j}^f, = T\left[N_{i,j}\frac{F_{i,j}}{Z_{i,j}}\left(1-e^{-Z_{i,j}}\right)\right]$	$\hat{C}_{i,j}^f$, $\hat{Y}_i^f$ T = ageing error matrix	Catch at the year *i*, and age *j* and the fleet *f*
$\hat{Y}_i^f = \sum_{j=1}^{12} \hat{C}_{i,j}^f w_{i,j}^f$		Total Catch biomass by year *i*
$\hat{C}_{i,l} = \Gamma_{l,j}\hat{C}_{i,j}$	$\hat{C}_{i,l}$	Catch at the year *i*, and length *l*.
$\Gamma_{l,j} = \int_j^{j+1} e^{-\frac{1}{2\sigma_j^2}\left(l-L_j\right)^2} dl$		$\Gamma_{l,j}$ is the proportion of length at age to transform from age to length.
	σ_j^2	Variance of the length at age *j*
$L_j = L_\infty(1- e^{-k}) + e^{-k} L_{j-1}$	L_∞ asymptotic length L_j mean length at age	von-Bertalanffy mean length at age
$\sigma_j = cvL_j$	*cv*= coefficient of variation of length at age	
$p_{i,j}^f = \hat{C}_{i,j}^f \Big/ \sum_j \hat{C}_{i,j}^f$	P_{ij}, $\sum_{j=1}^{12} P_{ij} = 1.0$	Proportion of the individuals caught in year *i*, at age *j* by the fleet *f*.
$p_{i,j}^s = N_{i,j} S_j^s e^{-\Delta^s Z_{i,j}} / \sum_j N_{i,j} S_j^s e^{-\Delta^s Z_{i,j}}$		Proportion of the individuals caught in year *i*, at age *j* by the survey *s* at the time of year Δ^s
$P_{i,l} = \frac{C_{i,l}}{\sum_{l=10}^{50} C_{i,l}}$	$P_{i,l}$, $\sum_{l=10}^{50} P_{i,l} = 1.0$	Proportion at length *l*, in year *i*

Table 3. Vector of estimated parameters, likelihood component of each data set, prior and objective function.

Likelihood/penalty component	Equations/ parameters	Description
Estimated parameters	$\phi_i, R_0, \varepsilon_i, \mu^f, \mu^s, \eta_j^s, \eta$	
Surveys and CPUE indexes	$L_1 = 0.5\sum_s \frac{1}{cv_s^2}\sum_j log\left(\frac{I_j}{\hat{I}_j}\right)^2$	Surveys and CPUE indexes. cv_s is the coefficient of variation
Prior for selectivities	$L_2 = \sum_m \lambda_2^m \sum_{j=1}^{12}(\eta_{j+2}^m + \eta_j^m - \eta_{j+1}^m)^2$	Smoothness (second differencing), Note: *m*={*s,* or *f*} for survey and fishery selectivity. λ_2 is the smoothness parameter for selectivity
Prior for recruitment	$L_3 = \lambda_3 \sum_{j=1958}^{2013} \varepsilon^2{}_j$	Influences estimates where data are lacking (e.g., if no signal of recruitment strength is available, then the recruitment estimate will converge to median value). λ_3 is the smoothness parameter for recruitment
Catch biomass likehood	$L_4 = 0.5\sum_f \frac{1}{cv_f^2}\sum_{j=1970}^{2014} log\left(\frac{C^f{}_j}{\hat{C}^f{}_j}\right)^2$	Fit to catch biomass in each year. cv_f is the coefficient of variation of catches.
Proportion at age/length likelihood	$L_5 = -\sum_{v,i,j} n^v P^v_{i,j/l} \log(\hat{P}^v_{i,j/l})$	*v*={*s,f*} for survey and fishery age composition observations. $P_{i,j/l}$ are the catch-at-age/length proportions *n* effective sample size
Fishing mortality constrain	F values constrained between 0 and 5	
Recruitment constrains	$L_6 = \frac{0.5}{cv_r^2}\sum_{j=1970}^{2011} log\left(\frac{N_{i,j=1}}{\tilde{R}_i}\right)^2$	Conditioning on stock-recruitment curve over period 1977-2011. cv_r is the coefficient of variation of recruitments.
Priors	R_0 non-informative	(Explored alternative values of σ_R^2)
Overall objective function to be minimized.	$\dot{L} = \sum_k L_k$	k = {1,..,6}

Table 4. Data weighting. Coefficients of variation and sample sizes used in the likelihood functions.

