Hydrography and Jack Mackerel stock in the South Pacific – Interim report

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Niels T. Hintzen, Ad Corten, François Gerlotto, Jérémie Habasque, Arnaud Bertrand, Patrick Lehodey, Thomas Brunel, Anne-Cécile Dragon, Inna Senina

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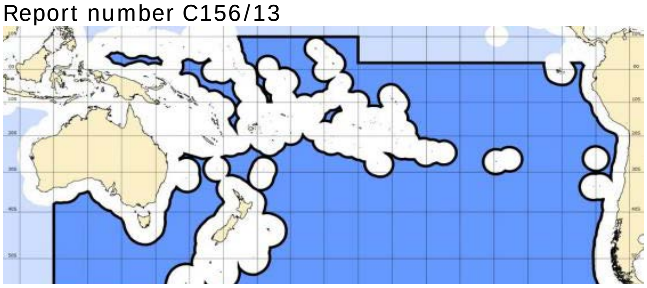

IMARES Wageningen UR

(IMARES - Institute for Marine Resources & Ecosystem Studies)

Client: European Commission
Directorate-General for Maritime Affairs and Fisheries
Unit MARE/F1
Office: J-99 5/7
B – 1049 Brussels

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P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 167
1790 AD Den Burg Texel
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 62
E-Mail: imares@wur.nl
www.imares.wur.nl

1. Contents

2. Summary

The study on Hydrography and Jack Mackerel stock (*Trachurus murphyi*) in the South Pacific is currently one year underway. The main achievement consisted of collecting detailed datasets on Chilean, Peruvian and European fisheries activities and information on the hydrographical / biochemical and environmental conditions present in the South Pacific. The hydrographical and environmental datasets are based on the analyses of available acoustic information collected on-board survey and fishing vessels and satellite imagery data. Jack Mackerel habitat models are being developed based on these datasets. These models will be used to produce maps of the potential habitat of Jack Mackerel, on the basis of which different stock structure hypotheses will be tested. The models developed so far are able to accurately represent the distribution of Jack Mackerel as observed by fishing and surveying activities, although some additional investigations are needed to improve the statistical fits. Good fits with hydrographical conditions have been found. The models are not yet ready to be used for testing stock structure hypotheses, but this should be the case in the near future. During the first year of the project, an extensive literature review on Jack Mackerel has also been conducted, and a synthesis has been written, giving an overview on the species biology, ecology and stock structure. The literature suggests that a meta-population structure can be seen as a potential stock structure hypothesis. The literature review also contributed to identify environmental variables that should be crucial to define the suitable habitat of Jack Mackerel. Previously published results indicate, among others, temperature and dissolved oxygen ranges in which Jack Mackerel is able to survive. Finally, a framework to derive reference points for Jack Mackerel, assuming the single stock structure as used within the SPRFMO assessment, has been developed and made available to the SPRFMO Science Committee for review. Analyses of the assessment results within this framework indicate that the fishing mortality corresponding to maximum sustainable yield might be at around 0.15 per year with a corresponding spawning stock biomass of around 10 million tonnes. Different harvest control rules have been evaluated and show little risk to overexploitation in the medium and long term, although these result heavily rely on strong incoming year classes. The tools to evaluate sustainable management options for the Jack Mackerel population, when a stock structure other than a single one is assumed, are currently under development. The design of scenarios to be tested depend on the results of the habitat modelling exercises. Therefore, preliminary results will only become available early 2014.

3. Context

This study focuses on the Chilean Jack Mackerel (*Trachurus murphyi*, Jack Mackerel from here onwards) population, a globally important exploited stock. This stock is distributed throughout the sub-tropical waters of the South Pacific Ocean, from South America to New Zealand and Australia, and its management is executed in the framework of the South Pacific Regional Fisheries Management Organisation (see figure 1). The European Union also has fishing interests in this area, both currently as in the past, with vessels reporting catches in the 1970s and 1980s and more recently from 2005 up to 2013. Hence, sustainable management of the Jack Mackerel population is in the interest of the EU.

Several studies on the stock structure of Jack Mackerel have indicated already the assumption of a single stock (i.e. one single homogenous stock in the entire area) does not match biological reality while the stock is assessed and managed according to this assumption. Not accounting for a more dynamic stock structure that changes under the influence of hydrographical conditions could result in mismanagement of the stock as stock resilience is not accurately estimated. Additionally, ignoring stock structure and dynamics may impact the accuracy of stock assessments.

Given the strong decrease of the biomass of the Jack Mackerel stock and the on-going debate on stock structure, more scientific research is needed to shed light on the most likely stock structure hypothesis and enable the exploration of more sustainable management scenarios for this stock.

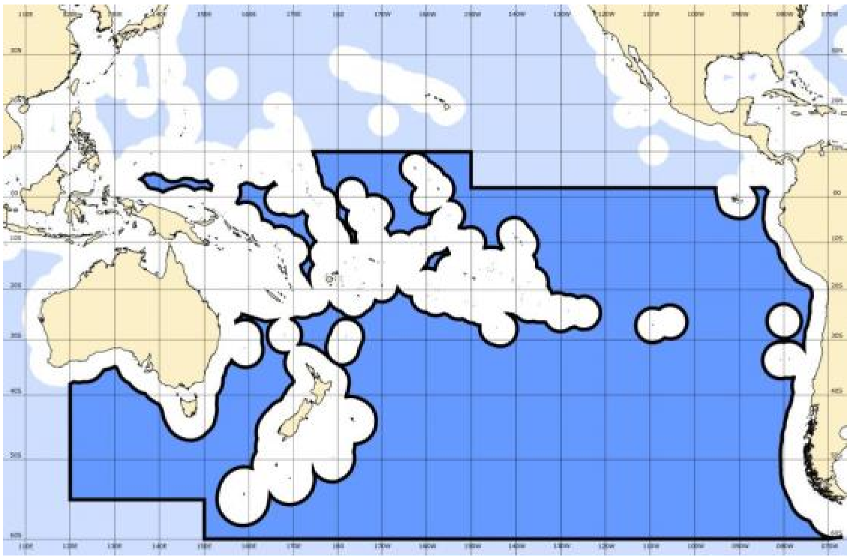

Figure 1: South Pacific Regional Fisheries Management Area. Dark blue represent international waters.

4. Objectives & Achievements

The objectives of the project are threefold:

- Identify the most likely stock structure hypotheses of Jack Mackerel
- Considering the most likely stock structure, identify management objectives for Jack Mackerel
- Evaluate sustainable management strategies to achieve these objectives

Achievements of overall objectives

In the context of fish resource sustainability, the objectives of this project are considered timely given the on-going discussion within the science platforms on Jack Mackerel stock structure and the poor state of the stock. There is a constant debate on the Jack Mackerel stock structure as no conclusive evidence has been provided by any of the stakeholders. This report reports on the progress towards achieving the three objectives listed above. Preliminary results on stock structure hypotheses and sustainable management strategies are presented and hence may change when new results become available.

Within this project, three different approaches are taken to identify the most likely stock structure. At first, a literature review, also considering grey literature, on Jack Mackerel biology, ecology and population structure is undertaken. This review provides the key knowledge on Jack Mackerel necessary for the research activities carried out in work packages 3 to 5 (Hydrography/biogeochemistry and Jack Mackerel stock structure interactions, Harvest control rule and Stock assessment and Jack Mackerel stock structure and management interactions respectively). Through this exercise, the findings of the work packages 3 to 5 can readily be placed into context with other scientific publications on Jack Mackerel stock structure. Significant progress has been made on this literature review and a synthesis (of which a summary is given under chapter 7) has been written to present a clear overview of the information already available. This synthesis reviews the different hypotheses on Jack Mackerel stock structure and a manuscript which is currently in preparation intends to identify the most likely stock structure. Preliminary results suggest that the Jack Mackerel stock is probably a meta-population. The literature review therefore contributes greatly to identifying the most likely stock structure as well as providing the necessary background information.

In the second approach, habitat modelling is used to identify the influence of environmental, physical and hydrographical conditions on the distribution of Jack Mackerel described from catch and survey data analyses. Fitting such statistical models requires a vast amount of catch and survey information to test the significance between key environmental, physical and hydrographical conditions. Under work package 1 (Data collection), these data have been collected from various sources such as the South Pacific Regional Fisheries Management Organisation (SPRFMO) secretariat, fisheries institutes from Chile and Peru and European vessels active in the region. The preliminary results of the statistical models show clear relationships between hydrographical conditions and the Jack Mackerel distribution and are able to outline a suitable habitat over time. The changes over time, and the extend of the area suitable for Jack Mackerel will be linked to the observed Jack Mackerel distribution. On that basis, the most likely stock structure can be identified as a continuous suitable habitat in space and time which is compatible with the single stock hypothesis, while the appearance of hydrographical boundaries might indicate that units are separated over time. At this stage, results are too preliminary to clearly identify the most likely hypothesis.

The third approach to investigate stock structure is the development of a SEAPODYM model for Jack Mackerel. SEAPODYM is a spatial population dynamics model (Lehodey et al. 2008), based on the analysis of spatially disaggregated catch and survey information (Senina et al. 2008), and in which the processes such as growth, maturation, survival dynamic of the species, its biology and migration are linked to environmental conditions, as described by the output of bio-physical models. Fitting SEAPODYM, incorporating catch, survey and environmental information allows describing the relationships between Jack Mackerel and its environment, and hence making spatio-temporal maps of the species distribution. The spatial population dynamics are based on the definition of feeding and spawning habitats. They are estimated using all available detailed observations (catch, size, acoustic) and compared to the statistical approach above. Both approaches can in the end be used to predict the potential habitats and the potential meta-population structure. In SEAPODYM, the equations describing the underlying dynamics of the population and of its sensitivity to the environment are a priori defined, and their coefficients are estimated through model fitting (Maximum Likelihood Estimation approach). Preliminary runs of SEAPODYM give contrasting perception of Jack Mackerel distributions, depending on the assumption made on the environmental forcing. Results are still very sensitive to the datasets used to optimize the model parameters. Especially in this modelling framework, highly detailed geo-referenced information is required to accurately determine the distribution of Jack Mackerel. On the basis of the preliminary simulations, no conclusions on a likely stock structure can be drawn as yet. Both additional data and updated environmental forcing will be used to obtain the optimal parameterization.

One of the likely stock structures is the single stock structure assumed in the assessment of Jack Mackerel in the SPRFMO Science Committee. The single stock structure is used and lumped catches of all fleets are used in the estimation of the stock development over time. On this basis, a framework that evaluates management objectives has been developed and tested. Using this framework, reference points for Jack Mackerel have been identified and potential harvest control rules have been investigated. Results show that there is a large chance for recovery of Jack Mackerel as long as fishing mortality remains at a low level. Differences in recovery rate, however, do depend on the choice of a harvest control rule design. Management objectives evaluated so far indicate that fishing mortality should not exceed the rate of 0.14 per year and that spawning biomass must recover above 10 million tonnes before total population size can be considered in a safe zone. Fishing is still possible under these scenarios, although a future recovery in recruitment is essential to allow the stock to recover.

5. Overall activities

The overall activities are described below in chronological order. All activities since October 17th 2012 are listed.

During the 11th Science Working Group meeting in Lima, October 2012, Niels Hintzen presented the outline of the 'Hydrography and Jack Mackerel stock in the South Pacific project'. The goal of the presentation was to explain the aims of this project to a large scientific audience and to stimulate collaboration of non-EU scientists with the project team. As a result, different members from Peru, Chile and Ecuador indicated interest in the project and requested further information. As a follow-up an email was sent to a large number of participants to the Science Working Group, as well as Preparatory Conferences, to further bring the project under the attention.

On the 21st of November 2012, a kick-off meeting was held between Niels Hintzen (IMARES, coordinator), David Miller (IMARES), Ad Corten (CMR), Patrick Lehodey (CLS), Arnaud Bertrand (IRD), Jeremie Habasque (IRD) and Francois Gerlotto (IRD). It was chosen to have a Skype online meeting as some partners were working in Peru on topics directly related to the project. The minutes of the meeting are included in this report under Annex A. The meeting touched upon items such as introducing the science questions and approaches to each other, dealing with the administrative issues of the project and getting a first overview of expected dates of initial results.

Since the kick-off meeting, Ad Corten, in charge of WP1, has contacted the SPRFMO secretariat and many other fisheries labs (not being partner in the project) in Chile, Peru, Poland and Russia to retrieve detailed information on fisheries and Jack Mackerel sampling. The development of the SEAPODYM model has most likely the highest demand for data. To streamline the delivery of data, Ad Corten has visited CLS to work out the data details. At the same time, Francois Gerlotto started to collect references of papers that needed to be considered in the reviewing exercise. Patrick Lehodey and Beatriz Calmettes in CLS prepared the environmental datasets and provided them to Jérémie Habasque in IRD, while Arnaud Bertrand, Jérémie Habasque, Patrick Lehodey and Anne-Cecile Dragon have started to develop the 3D habitat conceptual model, the statistical niche model and SEAPODYM model. Niels Hintzen has started to define the management framework model and software to be used to simulate Jack Mackerel stock structure hypothesis and their response to management actions.

On the 8th of April 2013, a meeting was held between the EC and the consortium (see Appendix A for minutes of this meeting and Appendix B for the agenda of the meeting) to discuss the inception report and discuss the issues encountered in collaborating with non-EU partners. The fruitful meeting resulted in a list of four action points, which all have been picked up in the meantime.

Jeremie Habasque and François Gerlotto participated in the ICES WGFAST (Working group on Fisheries Acoustics Science and technology) held in San Sebastian, Spain, on 15-19 April, 2013. A presentation was given on Jack Mackerel research under the title of "Effect of abundance on spatial strategies of the Jack Mackerel as observed through acoustic surveys" (François Gerlotto, Mariano Gutierrez, José Córdova).

From the 25th up to the 30th of June, Francois Gerlotto, Jérémie Habasque and Niels Hintzen joined in the 4th National Fisheries Society (SNP, Peru) Jack Mackerel workshop. The workshop was aimed at studying the status of the Jack Mackerel stock inside the Peruvian EEZ. For this reason, the main Jack Mackerel fishing companies had combined their registries of fishing activities and acoustic data, which was made available to all participants in the workshop. At the meeting, Jérémie, Francois, and Niels gave presentations on "How to use routine acoustic data as new tools for a 3D vision of the abiotic and biotic components of marine ecosystem and their interactions" and "ECHOPESCA: a processing tool for acoustic mono frequency data collected by the fishing vessels", the concepts of meta-population and its applicability to the case of Jack Mackerel and the general structure and goals of the EU project respectively. The main goal from the consortium perspective was to establish a working relationship with Peruvian partners. Although scientists from IMARPE (National fisheries institute of Peru) were to participate in the meeting, collaborations with SNP and scientists from the fishing companies have also been established. This resulted in the collection of additional high resolution data on Peruvian fishing operations in the years 2011-2013.

A midterm workshop was held at IMARES from the 10th to the 13th of September to discuss progress and prepare the first interim report. Presentations on all work packages were given and preliminary results were discussed.

A more elaborate description of the activities per work package can be found under paragraphs WP1-WP5.

6. WP1

Within this work package all relevant data sources available on the Jack Mackerel fishery and surveys are collected either from the public domain or through collaborations with marine institutes. The data collected under this work package contains aggregated or haul by haul catch information, acoustic back scatter datasets combined with hydrographical conditions and information on the biological composition of catches, as well as environmental time series on temperature and primary production from bio-physical models. The data is used to parameterize the models developed under work package 3 and 4.

Activities

Requests for data were sent to a number of institutes and organisations. These included, amongst others, the SPRFMO secretariat in New Zealand. The SPRFMO data base manager Craig Loveridge was very helpful in providing the maximum amount of data that he could release within the confidentiality restrictions that apply to the SPRFMO data set.

At the third meeting of the SPRFMO Data and Information Working Group, standards for the collection, reporting, verification and exchange of data were agreed. These standards stipulated that:

> "The interim Secretariat of the proposed SPRFMO is to compile and disseminate accurate and complete statistical data to ensure that the best scientific evidence is available while maintaining confidentiality where appropriate. Specifically the interim Secretariat is to:
>
> (a) Compile and disseminate on request the following “public domain” data:
>
> (b) Data on fishing activities, aggregated by flag state and calendar year and 5 degree by 5 degree areas, except in those cases where such data describes the activities of less than 3 vessels (in which case a lower resolution will be used)"

The restriction that SPRFMO could not release data for 5x5 degree rectangles in which less than three vessels had operated, limited the amount of data that could be released to approximately 90% of the total amount of data held in the SPRFMO data base, except for 2007 when this percentage was approximately 50%.

In addition to SPRFMO, a number of countries and organisations were contacted directly for information held in national data bases. The table below presents the persons contacted and the subsequent results of the contact:

Person contacted	Result
- Rodolfo Serra, the government fisheries research institute IFOP, Chile	Received detailed data on Chilean catches inside and outside EEZ and biological data
- Aquiles Sepulveda, the Research institute of the industry INPESCA, Chile	No response despite a number of repeated requests
- Italo Campodonico, the Chilean Ministry of Fisheries, Government fisheries research institute IFOP, Chile	Received Detailed data on Chilean catches inside and outside EEZ and biological data
- Ulises Munaylla, IMARPE, Peru	No response
- Jorge Csirke, IMARPE, the national fisheries research institute IMARPE and the fisheries producer's organisation INP, Peru	Received Acoustic data of Peruvian purse seine fleet
- Alexaner Glubokov, the National fisheries institute of the Russian Federation, VNIRO and the Atlantic fisheries institute AtlantNIRO, Russia	Received a reference to Dr. Kremeniouk
- Kremeniouk, Federal Agency for Fisheries, Russia	No response
- Nesterov, Atlantic Fisheries Institute AtlantNIRO, Russia	Received a report on Russian catches in South East Pacific in 1978-91
- Jerzy Janusz, the Polish Sea Fisheries Institute in Gdynia, Poland	No response
- Kim George, the National fisheries statistical office, New Zealand	No response yet (Email dated 11th September 2013)

Ad Corten visited the CLS laboratory in Toulouse on 13th December 2012 for a meeting with the colleagues working on the SEAPODYM model. During discussions with Patrick Lehodey, Inna Senina and Philippe Gaspar, the data requirements of the SEAPODYM model were discussed in detail, with particular emphasis on the spatial and temporal resolution. This in order to narrow the search for data to the specific requirements of the model.

Progress achieved towards deliverables & tasks

In total, three tasks and three deliverables have been described for WP1. The table below summarizes the progress towards these tasks and deliverables while below a more detailed description is given.

Task 1.1	Data from Dutch owned pelagic freezer trawlers (PFA) and SPRFMO database data is obtained. Data from Chile and Peru complement the dataset.
Task 1.2	Two environmental datasets have been prepared and are available to participants in the project
Task 1.3	Acoustic datasets are available from the fishing fleet and processed. Other survey information is still pending.
Deliverable 1.1	Databases have been created, and even extended beyond years indicated and include high resolution fishing information from Chile and Peru.
Deliverable 1.2	Two environmental datasets have been prepared and are available to participants in the project
Deliverable 1.3	Report is in progress

The following data sets have been obtained or requested so far:

Database origin	**Description of content**
SPRFMO data base	International trawler fleet outside Chilean and Peruvian EEZ: monthly 1x1 degree catches and number of tows for 2007 – 2011 - Chile inside and outside EEZ: annual catches of purse seine fleet by 1x1 degree rectangles for 2007 – 2009 - Chile: monthly catches distribution purse seine fleet by 1x1 degree rectangles for 2010 – 2011 for the international waters only
PFA trawler fleet in the Pacific database	This data set contains catch and effort data on a haul to haul basis for the PFA fleet in 2005 – 2013. The data set is regularly updated on the basis of new information obtained from PFA vessels in the Pacific. For a number of hauls, also the length distribution of the catch (obtained from observer information) is added to the data. The data set consists of a file for each year for each vessel. For each haul of each vessel, one line is provided with the following information: - date - time of start and finish - position of start and finish - water temperature - gear depth - catch of Jack Mackerel in kg - length distribution of Jack Mackerel in absolute numbers
Chilean database	The Chilean institute IFOP provided a comprehensive set of catch data for the Chilean purse seine fleet during 2007 – 2012 in the form of an Access data base. This contains day by day information on catch and effort both inside and outside the Chilean EEZ. Specifically, the dataset contains information on: - Retained catches abundance and weight by species (for each fishing haul) - Length frequencies - Sex and maturity stage IFOP collected acoustic data during three cruises of acoustic evaluation of Jack Mackerel biomass performed on board the RV ‘‘Abate Molina’’ in austral autumn/winter: 5 May to

17 June 1997, 3 June to 20 July 1998, and 15 May to 30 June 1999 (Cordova et al., 1998, 1999, 2000).
Specifically, the dataset contains information on:

- Acoustic nautical area scattering coefficient, sA integrated in 0.5 nautical miles elementary sampling distance units (ESDU) at a -65 dB threshold.
- In each ESDU, acoustic energy is available in four layers in 1997 (3-25 m; 25-100m; 100-200 m; 200-500 m), and in seven layers (3-25 m; 25-50 m; 50-100 m; 100-200 m; 200-300 m; 300-400 m; 400-500m) in 1998 and 1999.

Peruvian database IMARPE

The Peruvian Sea Institute (IMARPE) collected acoustic data during surveys performed since 1983 on several vessels, the R/V Olaya (41 m), the R/V SNP2 (21 m) and the RV Humboldt (76 m).
Specifically, the dataset contains information on:

- Acoustic nautical area scattering coefficient integrated in 1 nautical mile ESDU,
- Acoustic energy is available until 500m at 38kHz and 150 m at 120 kHz,
- Acoustic energy by schools

A request to the Peruvian Sea Institute (IMARPE) has been send to receive agreement to use these data in this project.

Peruvian database SNP

Peruvian fishing companies, own large industrial purse seiners, which a significant part of theirs vessels are equipped with digital echosounders SIMRAD ES60 (frequency 120 kHz) and split beam transducers.
Digital echograms are continuously recorded during all the fishing trips. Post-processing of echograms using Echoview software implies to execute a semi-automatic detection of fish schools. The assignation is based, (i) on the experience of the operator to identify echo traces, (ii) on the results of fishing sets. The detected schools are exported from the cleaned echogram to produce biomasses calculation (NASC) for each school and by ESDU of 0.5 nm. Such information represents around 200 000 ESDU sampled by the fishing fleet between January 2011 and May 2013. The interaction with SNP partners (mostly fishing companies) permitted to obtain catches and acoustic data from the main fishing companies for the period 2011-2013.

Environmental database

Two environmental datasets (NetCDFfiles) were produced and stored to be used in activities of WP3-4-5 (Deliverable D1.2) in:

- one long term (1960-2008) hindcast simulation at coarse resolution (2°x month) from a coupled physical-biogeochemical model NEMO-PISCES forced by atmospheric reanalysis NCEP.
- a second shorter time series (1998-2012) at higher resolution (1/4° x week) based on the GLORYS2 reanalysis and PSY3 operational model of Mercator-Ocean. Primary production and euphotic depth derived from ocean colour satellite data over the same domain and at same resolution were produced based on the VGPM model (Behrenfeld and Falkowski 1997). A dataset at degraded resolution of 1°x month was also prepared to facilitate the optimization approach (c.f. WP3).

The AtlantNIRO institute in Kaliningrad provided a document written by Dr. Nesterov with a summary of data on catches by the Russian catches trawler fleet in the Pacific in 1978 – 1991. The data is not available in a database format.

Catches by year and by statistical area for Trachurus murphyi have been obtained from a study conducted by Penney et al. (2010). A request for more disaggregated data has been sent to the New Zealand Statistical office.

In the table 6.1 the requests and availability of fishery independent datasets are described.

Table 6.1. Fishery independent data and their characteristics

Area	Fleet	Period	ESDU size (resolution)	With size structure?	Available?
Peru	IMARPE	1983 – 2013	1nm	No	Requested
	SNP	2011 – 2013	0.5nm	No	Yes
Chile	IFOP	1997 – 1999	0.5nm	No	Requested

CLS prepared two environmental datasets (temperature, currents, primary production, euphotic depth and dissolved oxygen) to be used for habitat modelling in WP2.

Deviations from the work plan

Deliverable 1.1 specifies the delivery of centrally stored aggregated catch data (by 5x5 nm rectangles) for all SPRFMO participants in the period 2000 – 2011 .

After consultation with Craig Loveridge, data manager of the SPRFMO secretariat, it became apparent that not all countries have fulfilled their obligation to upload the fisheries data to the database and therefore so far only data since 2007 has been obtained. The units mentioned in deliverable 1.1 (5x5 nm) should read 5x5 degrees, in accordance with the SPRFMO regulation stipulating:

> "The interim Secretariat of the proposed SPRFMO is to compile and disseminate accurate and complete statistical data to ensure that the best scientific evidence is available while maintaining confidentiality where appropriate. Specifically the interim Secretariat is to:
>
> (a) Compile and disseminate on request the following “public domain” data:
>
> (i) Data on fishing activities, aggregated by flag state and calendar year and 5 degree by 5 degree areas, except in those cases where such data describes the activities of less than 3 vessels (in which case a lower resolution will be used)"

Difficulties encountered

The project has succeeded in obtaining sufficient data to allow consortium partners IRD and CLS to set up their habitat and SEAPODYM models for the distribution of Jack Mackerel in relation to hydrographical conditions. However, with addition of data, the performance of the models improves. The project, therefore, continues to strive for more detailed information on historical catch distributions. The main sources of data that the project so far has not been able to access are:

Database origin	Description of content
Russian historical catch data	It has not been possible so far to obtain data in a digitised format from the Russian institute VNIRO in Moscow. Requests made by Dr. Inna Senina of CLS have so far remained unanswered. The problem is that the VNIRO institute is understaffed, and that the processing of data would involve costs for the deployment of extra manpower.
Polish historical catch and biological data	No positive response received from polish colleagues to collaborate
Chilean historical catch and survey data	The Chilean institute of INPESCA has not responded to our multiple requests for cooperation.
Peruvian historical catch and survey data IMARPE	The Peruvian government Sea institute IMARPE has so far not provided data from its national data base. The reason for this lack of cooperation is not clear.

Conclusions and way ahead

The project has so far assembled a large amount of data that can be used in the modelling studies by consortium partners IRD and CLS. The provision of detailed catch data by the Chilean institute (IFOP) was a major step forward.

Peru has not been forthcoming with data for its EEZ. Further attempts will be made to obtain disaggregated catch data and acoustic data also from this country.

Via the commission, another attempt will be made to retrieve historic catch and biological data from the Polish institute.

7. WP2

This work package consists of a literature study to describe and summarize the current knowledge on the Jack Mackerel stock structure. Reviewing existing literature on the biology, ecology and population structure of Jack Mackerel is crucial to interpret the results obtained in work packages 3-5. Many papers, in peer reviewed literature as well as in grey literature, have been published on the biology and on the exploitation of Jack Mackerel. The literature review has resulted in a synthesis. A summary of the synthesis is given in this chapter. The synthesis is an extensive document and key elements will be lifted out and discussed in more detail in a manuscript ready to submit to a peer-reviewed journal. In addition, statistical analyses have been undertaken to study the stock structure of Jack Mackerel. Getting a detailed overview of research readily carried out is key to prevent doubling of the work and to place the results of this project into the context of these previous studies. The literature review also details hypotheses on the Jack Mackerel stock structure, and by a critical analyses of the published results on the subject, it is possible to formulate hypotheses on what could be the most likely stock structure.

Activities

1. A general synthesis on Jack Mackerel has been prepared and will be delivered as a working document to SPRFMO on 30th September, to be distributed at the next meeting of the Scientific Working group (autumn 2013). It will then be published in a national journal (e.g. the Bulletin of IMARPE, Peru).
2. The structure of a scientific paper was defined and discussed within the Consortium. The objective is to have a manuscript ready for submission to a Scientific Journal within one year, as initially planned for this project.
3. Additional activities:
   a. Participation in the ICES WGFAST (Working group on Fisheries Acoustics Science and technology) held in San Sebastian, Spain, on 15-19 April, 2013. A communication was presented on Jack Mackerel research under the title of “Effect of abundance on spatial strategies of the Jack Mackerel as observed through acoustic surveys” (François Gerlotto, Mariano Gutierrez, José Córdova).
   b. Participation in the 4th workshop on the monitoring of the Jack Mackerel using the data from the fishing fleet of Peru, organised by the National Fisheries Society of Peru (Sociedad Nacional de Pesca, SNP) on 24 June – 3 July, 2013. A communication was presented on the theme of “Meta-populations, spatial strategies and management of Jack Mackerel: the role of acoustic data” (F. Gerlotto)

Progress achieved towards deliverables & tasks

In total, two tasks and one deliverable have been described for WP2. The table below summarizes the progress towards these tasks and deliverables while below a more detailed description is given.

Task 2.1	The literature review is finished and the bibliographic list is completed
Task 2.2	An outline of the peer reviewed manuscript is prepared and writing is underway
Deliverable 2.1	An outline of the peer reviewed manuscript is prepared and writing is underway

The general structure of the synthesis, that follows from the literature study, is the following:

- Introduction
- Chapter 1. Zoology
- Chapter 2. Fish biology
- Chapter 3. Ecology
- Chapter 4. Fisheries
- Chapter 5. Populations
- Synthesis and conclusions
- Bibliography

Zoology gathers the classical information on taxonomy, morphometric and meristic characteristics of the Jack Mackerel.
Main conclusion of Chapter 1. Supports the recommendation of SPRFMO to develop research on the analysis of the morphometric characteristics of fish in different sectors of its distribution area using multivariate analysis.

Fish biology presents the main biological characteristics of the fish in the areas of reproduction, migrations, alimentation, growth and behavior.
Main conclusions of Chapter 2. The biological characteristics show that Jack Mackerel presents a high tolerance to hydrological conditions.

Ecology focuses on the ecology, and especially the relationships between hydrology and fish distribution, trophic ecology and interactions between Jack Mackerel, the fish community and description of the habitat conditions.
Main conclusions of Chapter 3. (1) Two major points characterize the South East Pacific Ocean: the strength of the climatic signals (e.g. El Niño) and their high variability. Fish populations must develop a high resilience and plasticity to adapt to these characteristics. (2) Under these conditions Jack Mackerel has developed the ability to produce large cohorts through episodic successful recruitments; capacity to colonize a large part of the subtropical Southern Pacific Ocean seeking the most favorable areas for maintaining a correct abundance; a great individual tolerance to the local environment; considering that the species has no major predators in the bulk of its distribution area, the main limiting factor to its distribution and abundance is prey availability; although the species has a great plasticity, it has an environmental preference in terms of O^2, temperature, salinity and water masses.

Fisheries presents the fisheries of Jack Mackerel in the Pacific Ocean, and especially the four principal ones of these last years: Chile, Peru, Russia and EU. The fishing regulations and principal assessment methods are also presented. An important paragraph deals with fish population monitoring through the use of acoustic methods aboard scientific and fishing vessels. The use of the fleet for monitoring corresponds to a recommendation of the SPRFMO and is particularly efficient. Experiments on the Peruvian fishery were done by the SNP (see above) and demonstrate their richness (figure 7.1)

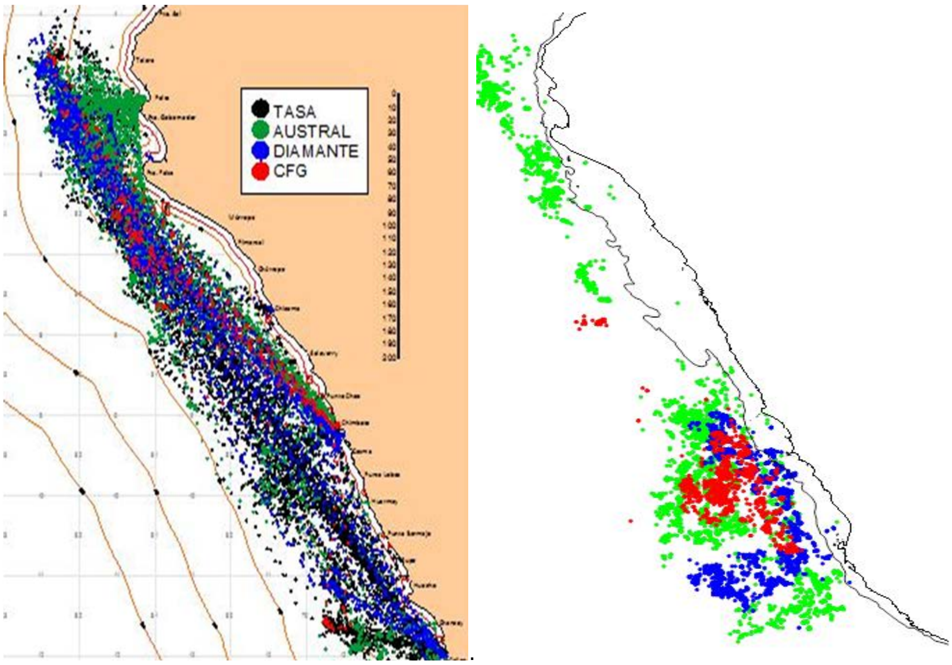

Figure 7.1. Left: Magnitude of the potential sampling effort: map of the points sampled acoustically by the fishing fleet of the four most important fishing companies in Peru (TASA, Austral, Diamante, CFG) during the period January-March, 2011 (from SNP workshop report, 2011). Right: Purse seine sets on Jack Mackerel and mackerel in 2011 (green), 2012 (blue) and 2013 (red). The spatial repartition of the fish can be observed, and particularly the fact that Jack Mackerels do not enter inside 180 m isodepth (left line) off the coastline (right line). From SNP workshop report, 2013)

Main conclusions of Chapter 4. Monitoring using fishing vessels is probably one of the most important recommendations for SPRFMO. The feasibility of such monitoring is demonstrated through its application in the case of the Peruvian fleet. The Chilean fishery is also monitored but there is no reference in the literature.

Populations describes the fish population, its evolution in distribution and abundance, the results on the population structure obtained by several biological markers (genetics, parasites, otoliths), the history of the demographic dynamics of the population, and analyses on population structure.