Abundance index	Model-1, *h*=0.8 (cv)	Model-1, *h*=0.65 (cv)
Acoustic North Chile	0.20	0.20
Acoustic Central south Chile	0.50	0.50
CPUE – Chile	0.15	0.15
DEPM – Chile	0.50	0.50
Acoustic-Peru	0.20	0.20
CPUE – Peru	0.20	0.20
CPUE- China	0.20	0.20
CPUE-EU	0.20	0.20
CPUE- ex USSR	0.40	0.40
Smoothness of selectivities (fleets)	λ	λ
North Chile	1	1
Central south Chile	25	25
Far North	12.5	12.5
Offshore Trawl	12.5	12.5
Proportion at age likelihood (fleets)	n	n
North Chile	20	20
Central south Chile	50	50
Far North	30	30
Offshore Trawl	30	30

ANNEX 4: Using population dynamic theory for understanding the interaction between jack mackerel (*Trachurus murphyi*) and fishery dynamics

Two kinds of models have been traditionally used in fishery management: 1) those based on the concepts of stock productivity, surplus production, and maximum sustainable yield (MSY) (Quinn and Deriso 1999) and 2) those models based in the spawner-recruit relationships (stock-recruit models) developed from ecological assumptions affecting the reproductive processes (Ricker 1954, Beverton and Holt 1957). The basic assumption of both surplus production and stock recruitment models is the existence of an equilibrium population size (or biomass) of unexploited fishes. However, equilibrium or near equilibrium dynamics can be caused only by the presence of negative feedback processes (e.g., competition) and limiting factors (Berryman 1999). For its part, the ecosystem based fishery management (EBFM) approach assumes that exploited populations are embedded in complex ecosystems involving large numbers of interactions. From this perspective, the sustainable management of fisheries can only be achieved if models used to harvest fish populations are able to include, or account for, other ecosystems components.

Here, we used another approach to deciphering the potential interactions between the fishery fleet and the stock of jack mackerel at southeastern Pacific Ocean. First, we applied the theory of population dynamics (Royama 1992, Berryman 1999, Turchin 2003 and Ginzburg and Colyvan 2004), in order to shed light on issues of basic importance in managing the harvest of the jack mackerel stock. In particular, we want to emphasize the fundamentally important role of population theory in managing fisheries, despite the attitude of many biologists that there are no laws or reasonable theories for explaining natural systems (in particular marine ecosystems) or the idea that marine ecosystems are too complex to be described by simple models. The objective is to demonstrate that ecological theory and simple models can be useful for understanding and PREDICTING the dynamics of fish populations.

Population Dynamic Theory

Following the work of Royama (1977, 1992), other authors have proposed that there are a few simple principles that can explain much (or even most) of the apparent complexity observed in the fluctuations of natural populations (Berryman 1999, Turchin 2003, Ginzburg and Colyvan 2004). Although the experts often differ on the importance of the basic principles of population dynamics and how they should be formulated, we used these principles (especially as formulated by Berryman 1999) to analyze how the jack mackerel dynamics and the fisheries are managed.

Classical single-species fisheries models rely, in principle, on our understanding of competition as a basic component of processes that lead to population biomass showing patterns of equilibrium or near equilibrium. Predation also contributes to these patterns, and fishing (predation by humans) will reduce population size towards lower numbers where individuals are faced with more abundant resources (per capita) resulting in increased recruitment rates. Many have criticized management based on the assumption that these principles are sufficient for realistic decision-making. One of the most common criticisms relies on empirical evidence that marine ecosystems show a great deal of variability, often explained as the effects of stochastic processes, oceanographic variability, and inter-specific interactions (Spencer and Collie 1997a).

The underlying reasoning behind these criticisms is that marine ecosystems are too complex to be managed by single-stock fishery models (Pikitich et al. 2004, Frid et al. 2006). Although it has to be recognized that single stock fishery models are a simplistic metaphor of nature, the inclusion of more parameters and variables always fails to achieve a complete understanding of the causes of fish population dynamics. In fact, however, it is highly likely that many fish stocks are governed through dynamics in which simple first-order dynamics and limited by resource availability (food, refuge, etc) count as primary factors. Some factors are clearly much more influential than others. We think that the principles behind population dynamic can never be ignored, either as they are developed to better understand the underlying causes of population dynamics, or (and perhaps more importantly) to better understand their role in implementing adequate management options to assure long term sustainability.