Main conclusions of Chapter 5.

(1) Unity of Jack Mackerel as a single species in the South Pacific Ocean, and although there are patches of high densities in several areas (North Chile, Peru, centre-south Chile, open ocean west of 90ºW, etc.) there is no biological evidence of significant differences between them.

(2) The dynamics of the Jack Mackerel is characterized by the occurrence of occasional strong cohorts, sometimes associated with El Niño occurrence (figure 7.2).

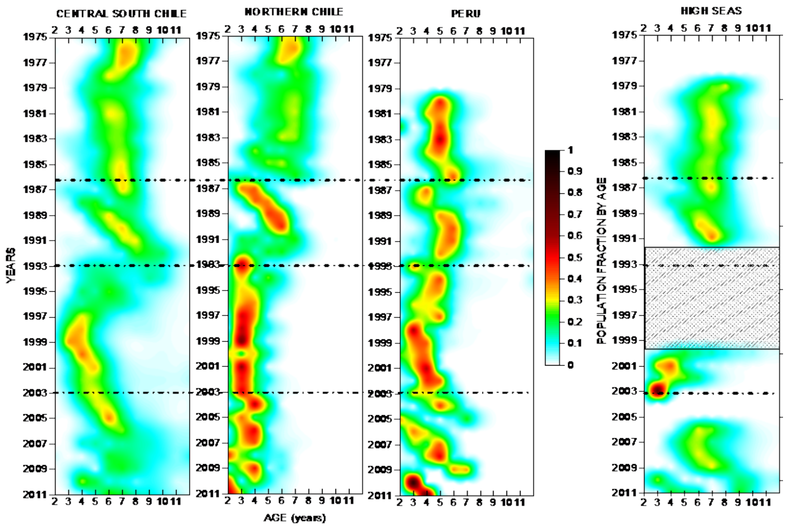

Figure 7.2. Age structure of Jack Mackerel caught in the four main fisheries during the period 1975-2011 (from SPRFMO data, in Gerlotto et al., 2012). The grey area in the high sea fishery corresponds to the period with no fishing activities between the end of the Soviet Union and the beginning of the Russian fishery.

(3) Jack Mackerel expansions and shrinking of the distribution synchronizes with strong changes in the environment; in periods of stable conditions, significant differences appear between the regions, especially as far as recruitment and distribution are concerned.
(4) The meta-population hypothesis is the one that seems to be the most consistent with the major biological and ecological characteristics of the Jack Mackerel.

Preparation of the peer reviewed manuscript.
A synthesis on the spatial strategies of Jack Mackerel will be submitted to a journal e.g. Fish and Fisheries or Progress in Oceanography. The synthesis, as tasked under 2.1, allows defining more precisely the framework of the peer reviewed manuscript. A proposed (but subject to changes) title is "Spatial strategies of the Jack Mackerel and consequences on its exploitation", with 4 major chapters on

(1) the main patterns of the Jack Mackerel related to spatial strategies;
(2) The Jack Mackerel habitat;
(3) The meta-population as a hypothesis of spatial structure;
(4) Ecosystem-based and population-based management of *T. murphyi.*

Deviations from the work plan

No deviations have been made so far.

Difficulties encountered

No major difficulties were encountered. A minor difficulty was the cooperation with scientists outside the EU project. The synthesis was supposed to be written in co-operation with scientists of the main countries exploiting the Jack Mackerel, and particularly Chile and Peru. We obtained agreement from Mr Teobaldo Dioses from Peru to be co-author, but the scientist that we contacted in Chile was not allowed to be involved in this work.

Conclusions and way ahead

WP2 is underway without major problems, with the exception of the difficulties to convince Chilean scientists to accept co-authorship on the synthesis paper. This has no impact on the work. The synthesis shows that there is important material available, mostly in unpublished reports that cover all the aspects of the biology, the ecology and the fishery of the Jack Mackerel. From this considerable bibliographic base the major characteristics of Jack Mackerel life history traits have been extracted, and particularly on the elements that can be used for defining the habitat of this species (table 7.1).

Table 7.1. Description of the limits and preferences of the Jack Mackerel for the main hydrological parameters

parameter	Lower limit	Upper limit	Lower preferendum	Upper preferendum
Oxygen	0.1 ml/l	-	0.2 ml/l	-
temperature	9º	26º	15º	20º
Salinity	<minimum observed	>maximum observed	34.9	35.1
Chl a	0.07mg/m3	26 mg/m3	0.1	?
oxycline	-	30 m	-	40 m

The conclusions of the work cover the three major aspects that are relevant for the project: habitat and plasticity of the Jack Mackerel, population strategies and population structure. They are detailed in the "General conclusion of the synthesis".

The framework of the scientific paper has been defined and the work on this paper has started. One major task to start in the next weeks/months will be to establish the list of co-authors that are needed for the writing and editing of the scientific paper. Ideally this list should include scientists from the EU project and scientists from other countries that exploit the Jack Mackerel, principally Chile, Peru and Russia. There are contacts with Peruvian scientists and there is a list of potential co-authors. The same action should be undertaken with Chilean and Russian scientists. This will be done during the next meeting of the SPRFMO Scientific Committee in October, 2013.

8. WP3

This work package centres around the question of how hydrographical, environmental and biogeochemical conditions shape the Jack Mackerel habitat and determine its distribution, composition and population structure. Combining fisheries and survey data with hydrographical data allow characterising the environmental conditions in which Jack Mackerel is present in the South Pacific region. Using different modelling tools, predictions of the potential habitat for Jack Mackerel can be made. The spatial distribution of the potential habitat and its temporal variations will provide information on the likelihood of different hypotheses on stock structure.

Activities

1. Skype meeting between Arnaud Bertrand, Jérémie Habasque, Patrick Lehodey and Anne-Cécile Dragon about the hindcast data (NCEP) available back to 1960
2. Using published information (see WP2) and data available (see WP1) we identified the key hydrological and biogeochemical factors determining the Jack Mackerel distribution
3. Based on the key environmental parameters we proposed a 3D conceptual habitat model
4. A bibliographic review was made on the niche and habitat models
5. A statistical niche model was developed to study different stock structure hypothesis
6. First optimization of feeding and spawning habitat with SEAPODYM
7. Additional activities:
    a. Participation in the ICES WGFAST (Working group on Fisheries Acoustics Science and technology) held in San Sebastian, Spain, on 15-19 April, 2013. A communication was presented on Jack Mackerel research under the title of “Hydrography, stock structure and habitat definition of the Jack Mackerel” (Jérémie Habasque, Hervé Demarcq, Anibal Aliaga, Alexis Chaigneau, François Gerlotto, Arnaud Bertrand). This presentation resulted in fruitful methodological discussions on data analysis and specifically niche models.
    b. Mission of Jérémie Habasque in Peru in June 2013. Participation to the 4th SNP (Sociedad Nacional de Pesqueria) Jack Mackerel workshop in Lima: interaction with Peruvian partners (mostly fishing companies). Catches and acoustic data from the 4 main fishing companies were obtained for the period 2011-2013.
    c. Mission of A. Bertrand in Peru and Cuba in May 2013 (co-funded by IRD). In Peru: interactions with partners from the Instituto del Mar del Peru (IMARPE / Peruvian Institute of the Sea). In Cuba: meetings at the “Instituto De Oceanología (IDO)” and the “Centro de Investigación Pesquera” to rescue catch data from the Cuban fleets. The data is virtually lost, i.e. the paper sheets where the information is recorded are no more located.
    d. Participation in the ICES annual conference 2013 (Session: *Responses of living marine resources to climate change and variability: learning from the past and projecting the future;* co-sponsored by PICES) held in Reykjavik, Iceland, on 23-26 September, 2013. A communication was presented on Jack Mackerel research under the title of “Between Scylla and Charybdis: Modeling the Challenging Impacts of Climate and Fishing on the Jack Mackerel” (Anne-Cécile Dragon, Inna Senina, and Patrick Lehodey).

Progress achieved towards deliverables & tasks

In total, three tasks and two deliverables have been described for WP3. The table below summarizes the progress towards these tasks and deliverables followed by a more detailed description.

Task 3.1	Key hydrographical and biochemical factors that determine the Jack Mackerel distribution have been defined
Task 3.2	A statistical habitat model on the 3D habitat for Jack Mackerel has been developed and is currently used to test stock structure hypotheses, effects of El Niño effects and potential area for reproduction
Task 3.3	Parameter optimization and design of the SEAPODYM model applied to Jack Mackerel is underway. Preliminary parameter estimations are available
Deliverable 3.1	A description of the 3D statistical habitat model is finished. Stock structure hypothesis are currently being tested
Deliverable 3.2	A description of the SEAPODYM model configuration for Jack Mackerel is available as a draft report. On-going simulations to achieve optimal parameterization from all available data will provide stock structure hypothesis.

WP3 consists of two distinct activities: 1) Develop the statistical 3D habitat model for Jack Mackerel and 2) develop a configuration of the SEAPODYM model for Jack Mackerel. For this reason, the detailed description given below first deals with 1) and thereafter with 2).

Statistical 3D habitat model for Jack Mackerel

The global methodology adopted is:

1. Identify the key environmental factors determining the Jack Mackerel distribution
2. Develop a conceptual model of the Jack Mackerel habitat in 3D
3. Study the impact of different contrasted habitat conditions on Jack Mackerel distribution and stock structure
4. Statistical niche modeling

The main explanatory variables selected for the study are:

- Dissolved oxygen
- Sea surface temperature
- Chlorophyll-a concentration

From the available data from different sources (satellite, scientific survey, fishing vessels capture and acoustic data, see WP1), we estimated the favorable range of each parameter in both horizontal and vertical dimension (see table 8.1 below). Note that as size-frequency data were not used, the work is realized mixing both adults and juveniles.

Oxygen concentration is crucial in the South-East Pacific, as it can be absent at very shallow depths (up to 20m below the surface along the Peruvian coastline). Jack Mackerel is unable to live in waters with oxygen concentrations below 1 $ml.l^{-1}$ although 2 $ml.l^{-1}$ is accepted as a more representative threshold. Moreover, according to the same authors, it seems that besides a minimum Dissolved Oxygen (DO) concentration, the Jack Mackerel requires a rather important height of the DO: if it presents a height lower that 40 meters, Jack Mackerel could not stay in the oxygenated volume (Bertrand et al. unpublished data).

As minimum temperature observed among all the datasets is 8.7°C, we consider 9°C as the lowest tolerable temperature. Results confirm the work by Bertrand et al., 2006. We also estimated the minimum depth of the 9°C isotherm at 60 meters depth.

The lowest tolerable chlorophyll concentration limit is between 0.1 and 0.2 mg/m3. This is outside the subtropical gyre where concentration is considered <0.07 mg/m3 (Polovina et al., 2008).

Table 8.1. Estimated ranges of selected explanatory variables in both horizontal and vertical dimension

Dimension	Parameter	Estimated range
Horizontal	Sea surface temperature	[9-26]°C
	Chlorophyll-a concentration	>0.07mg.m-3
Vertical	Dissolved oxygen	>2 ml.l-1
	Depth of DO 2 ml.l-1	>40 meters
	Depth of isotherm 9°C	>60 meters
	Maximum depth	400 meters

Furthermore, we make the hypothesis of a physiological interaction between both environmental parameters SST and CHL-a concentration. With higher temperatures, more food is needed. As shown in figure 8.1, we fitted the Sea Surface Temperature distribution (SST) for Jack Mackerel presence in relation with chlorophyll-a concentration.

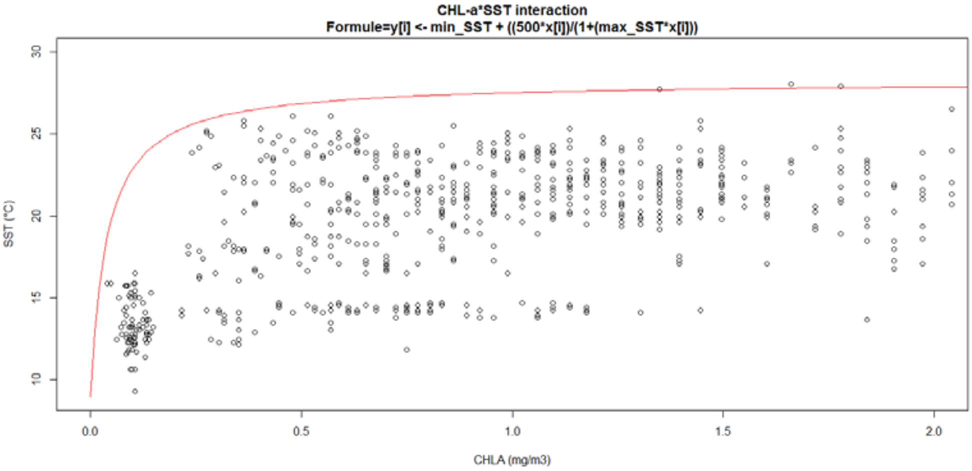

Figure 8.1. Model of CHL-a * SST interaction

Using the Dutch catch dataset, we observed the evolution of the fishing fleet positions between the external part of the subtropical gyre and Chilean ZEE limits. There is a strong correlation by month between the external part of the subtropical gyre and the vessels positions. Indeed, at basin scale, the inter-annual variability is lower than the seasonal variability. So, we propose to estimate the potential habitat limits and to develop a model by month (or season).

For each month, a potential habitat map can be drawn with horizontal limits (defined in task 3.1) using:
subtropical gyre limit (CHL-a concentration = 0.07 mg/m3),
isoline SST 9°C for southern limit,
isoline SST 26°C for northern limit,
interaction between SST and CHL-A as shown previously.

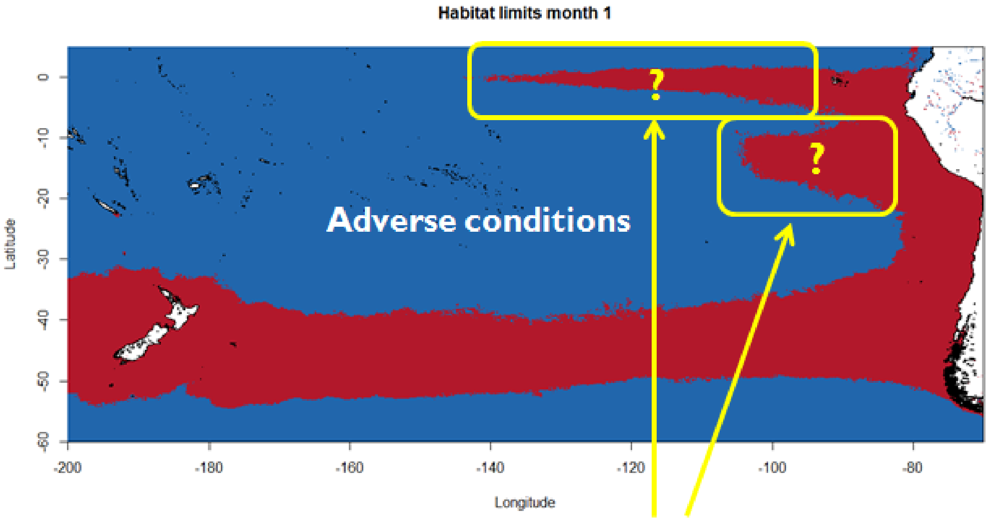

Figure 8.2. Suitable habitat limits map for month January. The red colour represents the suitable habitat for Jack Mackerel while the blue colour represents the area with adverse conditions for Jack Mackerel to survive. The areas identified with question marks identify suitable areas for Jack Mackerel but where Jack Mackerel observations are lacking from to ground the predictions.

From figure 8.2, we observe that the southern latitude boundary for the species is around 50°S that corresponds to the sub-Antarctic front. Analyzing this map, we see that some potential habitat zones (equatorial tongue, 15°S-20°S) aren't fitting well with the known distribution of Jack Mackerel based on historical catches (not shown in the map) and acoustic data points (not shown in the map) and/or published results.
Other parameters were explored to explain the habitat limits: advection, thermal amplitude, subsurface currents (Chaigneau et al., 2013) but no explanation for the equatorial tongue were found.
So, we suppose that probably biotic parameters (predation/competition e.g. interactions with different tuna species, giant squid, cetaceans) are playing a role in structuring the habitat.

Adding vertical parameters criteria, a conceptual model of the habitat of the Jack Mackerel in 3D has been developed (figure 8.3).

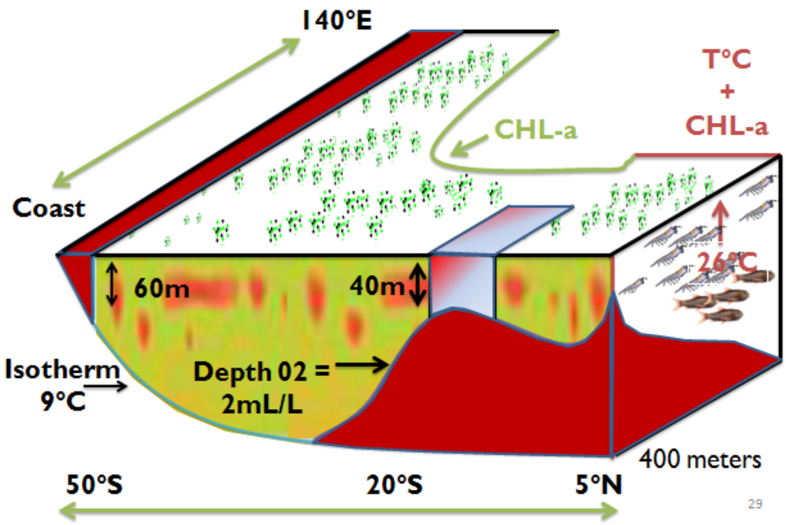

Figure 8.3. 3D conceptual model of the Jack Mackerel habitat describing the habitat on the basis of latitude (x-axis), longitude (y-axis), depth (z-axis), depth layer of the oxycline (Depth 02), the isotherm layer and chlorophyll concentration.

At 40°S, no environmental parameter is playing a role in the structure of Jack Mackerel habitat. Only prey distribution and the vertical migration (day/night) is impacting Jack Mackerel distribution and schooling behavior (Bertrand et al., 2006).

Habitat compression hypothesis

South Pacific historical landings present a strong collapse over the last decades. Many factors explain this trend (fishing fleet development, overfishing, etc.) but paleoceanography studies (Salvatecci, 2013) indicate that the environmental driver is probably highly important.

To explain this habitat compression hypothesis, we selected different scenarios of contrasted habitat conditions: high abundance period vs. low abundance period (e.g. the early 1990s vs. the 2000s) to study the impact of different ocean-shape on Jack Mackerel distribution and stock structure.
We choose to compare the parameters limits defined before (task 3.1) in both space and time.

A significant warming trend has been observed in South East Pacific over the past 30 years. However, this trend is not strong enough to change the habitat of the species. The same trend is observed for the primary production evolution. For the Peruvian and North Chilean waters (figure 8.4), the depth of minimum tolerable dissolved oxygen concentration seems to be a good proxy to validate the habitat compression hypothesis.

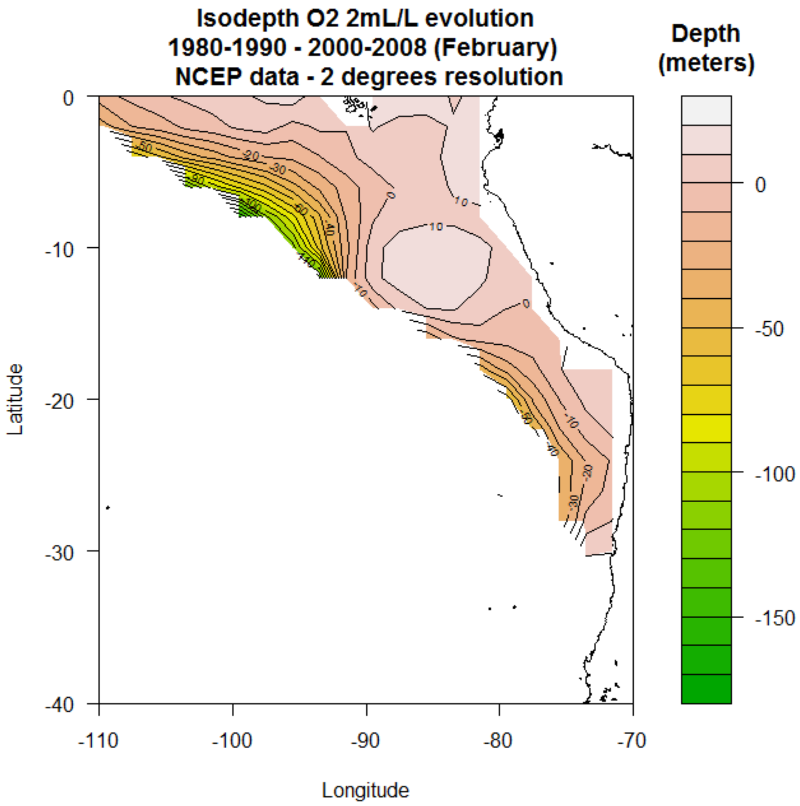

Figure 8.4. Difference between 1980's and 2000's February mean depth of the O2 2ml.l-1 (NCEP data monthly 2 degrees resolution)

Statistical niche modelling

Here we aim to test two types of models:
Presence/absence (with geostatistical approach for true/false absence discrimination)
Presence only with pseudo-absences
Environmental parameters can play different roles in different areas: for example, O^2 could have an impact on Jack Mackerel distribution in Peru but not in Chile. We have therefore tested different model types for each area.

The computational framework used for the model comprises the following steps:
Selection of a time series of species occurrence with the widest environmental window (including strong El Niño events)
Regression modelling (GLM, GAM) with a calibration dataset (90% of the all dataset)
Use of regression kriging to incorporate spatial dependence into predictions
Evaluation and best model selection with an evaluation dataset (10% of the all dataset)
Plotting monthly probability map of species distribution using the best model predicting the actual species distribution.

The methodology used for the statistical modelling is presented in figure 8.5.

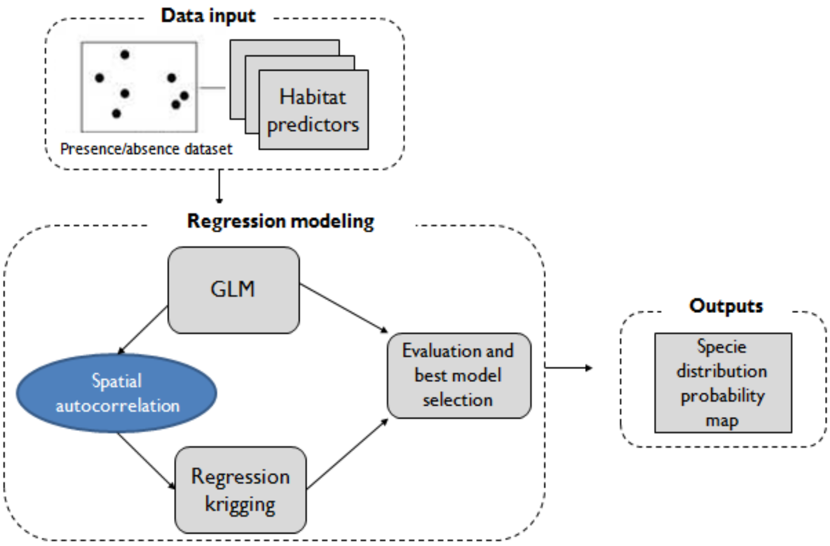

Figure 8.5. Statistical modelling methodology diagram. To design the model, input data describing habitat predictors (such as SST and Chlorophyll concentration) are used to setup a GLM model. The GLM model is thereafter used to predict the spatial distribution of the potential Jack Mackerel habitat using kriging methods.

The data required to perform the analyses is:

- Environmental data – 1 degree monthly climatology:
- SST,
- CHL-a,
- Depth 2mL/L O2,
- Depth isotherm 9°C.

Biological datasets:

- Acoustic data from IMARPE surveys,
- Acoustic data from IFOP surveys 1997-1999,
- Catches from Dutch fleet 2005-2011,
- Peru catches 2011-2013,
- Chilean catches 2007-2012

Figure 8.6 presents preliminary results/examples of the statistical niche modeling using a presence/absence model and GLM algorithm.

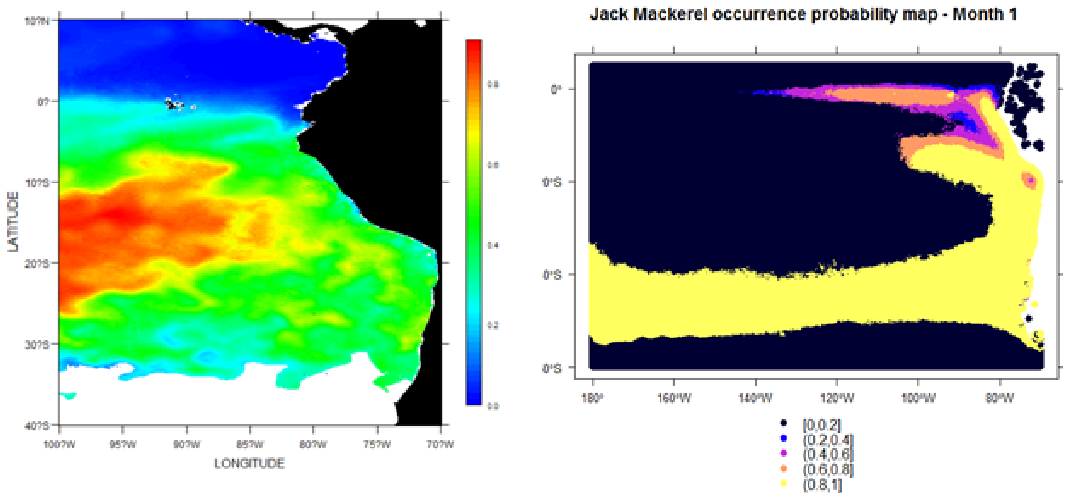

Figure 8.6. Left. Example of a probability map (values between 0 and 1) obtained using Biomod package (courtesy provided by Ricardo Oliveiros). Right. First try of modelling the probability that Jack Mackerel could occur in the area using a GLM

Configuration of the SEAPODYM model for Jack Mackerel

Available fishing data and acoustic data (Tables 8.2 and 8.3) were included in a first series of optimization experiments using coarse resolution configurations (NCEP-NEMO-PISCES) and a maximum likelihood estimation approach. Two Dutch fleets were defined based on the size of the fishing boats (Large = TW1; Small = TW2). A third fleet contains aggregated data of other foreign fleets in international waters ("Foreign" = TW3) and a 4th fleet was recently included for the Chilean 1°x month data (TW4). Since the environmental series stops in 2008, this optimization experiment is based on 2005-2008 data only. While these fishing data provide very detailed spatial information for the recent years (i.e. since 2005) it should be noted that they represent a very small amount of total catch over the whole exploitation period (i.e. since the 1970s).

Table 8.2. Fishing data available for habitat modelling and SEAPODYM optimization provided by WP1

Area	**Fleet**	**Period**	**Temporal scale**	**Georeference available**	**Size Structure available**	**Fleet code**
All	Dutch large-size trawlers	2005-2013 (no fishing in 2012)	Day	Yes	Yes	TW1
All	Dutch small-size trawlers	2005-2013 (no fishing in 2012)	Day	Yes	Yes	TW2
High Seas		2007-2011	Month	Aggregated 1°x 1°	No	TW3
All	Chilean	2010-2011	Month	Aggregated 1°x 1°	No	TW4
All*	Chilean	2007-2009	Annual	Aggregated 1°x 1°	No	
All*	Chilean	2007-2012	Day	Yes	Yes	
All*	Peruvian	2011-2013	Day	Yes	No	

*data provided recently and not yet included in the analysis.

Table 8.3. Acoustic data potentially available for habitat modelling and SEAPODYM optimization provided by WP1

Area	Fleet	Period	ESDU size (resolution)	Size structure availability	Availability
All	IMARPE	1997-1999	1nm	No	Requested
All	Peruvian	2011-2013	1nm	No	Yes
All	IFOP	1997-1999	0.5nm	No	Requested

Catch data, effort data and size frequencies obtained from catch data were used in a first optimization experiment conducted with a coarse resolution configuration of the model (2°x month) over the South Pacific domain based on a hindcast simulation with the coupled NEMO-PISCES model driven by the atmospheric reanalysis NCEP over the period 1958-2008. The model provided an excellent fit to the (available) fishing data both for catch and CPUE as well as for their spatial distribution (figure 8.7). However, several parameters were fixed to plausible values obtained from the literature rather than estimated through the Maximum Likelihood Estimation (MLE) approach. Predicted spatial distribution of adult fish match with the known distribution of catch over the last decade (figure 8.7) showing a core habitat with high fish density extending from the southern coast of Chile to the open ocean up till 100° W longitude, then decreasing in density further west. A secondary patch of relatively high density is predicted in the north extending off the coast of Peru. For spawning habitat and larvae density, the model prediction is maybe less convincing as it predicted the highest density in a latitudinal band of 25°S-35°S between longitude 85°-125°W that seems too far offshore and shifted north compared to existing knowledge suggesting a spawning ground offshore Chile below 30°S. It is worth noting that spawning is also predicted to occur in the north east of New Zealand waters, but at weak intensity.

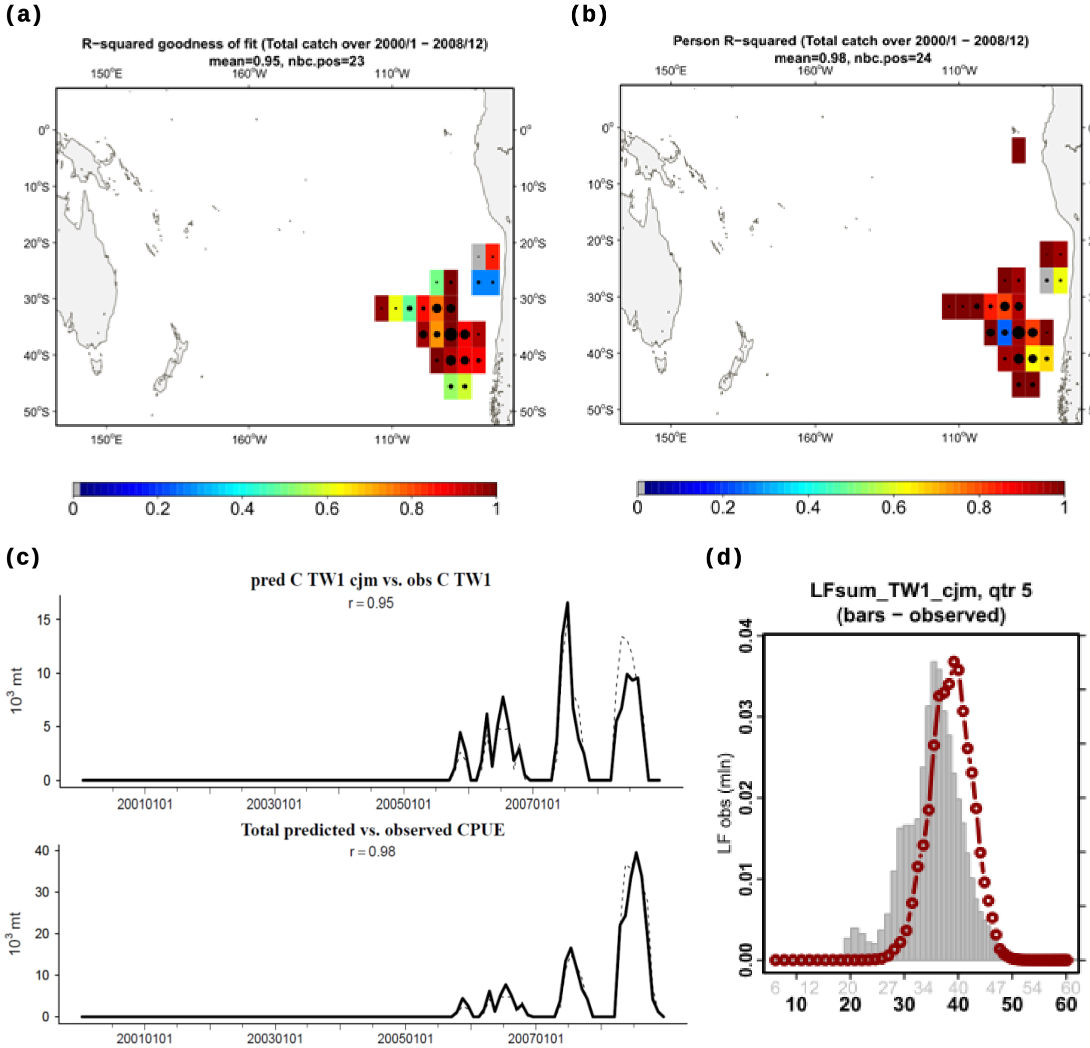

Figure 8.7. SEAPODYM fit to data: (a) Map of R-squared goodness of fit representing the spatial fit between all observed and predicted catch over the period used for optimization (white squares indicate negative correlation between observations and predictions), overlaid with the total catch in each cell (black circles proportional to catch); (b) Map of Pearson r-squared metric, which quantifies the percentage of the catch variance explained by the model in each cell, overlaid with the number of observations (fishing events). A good fit means that both predicted and observed series fluctuate in the same way; (c) predicted and observed catch and CPUE for the first fishery; (d) predicted and observed length frequency data for the first fishery.

The coarse resolution may be an issue explaining these results and a second experiment was conducted with a finer resolution configuration of the model (1°x month) over the South Pacific domain before envisaging to use a still higher resolution at ¼° x week. The physical variables are from the ocean reanalysis GLORYS-v2 (http://www.mercator-ocean.fr) and the primary production deduced from satellite derived primary production (Behrenfeld & Falkowsky, 1997). The time series is short (1998-2012) due to the availability of satellite ocean colour data. While in the first experiment the dissolved oxygen concentration was computed and provided from the biogeochemical model, here in absence of the biogeochemical model, the World Ocean Atlas climatology is used. The population structure is the same as in the first experiment. The model provides a reasonable fit to the data. But despite the more realistic physical environment this solution is not yet optimal since parameter values of temperature functions cannot be estimated within their boundary values. For the oxygen function, the value of the threshold parameter was estimated much lower than in the first experiment, which is likely due to the use of climatology data. Predictions of both adult feeding and larvae habitats are given in figure 8.8 and suggest a plausible distribution given the available data on catch distribution and knowledge on spawning grounds. Sensitivity to environmental forcing is currently explored, in particular oxygen and micronekton to understand the mechanisms that produce these two different solutions.