Fishing is, in most cases, the most important extrinsic force acting on fish populations (Jackson et al. 2001), often orders of magnitude larger than that of other predators (Fowler and McCluskey). Therefore, to understand and manage fisheries we need to understand the dynamic of the fishery fleet. For example, if fishing effort is constant in time, and the fleet behaves as a generalist or a highly mobile predator (capable of aggregating in high prey density areas), a potential consequence is to diminish prey (fish) populations toward low levels and cause a new dynamic equilibrium point (Holling 1965, Morris 1963, Berryman 1999). Under this scenario, fish populations show a tendency to be stabilized by generalist predators at low densities and regulated by enemy free space competition (Berryman 1999).

When fishing effort increases in response to economic forces (or other factors such as highly successful previous harvests), a delayed feedback can be created which leads fish population dynamics toward regular and large amplitude cycles (predator-prey cycles). It is interesting to note that predator-prey theory has been used vary rarely in fisheries, despite the classic predator-prey model developed by Vito Volterra as an attempt to give explanation to fluctuations in the Adriatic fisheries after First World War (Kingsland 1995). Cycles in marine fish or invertebrate populations can be the consequence of the destabilized forces imposed by the economic inertia behind fisheries (Berryman 1991); regular cycles in the numerical fluctuations of several exploited species have been documented (Bostford 1986, Spencer & Collie 1997a, Higgins et al.

1997). In these cases, the fishing effort and the fish stock are mutually connected by a feedback loop. Owing to this feedback, an integral management strategy is necessary: to reduce the amplitude of fish oscillations requires reducing the fishing effort or its variability (or both). In sum, we analyze the dynamics of the adult spawning stock of jack mackerel, recruitment, fishery effort and climate under the conceptual framework of population dynamic theory.

Statistical Models

Population dynamics of jack mackerel is the result of the combined effects of feedback structure (ecological interactions within and between populations), limiting factors, climatic influences, and stochastic forces. To understand how these factors may determine jack mackerel population fluctuations, we model both system-intrinsic processes (both within the population and between various trophic levels) and exogenous influences, as a general model based on the *R*-function (Berryman 1999). The *R*-function represents the realized per capita population growth rates that represent the processes of individual survival and reproduction (Berryman 1999). Defining $R_t = \log(N_t) - \log(N_{t-1})$, we can express the *R*-function (*sensu* Berryman 1999) as:

$$R_t = ln\left(\frac{N_t}{N_{t-1}}\right) = f\left(N_{t-1}, N_{t-2}, \cdots, N_{t-i}, C_{t-i}, \varepsilon_t\right) \qquad \textbf{(1)}$$

Here N_{t-i} is the adult spawning biomass (recruitment and Fishing effort) at different time lags; C_{t-i} is exogenous effects; and ε_t is a random normally distributed variable. This model represents the basic feedback structure and integrates the stochastic and climatic forces that drive population dynamics in nature. Our first step was to estimate the order of the dynamical processes (Royama 1977), that is how many time lags, N_{t-i} , should be included in the model for representing the feedback structure. To estimate the order of the process we used the partial rate correlation (*PRCF*(*i*)) between *R* and ln $N_{t-i} = X_{t-i}$ after the effects of shorter lags have been removed. We write (1) in logarithmic form to calculate the partial correlations.

$$R_t = \boldsymbol{ln}\left(\frac{N_t}{N_{t-1}}\right) = A + B_1 \cdot X_{t-1} + B_2 \cdot X_{t-2} + \varepsilon_t \qquad \textbf{(2)}$$

Where *R*, the realized per-capita rate of change, is calculated from the data, we fitted a multiple regression between the per capita growth rates and lagged population density to estimate the $PRCF_{t-d}$ coefficients at each lag (B_i, i=1, 2, ..3), for statistical convenience we assumed a linear relationship between *R* and X_{t-i} (Royama 1977).

The dynamics of spawning stock was better explained by a second order component [PRCF(2)], which suggest a second-order feedback system dominating the adult fish dynamics (Figure 1). A first-order negative feedback [PRCF (1)] was the most important component of recruitment dynamics (Figure 1). This result suggest a simple feedback structure, and low order dynamics of the recruitment process. The fishing effort dynamics appears to be described by a third-order component [PRCF(3)] suggesting a complex feedback structure (Figure 1).