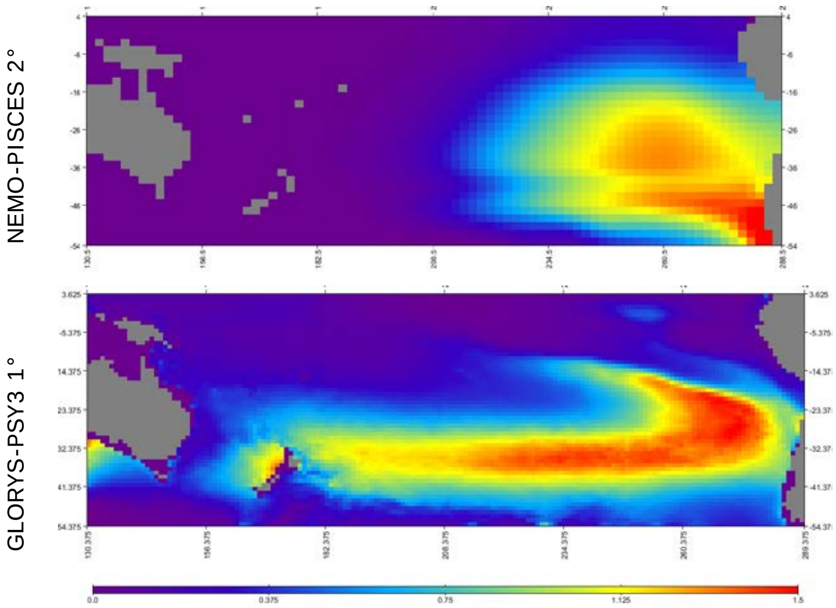

Figure 8.8. Average predicted density distribution for adult Jack Mackerel for the period 2000-2007 estimated with two different configurations (NEMO-PISCES and GLORYS-PSY3).

Already it appears that long term change in the oceanic environment over 1960-2008 can modify the spatial dynamics of habitat substantially. A second phase of optimization experiments needs to be conducted using additional fishing and acoustic data to converge toward an optimal parameterization.

Deviations from the work plan

No deviation except for limitations due to data availability.

Difficulties encountered

Spatial biological data are sparsely available in high seas area, especially in the New Zealand area. Ad Corten will investigate existence of this data. Prey field information is required to better understand the trophic interaction. Jérémie Habasque will investigate this aspect. Patrick Lehodey will contact colleagues in New Zealand who recently published a study based on acoustic transects in the south Pacific (Escobar-Flores et al 2013). The overlap of data time series (2005-2011) and environmental coarse resolution forcing (1960-2008) limited the SEAPODYM optimization with fishing data to only 4 years (2005-2008).

Conclusions and way ahead

WP3 is underway without major problems. Hydrographical and biological data obtained under WP1 and knowledge gained under WP2 were linked to estimate or validate the environmental parameters range. Suitable habitat limits for the species were proposed. Some areas are not well understood but globally results fit well with the known distribution of Jack Mackerel based on historical catches and published acoustic data points. Additional data that was recently provided by Peru and Chile and not yet included in this study will be used to update the analyses. Impact and sensitivity to the variability of dissolved oxygen concentration will be explored further.

The statistical niche model is almost developed and should allow determining if environment may limit the Jack Mackerel distribution. This tool is useful to test different stock structure hypothesis and to check the habitat compression hypothesis.

Statistical 3D habitat model for Jack Mackerel

Limits and preferences of Jack Mackerel for the main hydrological parameters will be studied by length or age when additional data becomes available as tolerance to hydrographic conditions at very-early and adult life stages could be different.

In addition to the decadal-related variability hypothesis, other scenarios have to be explored. In particular, we propose to compare extremes years (lowest abundance vs. highest abundance).
The niche model improvement is highly dependent on data availability. If data becomes available we will be able to improve the statistical niche model by adding the fish stage-structure (eggs/larvae, juveniles, adults).

Based on past and present oceanographic conditions and biological criteria estimated for the species, the most likely stock structure hypothesis has to be provided to WP5.
Arnaud Bertrand is going to Peru in November/December (mission mainly funded by IRD). During his visit workshops with Peruvian colleagues (IMARPE) will be organized to discuss how environmental parameters impact Jack Mackerel stock structure.

Configuration of the SEAPODYM model for Jack Mackerel

The first results based on the SEAPODYM optimization approach are encouraging and should still improve with additional fishing and acoustic data recently provided and potentially new available data. Jack Mackerel fishing data from New Zealand waters could provide useful information as they are at the limit of the species habitat. A request has been sent to New Zealand fishery scientists working on this species.

- An update of the hindcast simulation NEMO-PISCES is expected that could extend the overlap with the data time series to more recent years (i.e., 2009-2012) and also increase the resolution to 1°x 1°.
- Another physical forcing dataset based on a dynamic interpolation of all oceanographic data at 1°x month (called OMEGA) has been provided by Russian oceanographers and will be used also to achieve the best coherent parameterization of spawning and feeding habitat of Jack Mackerel.
- Key potentially explanatory mechanisms that explain the habitat of Jack Mackerel will be explored including the sensitivity of feeding habitat parameterization to the use of oxygen climatology and the separate definition of eggs and larvae habitats.
- The relationships between larvae recruitment and climate and environmental variability will be investigated to understand the mechanisms leading to recruitment and stock fluctuations.

9. WP4

Management of the Jack Mackerel stock in the South Pacific is currently based on ad-hoc advice given by the SPRFMO Science Working Group. To ensure sustainable exploitation of the stock, management targets need to be defined. These consist of reference points that indicate sustainable versus overfishing limits, as well as harvest control rules that stipulate fishing or biomass targets depending on the state of the stock. Within this work package, harvest control rules and reference points are designed and evaluated. These evaluations will provide stakeholders with sustainable harvest control options to choose from. In addition, the scenarios can be used to test the effects of mesh size increases or minimum landing sizes.

Activities

1) Discussions between consortium members to exchange information about population dynamics and exploitation of Jack Mackerel allowing to parameterize the population structure and evaluate the first results of a hindcast simulation back to 1960.
2) The low resolution dataset of oceanic variables (NEMO-PISCES) forced by the NCEP atmospheric reanalysis over 1958-2008 was used to simulate a hindcast projection of the Jack Mackerel population based on optimization achieved in WP3.
3) Model development in SEAPODYM to use environmental forcing to allow projections to be carried out
4) Development of Management Strategy Evaluation framework
5) Evaluation of Management Strategies under different harvest control rule assumptions
6) Discussion with Chilean scientists on best practices in reference point estimation and rebuilding plan development

Progress achieved towards deliverables & tasks

In total, five tasks and two deliverables have been described for WP4. The table below summarizes the progress towards these tasks and deliverables while below a more detailed description is given.

Task 4.1	Reference points have been estimated on the basis of the latest assessment results, as well as on the basis of previously determined results and provide robust estimates
Task 4.2	The framework to evaluate changes in mesh size and landing size has been developed. No simulations on changes in these aspects has been evaluated.
Task 4.3	Medium term projections have been evaluated against a set of harvest control rules
Task 4.4	Example harvest control rules have been defined and evaluated. Stakeholder workshop is scheduled for November 2013.
Task 4.5	A draft parameterisation of the SEAPODYM model has been designed and will be used to perform projections
Deliverable 4.1	A draft report on D4.1 ii, iii an iv is available
Deliverable 4.2	No preliminary scenarios are available

WP4 consists of two distinct activities: 1) Simulation of population development with the SEAPODYM model for Jack Mackerel and 2) design of a Management Strategy Evaluation on the basis of the most recent stock assessment results with indications of potential HCR and reference points. For this reason, the detailed description given below first deals with 1) and thereafter with 2).

Simulation of population development with the SEAPODYM

To test the environmental impact on Jack Mackerel at an interannual to decadal scale, a hindcast simulation of population dynamics was produced over the historical period using the NCEP-PISCES configuration between 1960-2008 without fishing, since these data are not yet available. The results suggest that environmental variability may induce a multidecadal cycle in the abundance of the stock (figure 9.1), showing a low productivity regime in the 1960-70s, a high productivity regime in the 1980s and 1990s and a decreasing trend in the 2000s toward a new low productivity regime. This pattern matches well the evolution of total catch over the historical fishing period. However, this result needs to be taken with caution. First it requires confirmation once a coherent parameterization will be achieved between the different model configurations (i.e., environmental forcing and resolutions), and then it is critical to introduce the total fishing mortality in this simulation by extracting the total catch from the simulated stock following the most plausible spatial distribution of fishing effort over the historical period of exploitation. While we still hope to get positive answers from Russian colleagues to recover a substantial part of historical fishing data, the alternative would consist in raising the level of catch based on available distribution to reach the total annual catch declared in the SPRFMO database.

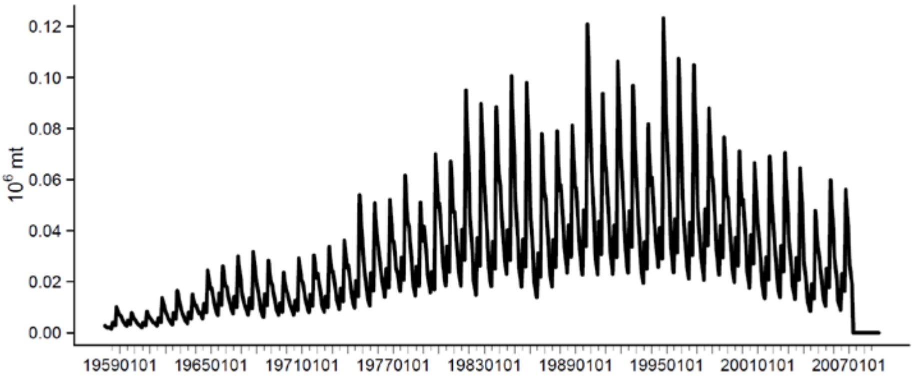

Figure 9.1: predicted Jack Mackerel recruitment from SEAPODYM hindcast simulation 1960-2007 using configuration NCEP-NEMO-PISCES. The x-axis is a combination of year, month and day notation.

Design of a Management Strategy Evaluation

A commonly used approach to test the performance of fisheries management consists of simulating the mid to long-term developments of the stock under a given management regime, based on the perception from the most recent assessment. Such simulations should represent the dynamics of the stock and of its fishery as precisely as possible and take account of the various sources of uncertainty in the assessment and in the management system. A range of diagnostics can then be calculated from the output of the simulation, which can be used to describe the performance of any given management strategy. Within the context of WP4 a management strategy evaluation tool was developed for the Jack Mackerel, based on the most recent stock assessment available.
The various components of this tool, and the different assumptions made are described in the Meeting document submitted to the SPRFMO 1st Science Committee meeting and annexed here as well (Annex D). Here, we only present a brief summary of the approach.

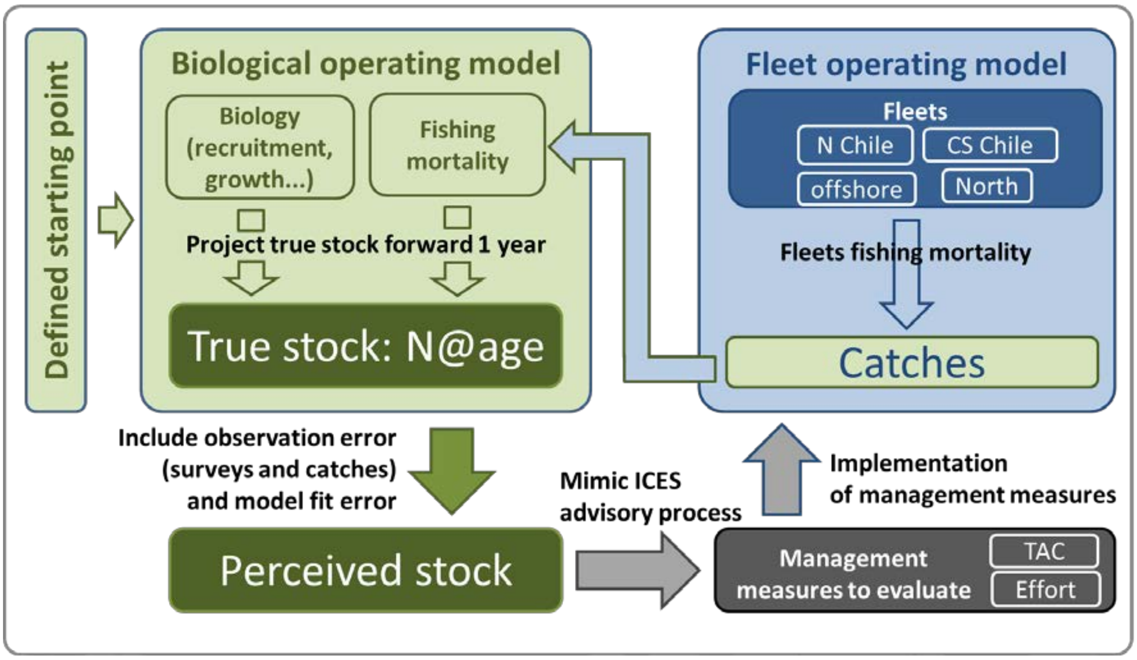

Figure 9.2. Conceptual representation of the management strategy evaluation where four main elements exist. A biological operating model simulating the dynamics of the fish species, the stock assessment process via the 'perceived stock' element, the incorporation of the advisory process under 'management measures to evaluate' and the implementation of these measures via the fishing fleet catching the fish species under element 'fleet operating model'.

<u>The simulation tool</u>

The principle of a Management Strategy Evaluation (MSE) is to represent the true dynamic of the stock and of the fleets exploiting this stock as realistically as possible, and to mimic the stock assessment and management procedure which are to be evaluated as closely as possible. The MSE should give a correct perception of the sources of natural variability in the stock and of the uncertainty in the management system. In order to reflect this uncertainty, the simulations are run simultaneously on a large number of replicates of the stock, each representing a likely version of the real stock.

A MSE typically consists in an assemblage of blocks or models, which can be defined as followed (figure 9.2):

- The biological operating model, which is an age structured population model, representing the real stock. Natural processes such as reproduction, growth, sexual maturation, natural mortality should be represented as realistically as possible, and based on the available knowledge of the biology of the stock. Here a particular effort was made to properly represent the variability in Jack Mackerel recruitment and growth (while due to the lack of information, natural mortality and the maturity ogives were kept constant, as in the stock assessment).
    - In the Jack Mackerel MSE, two different options were designed to simulate recruitment. First, a classical stock to recruitment approach: a stock-recruitment function is defined for each of the replicates of the stocks. We used the Bayesian method developed for North East Atlantic mackerel (Simmonds et al., 2012) using a Bayesian estimation of the model parameters, and calculating the probability of the different stock recruitment functions. In the case of Jack Mackerel these probabilities were 50% for the Beverton and Hold model, 40% for the Ricker model, and 10% for the hockey stick model.
    The second approach used Fourier surrogates time series as simulated recruitment (see example of application in Planque and Buffaz, 2008). The resulting surrogate's recruitment time series are Gaussian and have the same mean, variance and power spectrum as the original data time series but have different temporal trends. Using the

surrogate's recruitment time series in the simulation implies that the strength of a year class is not related to the size of the spawning stock from which it originates. This recruitment scenario represents therefore a situation where recruitment would be driven by a hypothetical environmental signal.

- o Growth was modelled using ARMA (autoregressive moving average) models. ARMA models were fitted to the time series of weights at age 1 and weight increment in the subsequent years. These models were then used to produce simulated time series, for each replicates of the stock

- The fleet operating model represents the different fleets harvesting the stock. Each has its own selection pattern (age decomposition of the fishing mortality) and the total fishing mortality imposed to the stock is the sum of the partial fishing mortalities of the four fleets. The proportions of the total fishing mortality (or equivalently, of the total catch) caused by each fleet was constant in time, equal to the 2012 proportions (terminal assessment year)

- The perceived stock should give a correct representation of all the sources of uncertainty linked to observation (catch estimation, biological sampling, and surveys) and to the assessment model (uncertainty due to model specification and fitting). At each new year in the simulation, a new perception of the stock has to be generated, in a way that mimics the uncertainty related to stock assessment as closely as possible. The approach taken for the Jack Mackerel MSE consisted in adding an error term to the output – abundance and fishing mortality at age - of the biological operating model. This error term was defined as the product of cohort-specific normally distributed deviations and an error amplitude proportional to the assessment uncertainty of the corresponding estimate.

- The management measures to evaluate part of the model reproduces the rules according to which a management advice is given based on the most recent output of the stock assessment model. Here, the procedure implemented is similar to the standard ICES procedure, where in a given year y, the TAC advice is given for the following year y+1, based on a perception of the stock in the previous year y-1.

The initial vectors (numbers at age, fleet selection patterns, biological parameters) used for the first year of simulation are taken from the most recent assessment of the stock. The output of the MSE simulations is influenced by the starting conditions. Furthermore, the output of the assessment is given with confidence intervals, representing the spread of the likely values around the point estimates. In order to have starting conditions reflecting the magnitude of the assessment uncertainty, a range of likely stocks was generated by resampling the parameters estimated in the assessment, using the variance-covariance matrix for the parametric uncertainty.

<u>Results</u>

The MSE tool is primarily designed to evaluate the performance of difference harvest control rules, it can also be used to simulate the stock's dynamic equilibrium for a range of fishing mortality values, and hence identify fishing mortality and biomass corresponding to MSY (Maximum Sustainable Yield). In the simulation, the selectivity of each fleet can be changed to represent the effect of changes in mesh size or in minimum landing size.

Simulations were run to investigate the link between SSB, Yields and fishing mortality at equilibrium. These simulations were run by imposing a constant F value over the simulation period (2013 to 2040) directly in the biological operating model (i.e. not based on the perceived stock, and not implementing any management rule). The aim of these simulations at constant F is to reach a "dynamic" equilibrium, where the stock would be on average at an equilibrium situation corresponding to the level of F imposed, but will still fluctuate around this equilibrium due to the stochastic variability in the model. The equilibrium state is defined by computing the mean of SSB and Yield over the period 2030 to 2040. The MSY estimates from these simulations are given in the table below, as well as values proposed for other reference points and there justification.

	Value	Description	Origin
Biomass reference point			
Bmsy	10.6 mt	Biomass at MSY	Simulations using the Bayesian SR models (see above)
Blim	2.8 mt	Biomass under which recruitment may be impaired	Median of the breakpoint of the 1000 hockey-stick stock recruitment models fitted with the Bayesian approach
Bpa	3.9mt	Biomass below which there is a risk to fall below Blim, given the uncertainty in the assessment	Bpa=Blim * exp(1.645 σ) with σ being the standard error of the SSB estimate, here equal to 0.2 (see ICES, 2007)
Fishing mortality reference point			
Fmsy	0.14	Fishing mortality at MSY	Simulations using the Bayesian SR models (see above)

Managing Jack Mackerel based on effort or on catch limitation will not make any difference on the trajectory of the stock, as long as effort or catch limits are set to reach the same target (e.g. MSY). Divergence of stock development can occur in the case of mixed fisheries, when the effort allocated to one species may depend on the quota available for another species. For instance, when the quota available for species A is taken, the fleet may not be able to continue using the remaining effort to catch species B, since this will also involve catching species A, and hence overshoot the quota. In such a case, the link between effort of the fleet and fishing mortality on a given species depends on the availability of the fish, the quota for the different species and the strategies of the fishers. This is not the case for Jack Mackerel, where defining an effort limit or defining a TAC limit are both equivalent to defining the value of fishing mortality.

In order to illustrate how harvest control rules developed in collaboration with the stakeholder can be evaluated, example management scenarios were run from 2013 to 2040. The Bayesian stock-recruitment scenario was used in these examples. For the purpose of illustration three management strategies (Harvest Control Rules, HCR) were tested:

1. Applying a constant fishing mortality at **Ftarget** = Fmsy =0.14
2. A **recovery strategy** where F is reduced of 25% per year when SSB<Blim, of 15% per year when Blim<SSB< Bpa, and F=Fmsy when SSB>=Bpa
3. A **hockey stick** harvest control rule where F=Fmsy at SSB>=Bmsy, and F = Fmsy * (SSB/Bmsy) when SSB<Bmsy.

Figure 9.3 shows the simulated stock trajectories for the three management strategies implemented. The diagnostics are presented in table 9.1. SSB trajectories are very similar for the three management scenarios, with an instantaneous increase at levels above Blim, and with Bpa being reached within less than 2 years for the hockey-stick HCR, and within 3 years for the F target scenario. In the long term, SSB reaches Bmsy, and even goes slightly above for the hockey-stick HCR. The risk to fall below Blim is never higher than 1% in the mid and long term. Minor differences are found for fishing mortality, with Fbar (mean F over ages 1-12) going immediately to Fmsy in the F target management, decreasing slightly in 2014 but then going to Fmsy for the recovery strategy, and declining abruptly in 2014 and slowly increasing towards Fmsy for the hockey-stick HCR. In all cases, Fbar is close to Fmsy in the long term. The hockey-stick HCR leads to higher yields in the mid and long term, but at the price of lower yields in the short term and of slightly higher yield variability. In all cases, the discrepancies between real and perceived stocks are small. Assessment error is similar in the three management strategies, with a small imprecision on SSB with no bias, and a minor bias on Fbar.

Table 9.1. Diagnostics of the simulations.

	Management scenario		
Diagnostics	**F target**	**Recovery plan**	**Hockey stick HCR**
Risk	proportion of the stock replicates falling at least once below Blim		
Mid Term	1%	0%	0%
Long-term	1%	1%	0%
recovery time	Average number of years to go above the specified SSB level		
to Blim	0.33 yr	0.19 yr	0.18 yr
to Bpa	3.02 yr	2.65 yr	1.79 yr
SSB	Average SSB		
Long Term	9.9 mt	10.4 mt	11.0 mt
End	10.7 mt	10.8 mt	11.6 mt
Fishing mortality	Average Fbar		
mean	0.141	0.140	0.126
Long term	0.143	0.142	0.136
End	0.143	0.143	0.138
Yield	Average yield		
Short Term	578 t/yr	555 t/yr	444 t/yr
Mid Term	1269 t/yr	1338 t/yr	1453 t/yr
Long Term	1909 t/yr	1942 t/yr	2071 t/yr
Yield Variability	Mean absolute yield difference between two consecutive years		
	9.6%	10.0%	11.6%
Assessment errors	Difference between real and perceived stock relative to the real stock		
SSB (absolute bias)	4.3%	4.3%	4.0%
SSB (bias)	-0.2%	-0.3%	0.1%
Fbar (absolute bias)	2.1%	2.1%	2.1%
Fbar (bias)	2.0%	2.0%	2.0%

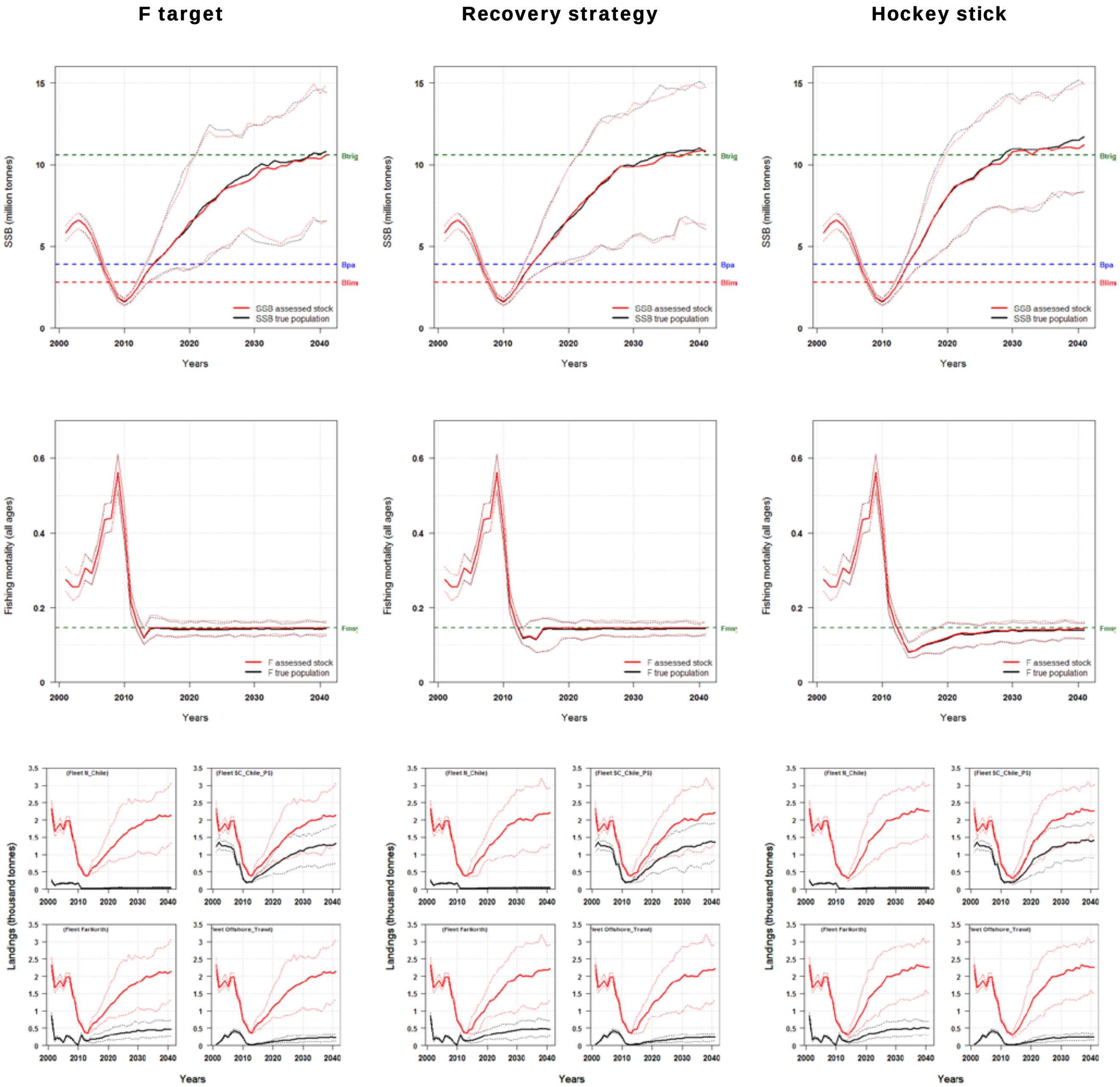

Figure 9.3. Simulation output for three management scenarios. Jack Mackerel SSB (Top panels), fishing mortality (medium panels) and Yield (bottom panels) trajectories (solid lines: median values; dashed lines: 5% and 95% quantiles of the inter replicates distribution)

All the projections shown here are based on the Bayesian stock recruitment models. It is expected that recruitment will increase if SSB starts to rebuilt. However, the decrease in recruitment to low levels in the recent years is quite likely to be associated to environmental drivers, which may have acted in combination with overfishing. The stock recruitment models being fitted based on the historical time series, do not take the recent low productivity of the stock into account. It is not known whether recruitment can rebuild to levels as high as in these simulations if the SSB starts rebuilding. Until a better knowledge on the drivers of Jack Mackerel recruitment are available, the MSE simulations based on the stock-recruitment models should be considered with caution, and for illustration purpose only.

Deviations from the work plan

There were no deviations from the work plan

Difficulties encountered

- Difficulties to access old historical fishing data (Peru, Chile, Russia, Poland), at minimum resolution, e.g., 1° or 5° x month or even quarter.
- Confidentiality rules established by the SPRFMO led to removing data in cells where less than 3 vessels are fishing, i.e. potentially removing a substantial part of data.

Conclusions and way ahead

With the use of the SEAPODYM model, new optimisation experiments and hindcast simulations will be conducted with final optimal parameterization achieved, and revised fishing mortality. Results will be evaluated against all existing data and knowledge. The dynamics of the population will be projected after 2012 using average environmental conditions. SEAPODYM stock dynamics (recruitment, spawning biomass, catch and fishing impact) results will be compared to those of the stock assessment model. A meta-population structure will be proposed and documented in a report for the WP5, with hypotheses on future projection of recruitment based on established relationship with the environment and climate.

Within the MSE framework, a better understanding of the drivers of Jack Mackerel recruitment is needed. Until such knowledge is available, MSE simulations based on the stock-recruitment models should be considered with caution. The reasons for the current low productivity regime are still unidentified, and it is impossible to make an assumption on its duration.

In the framework of this project, some simple correlation analyses will be carried out to investigate whether Jack Mackerel recruitment is related to any large scale climate index. This could be used to propose an alternative recruitment scenario to be used in the simulations. The framework will be further used to test different harvest control rules. Suggestions on potential HCRs should follow from the discussions in the SPRFMO Science Committee meetings and a stakeholder workshop to be held in November 2013. Additional evaluations will be carried out to simulate the change in stock development under different assumptions of mesh size and landing size (i.e. a change in selection of the fisheries).

10. WP5

Several studies on the stock structure of Jack Mackerel, including the findings in this project, have already indicated that the assumptions made within the assessment and management, assuming a single stock unit in the entire area, does not match the biological reality. The potential mismatch between true stock structure and assessed stock structure will be investigated in this work package. Management Strategy Evaluation software tools are in development and will be used to simulate the consequences of different potential stock structures and fishing scenarios for sustainable management.

Results from WP3 indicate the most likely stock structure (the number of units and interaction between the units) which will be simulated in the interaction with the fishery. The combination of the simulated biological units with the different fisheries who exploit these units (generating catches), provide the necessary data for assessments. Whether one or more assessments are simulated (lumping two or more units) will vary as well, since under not all circumstances it is necessary to design an assessment for each unit separately. Simulating these processes over time, whereby management actions feed back into the dynamics of the fisheries and thereby cause fishing mortality, allows us to test which assessment simplifications do and do not jeopardize sustainable management.

Activities

1. A first long term simulation hindcast back to 1960 was produced, without fishing effort to test the environmental variability impact. Results are not presented here as the hindcast is currently based on a draft SEAPODYM model configuration
2. Development of a management strategy evaluation framework to simulate different stock structure hypothesis and fleet designs

Progress achieved towards deliverables & tasks

In total, three tasks and two deliverables have been described for WP5. The table below summarizes the progress towards these tasks and deliverables followed by a more detailed description.

Task 5.1	The MSE tool is in development with progress according to planned progress. By the end of 2013 a fully operational MSE tool should be available, enabling flexible and robust evaluation of management strategies.
Task 5.2	Simulation of the SEAPODYM model is underway and according to planned progress. A robust parameterizations is required however prior to future simulation of fishing scenarios.
Task 5.3	No progress. Preliminary scenarios will be available at the start of 2014 when more results from WP3 and WP4 become available.
Deliverable 5.1	Introduction and Material sections are in development. No preliminary scenarios are available.
Deliverable 5.2	Introduction and Material sections are in development. No preliminary scenarios are available.

The work package commenced in month 6, hence only five months have passed. The design of the simulation framework, an add-on software library to the widely used R statistical package is currently developed. The add-on library interfaces with existing software in the FLR (fisheries library for R) framework which is one of the most commonly used software tools to perform MSE. The add-on package (working title FLMeta, i.e. for meta-population analyses) is based on three blocks: 1) simulation of the biological structure of the population, 2) the simulation of the fisheries and 3) the simulation of the stock assessment. On the basis of the biology and fishery we derive the input data for a stock assessment. The stock assessment, together with an assumption on a management scheme obtained from WP4, provide the input to evaluate management decisions over time. A yearly management decision is thereafter translated into a TAC which is, in turn, taken by the fisheries causing fishing mortality that affects the biology, and hereby closing the full-feedback loop. These processes are evaluated over the course of several years.

The functionality in FLMeta allows easily designing and parameterizing different assumptions of biological units, e.g. one unit for the entire region, two units in the northern area and southern area, or even a multitude of units in different areas scattered over the entire region. The design of the fishery is more restricted in that sense as there is no strong indication that the current setup of the fleets in the SPRFMO assessment (assuming four different fleets) is inappropriate. To what extend each of these fisheries has access to any combination of population units is a different aspect and requires the design of an allocation scheme. The allocation scheme, in combination with the required number of stock assessments one wants to get out of the simulation, generates the appropriate input data for the stock assessments. The functionality to simulate the processes described above have been developed since the start of WP5. The general framework to perform an MSE is similar to the design used in WP4 and can therefore be used here as well. Potential scenarios, detailing the setup of biological units, fisheries and stock assessments is given in Figure 10.1.