The statistical models

Our starting point in the analyses was to model jack mackerel spawning stock, recruitment and fishing effort tropical using simple statistical models. The PRCF analysis suggests that jack mackerel spawning biomass and fleet dynamics could be dynamically connected by higher order processes. Our starting point for a simple statistical model is:

$$\begin{aligned} RS_t &= f(B_t, E_t, \varepsilon_t) \\ RE_t &= g(E_t, B_t, \epsilon_t) \end{aligned} \qquad \textbf{(3),}$$

Where RS_t is the population growth rate of spawning biomass at time t, B_t is the spawning biomass and E_t is the fishing effort and ε_t is a random normal variable. On the other hand, RE_t is the rate of change of fishing effort, ε_t is another random variable an f and g are simple linear functions. In addition recruitment dynamics appears to be a simple first order dynamic process; hence, we used a simple statistical representation;

$$RR_t = h(RC_t, C_t, \varepsilon_t) \qquad \textbf{(4)},$$

Where RR_t is the realized growth rate of recruitment, RC_t is the recruitment abundances; C_t represents an exogenous climatic variable (e.g. El Niño) and ε_t a random normal variable.

RESULTS

Population dynamics of the spawning stock of jack mackerel and fleet dynamics are characterized by large and regular oscillations (Figure 2), which are typical of second-order processes. In fact, both systems appear to be linked, the rate of growth of spawning jack mackerels seem to be a negative linear function of the logarithm of fishing effort and a positive linear function of the logarithm of recruitment (R^2 = 38%, $F_{2,\ 28}$ = 8.59, p = 0.0012). On the other hand, the rate of change of fishing effort appears to be a positive linear function of the logarithm of spawning biomass of jack mackerel (R^2 = 30%, $F_{1,\ 29}$= 12.40, p = 0.0014). The phase diagram between spawning biomass of jack mackerel and fishing effort suggest that both are mutually influenced and are connected in a predator/prey like dynamics (Figure 3). Finally, the recruitment dynamics appears to be simpler, the recruitment growth rates are negatively influenced by the logarithm of recruitment biomass (first-order negative feedback), and positively affected by the El Niño anomalies suggesting the importance of endogenous and exogenous effects (R^2 = 44%, $F_{3,\ 27}$= 7.09, p = 0.0012).

DISCUSSION

Fishery science has been developing around a variety of basic concepts and ideas since the 1950s (Quinn & Collie 2005). One of the most important assumptions in this history is that fish stocks are near the “equilibrium” of the system and the only effect of fishing mortality is to reduce the abundance of the harvested population. Although fisheries scientist have long been aware of the multiple effects of fishing in marine communities (Pitcher 2001), the problem of dealing with this issue, using a more general and theoretical perspective, has been absent. During this time, the models used in fisheries research incorporated varying degrees of complexity by adding explanatory variables and exploring alternative sources of variability (see, Quinn & Collie 2005 for a review). Despite these advances in accounting for environmental factors, most of the well-accepted general ideas and concepts derived from straight-forward population dynamics theory are ignored in applied fishery models. For example, although the concept of predator functional responses is quite well developed and used in the conventional management (control) of pest species, it has not been incorporated in the theoretical toolbox of fisheries scientists (Holling 1965, Morris 1963, Royama 1977, 1992, Berryman 1999). Therefore, instead of trying to compare single species models with ecosystem models (as currently being proposed as a basis for Ecosystem Based Fishery Management), we call for an acceptance and understanding of the magnitude of our ignorance regarding simple population dynamics, especially insofar as population dynamics is brought to bear in management.

There is an important need for simpler and theoretically based models as proper diagnostic tools for analyzing fish population fluctuations. We think that the theory behind population dynamics offers the proper conceptual background to develop simple models for understanding and predicting the dynamics of fish populations.

The present analysis suggests that jack mackerel and fishery dynamics are linked in a predator/prey like system of mutual causal second-order loop. This hypothesis represents a new view of how this fish population is responded to the fishery and put new challenges to fish management. In particular, if a cyclic dynamics is underlying the mutual connection between jack mackerels and the fleet it could be needed an integral approach similar to what is used in pest control (Berryman 1999). On the other hand, recruitment dynamics appears to be simpler, basically is the interaction among density-dependent process and El Niño variability (Figure 4).