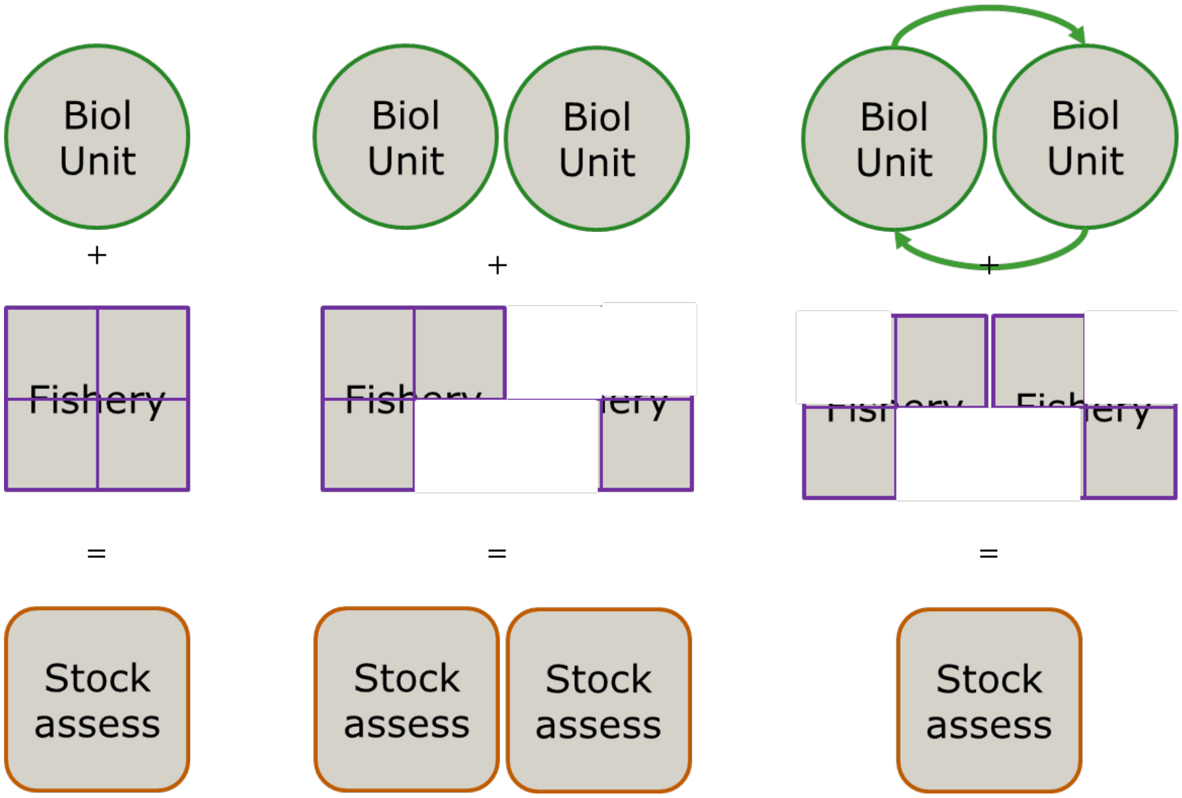

Figure 10.1: Potential scenarios of biological unit, fisheries and stock assessment design which can be evaluated inside the MSE. Left: The current setup in the SPRFMO Science Committee assuming one single stock being fished by four fleets and assessed in one stock assessment. Middle: A potential scenario assuming two population units, being fished by a mixture of fisheries and assessed separately in two stock assessments. Right: A potential scenario assuming two population units, being fished by a mixture of fisheries and assessed as one unit. Arrows between biological units indicate interaction between units.

Deviations from the work plan

There are currently no deviations from the work plan.

Difficulties encountered

There are currently no difficulties encountered.

Conclusions and way ahead

Progress on the MSE tool, as well as a robust configuration of the SEAPODYM model, is well on track. It is expected that by the end of 2013, the MSE framework is ready to simulate a suite of scenarios, which are informed by the results of WP3 and WP4 but also with a strong focus on the results obtained by the Science Committee of the SPFRMO regarding their 'single species' stock assessment. During April and May 2014, preliminary results will become available for both the SEAPODYM configuration as the MSE tool. These results will be discussed during web meetings where other consortium partners, but also external partners, can comment on these results to improve them. Final results of the modelling exercises will be written in Working Documents, to be submitted to the SC and presented at the SC meeting in 2014, and then should be published in scientific journals.

11. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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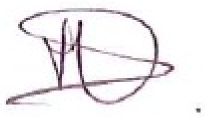
Justification

Report number: C156/13
Project Number: 430.110.3301

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Drs. .H.M.J. van Overzee
Collega onderzoeker

Signature:



Date: 9 oktober 2013

Approved: Dr. ir. N. A. Steins
Hoofd afdeling Visserij

Signature:

Date: 9 oktober 2013

Appendix A. Minutes EC – consortium meeting 8th of April 2013

Meeting report of kick-off meeting on: Hydrography and Jack Mackerel stock in the South Pacific Contract Number – MARE/2011/16 – Lot 1 – SI2.628636
Date: 8th of April 2013
Attendees:

European Commission (EC)	Veronika Veits (Head of Unit and Head of the EU Delegation to SPRFMO) Rafael Duarte Pavlina Nikolova Angela Martini
Contractor	Niels Hintzen (meeting notes) Francois Gerlotto

Aim of the meeting

A kick-off meeting between the EC and the contractor on the Hydrography and Jack Mackerel tender was held in Brussels, DG MARE premises, in the morning of the 8th of April (meeting agenda in Annex I). The meeting followed the inception report that was due the 17th of January 2013. The meeting aimed at discussing the objectives of the study from the EC stand point as well as discussing the approach taken by the contractor and the contents of the inception report.
As the contractor participants that were present are also highly involved in the South Pacific RFMO Science Committee work, the meeting was also used to discuss on-going matters in preparation to the EC RMFO meeting to be held at the 9th and 10th of April 2013.

Action points

The main action points agreed for the short term are the following:

- Perform simulations as part of WP 4 aimed at designing a rebuilding plan for Jack Mackerel to be presented at the Science Committee meeting 2013 (Contractor),
- Submitting results of study as Working Documents to the Science Committee 2013 (Contractor),
- Prepare a letter to Chile or to the SPRFMO for distribution to all SPRFMO members, to stimulate collaboration, involving access to spatial catch data over time (EC),
- Contact the administration in Poland to request historical Polish data for Jack Mackerel in the South Pacific (EC).

Meeting notes

A presentation by the EC was given on the study objectives and tasks. The EC detailed the history of how the South Pacific RFMO was setup (from 2009 onwards) and how the group derived at the current assessment model that is used for the catch advice. The EC also outlined the initial plans of coastal states to setup a large sampling program and study to investigate the stock structure of Jack Mackerel (in 2008). The sampling project has not yet found appropriate funding (initial indicate budget reached 7.5 million USD). The EC study on Hydrography and the Jack Mackerel stock should complement this study with specific evaluation of management scenarios. Thereafter, the EC outlined the setup of the tender with three core elements: first the data / literature collection, second the studying the most likely stock structure and third the evaluation of sustainable management scenarios under the most likely stock structure. The EC also highlighted the very sensitive political context in the SPRFMO organization with very difficult relations between Chile and Peru. As an example, it was noted that to date, no Jack Mackerel species profile is agreed as yet, potentially due to these difficult and sensitive relations (while there are species profiles for many pelagic and demersal species, see also: http://www.southpacificrfmo.org/species-profiles/).

The EC also stressed that management areas should be defined based on biological criteria and that from a management point of view it is important that management areas are stable in time. It is therefore important that changes in management areas should occur at a certain point in time when scientific evidences are robust and available from different sources (rather than changing management areas year after year, potentially driven by the strengths of different delegations bringing in new subsections of scientific evidences).

It was suggested by the EC that it could potentially be interesting to organise a workshop after the EC study has come to an end to present the results of the study and to discuss a way forward. This was well received by the contractor.

The contractor thereafter gave a presentation on the outline of the project, specifically detailing how the different work packages link together. This followed by a description of the progress made in each of the Work Packages.
The aspect discussed in great detail was the data collaboration within and outside the EU. It was mentioned that for the EU the data for the Polish vessels and biological sampling was lacking, dating back to the 1970s. The rest of the EU data, monitored through the observation program by Ad Corten, is covered in the project. Getting in touch with Chilean colleagues and setting up collaborations has proven to be difficult. So far, the contactor has not succeeded as yet to establish collaborations with Chilean Scientists. The EC commented here that they might prepare an official letter to the Chilean delegation and to all Members of the SPRFMO to promote collaboration. Collaborations with Peruvian scientists are on-going but have not yet resulted in direct access to the spatio-temporal catch and effort time series. A workshop to be held at the end of May (during the presentation mid-May has been mentioned, but the workshop has been postponed by two weeks) in Lima could result in agreements on a data collaboration. The contractor participation is currently discussed with Francois and Arnaud Betrand (consortium partner from IRD). The contractor has also tried to setup collaboration with Russian scientists as they hold catch and biological sampling data from the 1970s. However, time and money constraints from the Russian side have caused a rejection to collaborate at this point in time. The SPRFMO secretariat is very helpful in delivering data, however, confidentiality issues refrain them to send the requested data at the low aggregation level wanted.

Furthermore, the progress on WP2 – WP5 was discussed with little deviations from the initial work plan or difficulties encountered. For WP3 collaborations on data with Peruvians and Chileans would be highly beneficial. It was mentioned under WP4 that it is the wish of the EC to closely monitor the results of the harvest control rule exercise before it would be sent off to the Science Committee in 2013. This to ensure that it is likely that the results are interpreted in the way they are meant to and will not be used to hijack the political process. Also, it would be useful to include examples in the working documents, to be sent to the SPRFMO Science Committee in 2013, detailing rebuilding plans for Jack Mackerel.

The contractor replied to the four main concerns mentioned in the review of the Inception report:

1. Role of single stock structure in the project
   The contractor indicated that under WP4, the assumption of a single stock structure would form the baseline of the analyses and that under WP5 the single stock structure would be treated as a baseline scenario as well.
2. Linkage of WP2 to other WPs
   The contractor indicated that indeed the linkage between WP2 and the other WPs was not clearly described in the inception report. However, the results of WP2 are crucial to refresh the current status of stock structure research in the South Pacific, as well as indicating the relevant biological processes, and parameters associated, for the modelling work that goes on in WP3 and

WP4. As well, if alternative stock structure hypotheses are identified in WP2, these might be evaluated under WP5 to investigate how sustainable management can be achieved.

3. Collaboration with other non-EU partners

   This aspect was already discussed at length and is described above. It is encouraged by the EC to collaborate with non-EU partners.

4. Success of project without non-EU partner collaboration

   The contractor pointed out that the agreed project proposal indicates that it would be highly beneficial for the project to collaborate with non-EU partners. However, given the anticipated difficulty in setting up these collaborations, the contractor has agreed in the proposal to work on EU Pelagic Freezer Trawler data. Given that this data is available to all consortium partners, it is not expected that unforeseen problems arise and therefore concluding that the deliverables can be achieved within the time frame of the project.

The future plans of the project, directly linked to the work in the SPRFMO Science Committee, were discussed and the contractor mentioned that it was the projects intention to submit different Working Documents to the Science Committee with the results of the different WPs. As the second interim reporting deadline is closely matched by the Science Committee meeting, it was suggested to combine both Working Documents and reporting to the EC. The proposed meeting on WP5 on management strategies is currently scheduled for June 2014. The contractor mentioned that it could be beneficial to move this meeting forward by a few months to ensure suggestions by the EC could be taken into account in the final results. It was suggested to keep in close contact on this matter.

As the contractor participants that were present are also highly involved in the South Pacific RFMO Science Committee work, the meeting was also used to provide feedback on the latest SPRFMO Commission meeting to the scientists. Three points stood out of this discussion:

1. The origin of the advice was unclear (what was the numerical basis of the TAC advice)
2. The applicability of the advice was unclear (which areas it should apply to)
3. It is expected that the Science Committee will concern conservation issues regarding deep-sea fisheries as well. It is expected that New Zealand will send a delegation to detail their advanced with respect to this point

All these points were noted as important aspects to take up at the next Science Committee meeting in October 2013.

Appendix B. Agenda EC – consortium meeting 8th of April 2013

Hydrography and Jack Mackerel stock in the South Pacific
Contract Number – MARE/2011/16 – Lot 1 – SI2.628636
Kick-off meeting – Brussels 8 April 2013
DG MARE – Rue Joseph II 99, 03/SDR1 Aquarium
(10:00 to 13:00 and 14:00 to 17:30)

Draft agenda

1. Study overview (objectives, tasks and working packages, expected outcome) [MARE]

MARE provide an overview of the study and how the original idea was developed in the context of the SPRFMO. What the main objective was and what could be expected from the study.

2. Presentation of the inception report [Contractor]

- Data compilation and collaboration with coastal states
- Stock structure studies for Jack Mackerel – current knowledge and contribution of the study

The contractor should present the inception report, describing the work already undertaken and the main difficulties encountered. The contractor should clarify what was done to have the collaboration of coastal states and where we currently are. The contractor should also clarify what would be the consequences of not having coastal states collaborating – and no access to data.
The contractor should present the stock structure study (meta-population) presented at the last SWG.

It is important to have a balanced approach between Chile and Peru. It is also important to have the current single stock hypothesis as the base case for the future development of the project.

3. EU study in the context of the SPRFMO [Contractor/MARE]

How the study could contribute to the work of the Scientific Committee of the SPRFMO. The importance of having the work accepted by the SPRFMO.
To organize in 2014 a major Symposium/Conference or Working Group on stock structure in the context of the SPRFMO? This should be between Managers and Scientists.
This could be a way forward if the stock structure issue continues to be important and under discussion. Management areas (stock structure) should not be changed unless there is a major reason to do so. So, this should not be subject to major discussions. However, there is some tendency to use this argument from time to time by certain delegations – if results are not satisfactory. In particular, depending on the "strengths" of delegations to science/commission meetings.
The objective would be to postpone any discussion on this subject up to the moment when parties would agree to discuss stock structure and management measures.

4. Planning and calendar [Contractor]

Contractor to explain next steps and future development of the project.
MARE to highlight the Management Strategy Evaluation Working Package as one of the main final goals of the study.

Appendix C. Minutes consortium meeting 10th – 13th of September 2013

Minutes on the second consortium meeting of the "Hydrography and Jack Mackerel stock in the South Pacific" project. Contract Number – MARE/2011/16 – Lot 1 - draft

Date: 10th – 13th of September 2013

Attendees:

Ad Corten (CMR), Francois Gerlotto (IRD), Jeremie Habasque (IRD), Patrick Lehodey (CLS), Anne-Cecile Dragon (CLS), Thomas Brunel (IMARES), Niels Hintzen (IMARES)

Aim of the meeting:

The meeting was scheduled to present, discuss and report on the progress made within each of the five work packages of the project. The meeting was scheduled approximately one month before the delivery date of the first interim report as well as the 1st Science Committee (SC) meeting of the South Pacific Regional Fisheries Management Organisation. Besides the effort allocated on reporting to the EU, time was reserved during the meeting to write and discuss potential Working Documents, to be submitted to the SC. Furthermore, during the meeting the scientific approach for the upcoming months was discussed as well as organisation elements such as meeting with the EU and the SPRFMO.

Action points:

The following action points were concluded. The deadline column indicates the approximate timeframe of the points.

Action point	Person responsible	Deadline
Check potential for access to Peruvian Acoustic data years 2011-2013 & 1994-2013	Francois Gerlotto	20th of September
Check potential for access to Chilean Acoustic and egg / larvae survey data	Ad Corten via Rodolfo Serra / Jorge Castillo	20th of September
Define database for deliverable D1.1	Niels Hintzen	20th of September
Check historic catch information availability in SPRFMO database	Ad Corten & Niels Hintzen	SPRFMO SC meeting
Prepare letter to ask for extension of project	Niels Hintzen	30th of September
Contact Nesterov	Patrick Lehodey (via Inna)	20th of September
Letter to ask for the Peruvian data	Niels Hintzen	20th of September
Consult Gerard van Balsfoort for interest in WP4 Harvest Control Rule meeting	Niels Hintzen	30th of September
Arrange WP4 meeting with EC and consortium partners (between 5-8th of November)	Niels Hintzen	30th of September
Arrange Skype meeting on results 3D modelling	Jérémie Habasque	30th of November
Arrange Skype meeting on results SEAPODYM modelling	Patrick Lehodey	February
Arrange Skype meeting on results HCR and MSE modelling	Niels Hintzen	March
Update Interim report text at WP level	All	20th of September

Meeting notes:

Tuesday Afternoon:

Introduction & general items:

The meeting was opened at 13:00 by Niels. A quick round of introduction followed as some members joined in for the first time. A short presentation on the goals of the meeting, the agenda and facilities of the venue was given.
It was suggested by Niels to contact the EU to investigate if an extension of the project (in time only) would be possible, hereby extending the project up till 31st of December 2014. Three reasons to propose an extension were given: 1) most likely the 2014 SPRFMO meeting falls within or just after the official deadline of the project (17th of October 2014) and to be able to cover the whole of the SC meeting under the EU project (both financial as scientific) it would require an extension. 2) Embedding of the SC work and comments in the EU project is a clear wish from the EU. This can only be warranted if the EU project deadline falls well after the 2014 SC meeting. 3) Collaborations with non-EU partners are picking up, although almost one year has passed already. The consortium was aware that establishing collaborations was difficult and is pleased with the collaborations at hand. If more time is granted however, it becomes easier to make full use of this collaboration as time is a limiting factor at this stage. All consortium partners agreed that the IMARES would write a letter to the EU asking for an extension.
The attendance of the upcoming meeting with the EU was discussed, in which the consortium reports back on the first interim report and discusses the management evaluations as proposed under WP4. In earlier email communication with Rafael Duarte (EU) the week of the 4th of November was proposed. Rafael requested the contribution of Ad Corten and Francois Gerlotto to this meeting. Unfortunately, Ad cannot make this meeting due to other obligations. Francois indicated that he is available for this meeting during that week (except the 4th of November).
At the 16th of August, Italo Campodonico (head of delegation at SC meetings of the SPRFMO for Chile) indicated that Chile was willing to actively collaborate in the EU project and suggested Rodolfo Serra to become an official member of the EU project. The involvement of Rodolfo was discussed. The expertise of Rodolfo could make a valuable contribution to the project, given the many years he has worked with Jack Mackerel. Especially under WP2 and WP3 it could be useful to have Rodolfo actively involved in reviewing the work that has already been done. To get Rodolfo become an official member of the consortium might mean that the contract between the EU and consortium needs to be amended, a large administrative hurdle. For this reason, it is suggested to officially (via EU and IMARES) acknowledge the contributions of Rodolfo to the project and add Rodolfo to the email lists, SharePoint site and as author on the reports.
Other points that were discussed outside the scope of the agenda were: 1) potential for follow-up project after the current project. Niels indicated that he expects the chances to be slim, it is more likely that the SPRFMO funds a collaboration project. 2) Reporting back on the points discussed during the EU-consortium meeting in April 2013. 3) The ability to get access to Polish data. The Polish data, if available after intervention of the EU as discussed during the EU-consortium meeting, might come in too late to use within the project modelling studies. However, the information is of great importance to the SPRFMO and its assessments. For this reason, Niels suggested to keep asking for this data.