A final comment: as substantiated elsewhere (Berryman 1991, Berryman and Lima 2006), we think that a proper analysis of empirical information is preferable to ecological modeling to inform the management of harvesting to achieve sustainability in fisheries. It is the only way to deduce the proper feedback structure to be responsive to change. It provides important insight to the importance of exogenous effects (e.g., climate), and how fishing influences fish stocks. Such an approach is essential for the analysis and *a* *posteriori* modeling of observed data to estimate model parameter and establish causal connections between variables Berryman (1991).

In summary, it is fundamentally important that we avoid management that focuses on ecosystems to the exclusion of populations and their dynamics: an essential part of what is brought to management must be our understanding of population dynamics. The science of population dynamics provides crucial insight to, and understanding of, populations that must be accounted for in management of fisheries.

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FIGURES

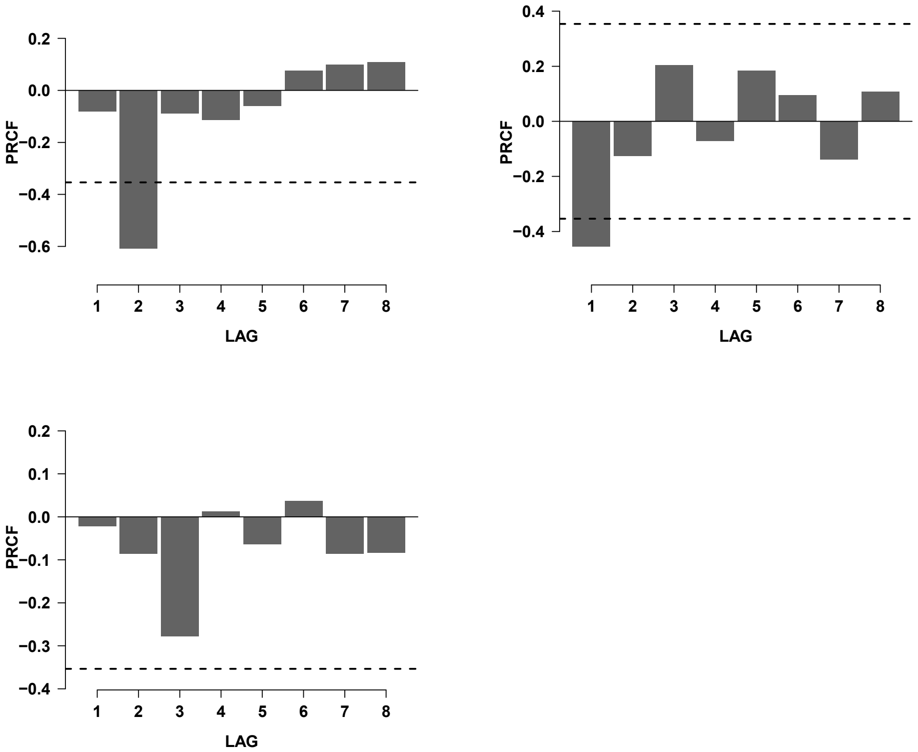

Fig. 1. Partial rate correlation function (PRCF) of the growth rate of spawning biomass (top-left), recruitment (top-right), and fishing effort (bottom-left).

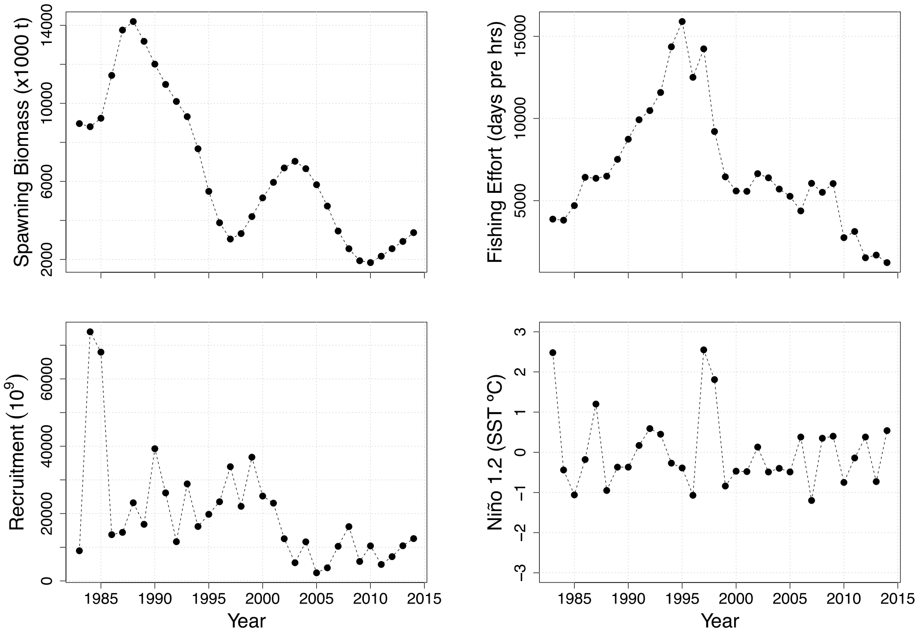

Fig. 2. Spawning biomass, recruitment, fishing effort of jack mackerel in the South Eastern Pacific. Environmental index El Niño 1.2 sea surface temperature.

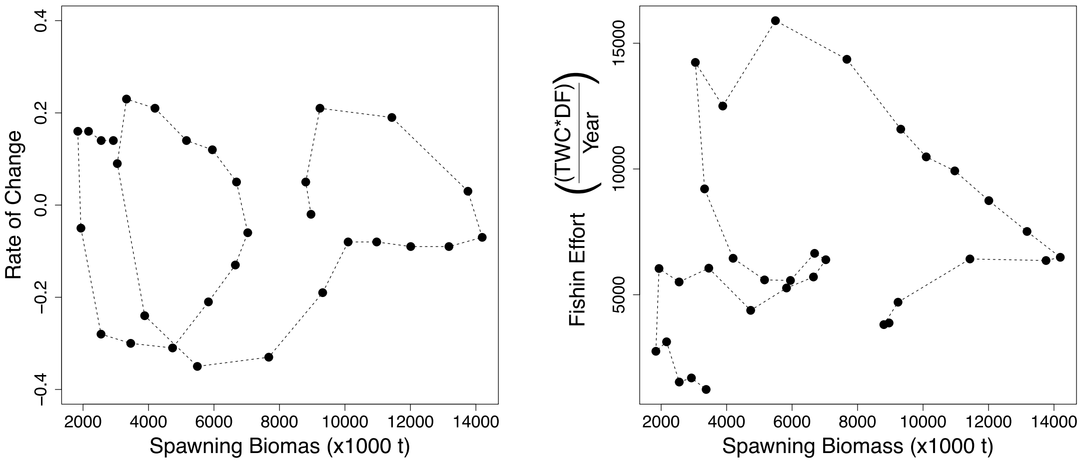

Fig. 3. Phase diagrams between spawning biomass of jack mackerel and fishing effort in the South Eastern Pacific. Both variable are mutually influenced and connected in a predator/prey like dynamics.

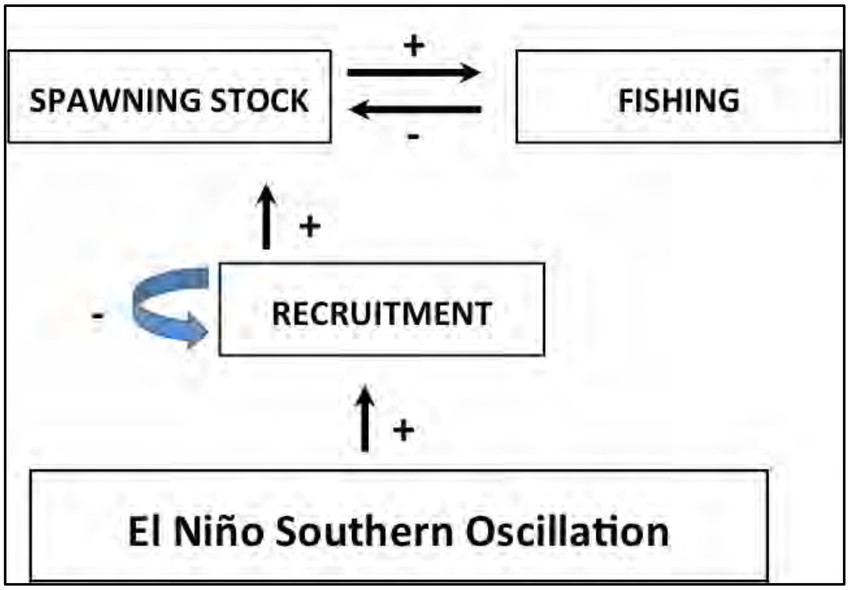

Fig. 4. Interactions between recruitment and spawning biomass of jack mackerel and the fishing and El Niño.