Status & progress on WP1:

Ad Corten presented an overview of the data currently available to the consortium. It consists of the PFA vessels, Chilean data received via Italo, Peruvian data obtained from SNP and extractions from the SPRFMO database. On the basis of the PFA data, he showed the shift in distribution of the fisheries over the past years, where in some years the fishery 'migrates' northerly rather than westwards. Data on the New Zealand fishery is still missing from our collection why it should be available since Andrew Penny, former chair of the Science Working Group, published a Working Document in 2010 on it. Ad indicated to investigate how to obtain this data as well. Francois indicated that more acoustic and fishery information might become available through SNP as well as via IMARPE once they have officially indicated to be

willing to share the data with us. Francois has access to this data from earlier projects, but needs to acquire permission to use it for the EU study as well.
The data detailing the oceanographic variables are available in NetCDF files and have been used already by Jemerie in his analyses. Both the weekly time series at ¼ degree as well as the ocean hindcast at 2 degrees resolution are available.
Francois and Jeremie will work together to describe the biological and fisheries independent information available to the project, which is obtained from collaborations with SNP and IMARPE. Ad will contact Rodolfo to see if more detailed information on the survey time series of the Chileans can be made available to the EU project.

Status & progress on WP2:

Francois has drafted a synthesis on Jack Mackerel covering many topics from ecology, environment, genetics, behaviour to management. Most of the sections have been written and he will spend two weeks with Teobaldo (IMARPE) to finish the synthesis. He is looking for paragraphs on the fisheries and management. Niels indicated that he might have available a section on management regulations and is willing to write a section on the assessment of Jack Mackerel. Francois further shows examples of each of the chapters and explains in short what his main conclusions will be. Niels indicates that some conclusions are factual and some should belong in a discussion section. Francois agreed and will separate these sections where needed. Francois will aim to submit the synthesis as a Working Document the SC at the end of September.
Francois has started to draft a manuscript which will be submitted to a peer-reviewed journal. The structure of the MS follows closely the outline of the EU project. For this reason, additional care is needed in drafting the MS to ensure that MS to be written on individual WP results will not clash with the MS Francois is drafting. Niels mentions that the first suggested chapter (on comparing Jack Mackerel with other horse mackerel species) could be merged with the other chapters to improve the flow of the MS.

Wednesday:

Status & progress on WP3

Jeremie presents the progress of Arnaud and himself on the 3d habitat modelling of Jack Mackerel. The statistical elements of the model consist of 3 factors: a resource, direct and indirect element. The relationship between each of these factors and the appearance / abundance of Jack Mackerel is analysed on the basis of catch and survey (acoustic) data. Thomas mentions that the model does not include a spatial position (like longitude-latitude) and asks if there is a specific reason for this. Jeremie indicates that he might investigate this. The question arises if the model is stage specific (adults vs. juveniles), which is not the case as data to support this is not available. The analyses show that there is a clear relationship between dissolved oxygen, with a minimum of 2mL/L for schools. The horizontal distribution of Jack Mackerel can be described by SST, CHL-a and an interaction between these two components. The vertical distribution is related to the isotherm and depth of the oxycline.
In the results, two areas of potential habitat are shown where Jack Mackerel has never been observed. Francois indicates that it might be due to predators such as tuna. For the equatorial habitat suitability Arnaud has mentioned before that it might have conditions that are too variable for Jack Mackerel. Another result shown is the low probability of a suitable habitat around 20 degrees South. Only in El Niño years the oxycline drops enough to make it a suitable habitat (and to allow migration of Jack Mackerel to more northerly areas?). Another aspect of the study is to test the habitat compression over the years. Over the more recent years, the oxycline has limited the potential habitat for Jack Mackerel (in the north). All in all, Jeremie concludes that environmental conditions did not change significantly over time to explain the collapse of Jack Mackerel. Ad suggests however that recruits / juveniles might have experienced less favourable conditions, and Niels adds that it could be that the plasticity at very early life stages might be much smaller than for older fish.

Niels mentions that the results do not indicate likely stock structure hypothesis yet. Jeremie will work on that. Anne-Cecile indicates here that it might be an option to prepare two GLM models between a Peruvian and Chilean component and see if the models are alike or not, as a first impression of stock structure (would Peruvian Jack Mackerel survive in Chilean waters?). Jeremie wants to add data from New Zealand and prey distribution areas to improve the model. Ad mentions that year-to-year variability in the distribution of Jack Mackerel observed in the fishery, something not shown yet in the results by Jeremie

Patrick thereafter presented the results on the SEAPODYM modelling on Jack Mackerel. After a short introduction on the model itself, he highlights some of the problems encountered when fitting the data. What data is available to the project already and what is currently used in the model needs to be investigated. It is shown however that in total not a lot of catch data (of the total) is available as spatial data to the model. Hence, there is a need to 'raise' the spatial distribution of the data to the total catch taken over the years. Patrick shows a number of figures which indicate the fit of the model to the data. For some aspects there is a good fit to the data, for other aspects, such as estimated selection, the fit needs to improve. Finally, maps of the distribution of Jack Mackerel over the years are given. It is discussed whether the maps show a distribution that is too large for the current status of the stock. Patrick indicates that the model is still in a preliminary phase and that different model assumptions already result in rather different results too. They will improve on the data used to drive the environmental forcing as well as the catch data.

The presentation by Patrick is followed by a presentation by Anne-Cecile on her work correlating Pacific Decadal Oscillations to development of habitats throughout the South Pacific. The SEAPODYM work of also shows habitat / distribution of Jack Mackerel in areas where no Jack Mackerel has ever been observed. This could be due to lacking data, and data from New Zealand might actually improve the fit considerably.

Thursday:

Status & progress on WP4

Thomas presented his approach and preliminary results of the Harvest Control Rule simulation framework. The model uses assessment results as starting values and adds noise to most key elements such as recruitment, weight-at-age and assessment noise to capture a large range of uncertainties in the assessment and management of Jack Mackerel. He questions however what the best way to include recruitment time series might be, he has tested two approaches, one based on a stock-recruitment relationship and one based on resampling strategy from historic observations. Anne-Cecile indicates that linking recruitment to environmental drivers, such as the PDO might be an option. The problem here is that not very often these relationships hold for a long time period and forecasts of the PDO are not available. Anne-Cecile further mentions that she expects that uncertainty in the model setup should be larger in historic periods. Thomas indicates that this has no effect on the simulation as only the most recent years are of importance to set a TAC advice. Niels also mentions that although he thinks uncertainty is a bit too low as well, it is common to see however that uncertainty decreases with the increase in data availability on the cohort structure. Also, ways to improve the variability in the selection of the fishing fleet are discussed. Niels mentions that it could be a good idea to let selection of a fleet follow the cohort structure of incoming strong year classes rather than a fixed selection pattern.

Status & progress on WP5

Niels presented his results earlier obtained in a study on managing the complex population structure of herring units west of the British Isles. The analogies with Jack Mackerel are manifold and for this reason can the generic lessons learned in the herring study be used as guidance for the Jack Mackerel study. Besides the herring study, Niels also presented the framework that he is currently developing to simulate a range of different assumptions on stock structure, fisheries units and their availability to each of the population units and the assumptions on the aggregation level to come to one or more assessments. As the framework is still in development, no preliminary results could be shown.

Ad mentions that there is a chance that, if more units exist, they share a common spawning ground and therefore, a multitude of units should be treated as one when we'd like to predict recruitment (one stock-recruit relationship instead of as many SR relationships as units exits). A discussion follows on what the most likely structure of spawning grounds might be and Francois indicates that he expects that there are two separated spawning areas and that in years with strong recruitment, the Chilean spawning area might contribute to recruitment in the Peruvian area. Niels indicates that processes as such can be simulated and could be a good candidate for a scenario to explore. Francois is doubtful over the situation of monitoring. Monitoring is not an embedded part of the simulations here. Although he sees that aim of the study is not to evaluate monitoring programs, he suggests that one of the take-home messages should not be that monitoring is not important. Niels fully agrees with this and indicates that it was not his intention to convey that message, in contrary, monitoring can give very useful insight besides assessment results.

Friday morning:

The morning session was used to discuss the progress on the report, the progress on working documents to be submitted to the SPRFMO SC, the action list (see top of document) and plans for the upcoming months. Progress on the reports was good, and specific comments were made related to each WP. The deadline is set at the 20th of September to finish the first complete drafts of the WP text. In total, 4 WD will be submitted to the SPRFMO SC: 1) National report on the PFA fisheries (not a result of this project), 2) a WD on WP2 (synthesis on Jack Mackerel), 3) a WD on WP4 and an example advice sheet.
To implement feedback from the consortium and potential other partners, from the beginning of 2014 onwards, Skype meetings will be held to demonstrate the core results of each of the WPs. Timeline of these meetings are given below.
A physical meeting with the EC will be arranged for November, which will cover a reporting back on the 1st interim report and a discussion on WP4, discussing harvest control rules. Niels will approach Gerard van Balsfoort (PFA) if he shares interest to join the WP4 meeting with the EC as stakeholder participation might be relevant.
Furthermore, Niels will contact Rodolfo to update him on our progress and discuss his contribution to the project.
The meeting closed at 11:30 Friday morning the 13th.

Meetings to be planned:

Skype meeting on results 3d habitat modelling Jérémie and Arnaud: End of January 2014.
Skype meeting on results of SEAPODYM modelling Patrick, Anne-Cécile, Inna: April 2014
Skype meeting on results of Harvest Control Rule and Management Strategy Evaluation Niels, Thomas: May 2014

Appendix D. Meeting documents submitted to the SPRFMO Science Committee meeting, October 2013

A framework to management strategy evaluation for the south pacific jack mackerel

Thomas Brunel and Niels Hintzen (IMARES / The Netherlands)

I. Background

A commonly used approach to test the performance of fisheries management consists is simulating the mid to long-term developments of the stock under a given management regime, based on the perception from the most recent assessment. Such simulations should represent as precisely as possible the dynamics of the stock and of its fishery and take account of the various sources of uncertainty in the assessment and in the management system. A range of diagnostics can then be calculated from the output of the simulation, which can be used to describe the performance of any given management strategy.

A management strategy evaluation (MSE) tool was developed for jack mackerel, based on the most recent stock assessment available. This document describes the various components of this tool, and the different assumptions made. Some examples of application of this MSE tool are also given.

Though the MSE tool is primarily designed to evaluate the performance of difference harvest control rules, it can be used to simulate the stock's dynamic equilibrium for a range of fishing mortality values, and hence identify fishing mortality and biomass corresponding to MSY. In the simulation, the selectivity of each fleet can be changed to represent the effect of changes in mesh size or in minimum landing size.

The setup of the framework is such that it can easily be updated with the latest assessment results, alternative management plan design and evaluate the performance of the combination on the spot.

II. The management strategy evaluation (MSE) approach

The principle of an MSE is to represent as realistically as possible the true dynamic of the stock and of the fleets exploiting this stock, and to mimic as closely as possible the stock assessment and management procedure which are to be evaluated. The MSE should give a correct perception of the sources of natural variability in the stock and of the uncertainty in the management system. In order to reflect this uncertainty, the simulations are run simultaneously on a large number of replicates of the stock, each representing a likely version of the real stock.

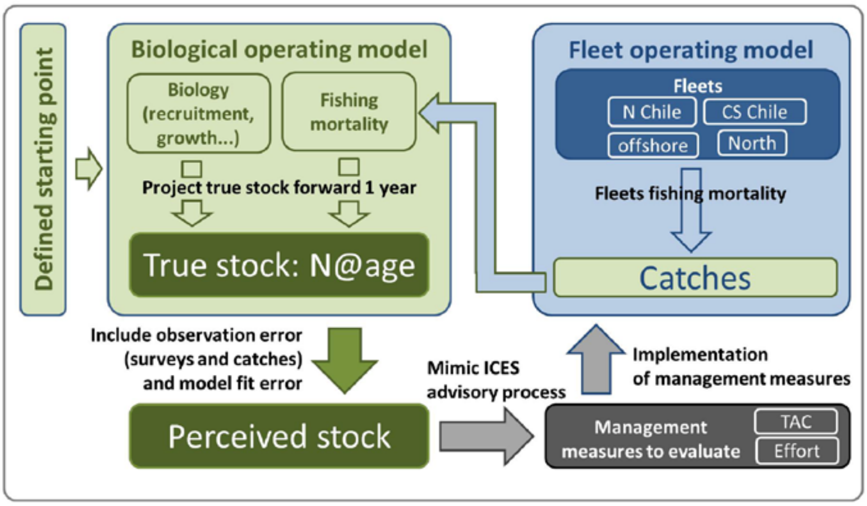


Figure 1 : conceptual representation of the management strategy evaluation

An MSE typically consists in an assemblage of blocks or models, which can be defined as follows (figure 1) :

- The biological operating model which is an age structured population model, representing the real stock. Natural processes such as reproduction, growth, sexual maturation, natural mortality should be represented as realistically as possible, and based on the available knowledge of the biology of the stock.
- The fishery operating model represents the different fleets harvesting the stock. Each has its own selection pattern (age decomposition of the fishing mortality).
- The observation model should give a correct representation of all the sources of uncertainty linked to observation (catch estimation, biological sampling, surveys) and to the assessment model (uncertainty due to model specification and fitting).
- The management module which reproduces the rules according to which a management advice is given based on the most recent output of the stock assessment model.

The initial vectors (numbers at age, fleet selection patterns, biological parameters) for the first year of simulation are taken from the most recent stock assessments.

The following sections give a detailed description of the different building blocks of the MSE for jack mackerel. All the analyses and simulations were done in R (R Core Team ,2013) using the Fisheries Library in R (FLR, Kell et al., 2007).

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1. Starting points

The starting point of the simulation was based on the output of the 2012 jack mackerel assessment (SPRFMO, 2012). The assessment output – numbers at age, fishing mortality at age, weights at age etc.. – were available from 1971 until 2012. The simulations start in 2013.

The output of the MSE simulations are influenced by the starting conditions. Furthermore, the output of the assessment are given with confidence intervals, representing the spread of the likely values around the point estimates. In order to have starting conditions reflecting the magnitude of the assessment uncertainty, a range of likely stocks was generated. In practice, for each replicates of the stock in the MSE, the recruitments and the fishing mortality and selectivity at age of each fleet in the historical period were resampled from a multivariate normal distribution of mean and variance-covariances taken from the assessment output. From these newly drawn parameters, the full numbers at age, catch at age, and fishing mortality at age matrices were computed.

2. The biological operating model

The biological operating model is an age structure population model (same age range as the assessment model), in which the real stock is calculated at each time step (usually one year) of the simulation, given the fishing mortality imposed by the fleets. It is crucial that the natural variability of the stock is accurately represented in the biological operating model, in order to be able to evaluate a range of potential reactions to a given management system.

Recruitment

Recruitment is the key component of stock productivity and it is crucial to have a realistic recruitment function in the model. The simulated recruitment should have the same variability as the recruitment observed historically. The stock to recruitment relationship, if existing, should be accurately modelled.

In the simulation tool designed for jack mackerel, two different approaches to model recruitment were implemented : stock to recruit models - where the average recruitment level is linked to the size of the spawning stock – and a recruit to stock approach – where recruitment varies independently from stock size, following another driver e.g. environmental signals.

<u>Recruitment simulation based on Bayesian composite stock - recruitment models</u>
A variety of stock-recruitment models are available to represent the link between SSB and the subsequent recruitment. However for many stocks, the data does not really support one of this model more than the others, and the choice of one stock recruitment model, even if supported by statistical comparison, often remain quite subjective. In addition, simply fitting a stock-recruitment model (e.g. using maximum likelihood) does not really allow to represent the uncertainty in the estimated parameters.

Here, a method combining different stock-recruitment functions, and based on a Bayesian estimation of model parameters was used to give a full representation of the uncertainty in the stock-recruitment model. A complete description of the method can be found in Simmonds et al. (2011). The basic principle are as follow :

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- For a range of selected stock-recruitment functional forms (here hockey stick, Ricker and Beverton and Holt were used), a Bayesian estimation of the model parameters is performed.
- For each stock-recruitment function, a set of 1000 models are kept from the MCMC chains.
- Based on the likelihood of each of these models, a probability can be computed for each functional form.
- A subset of stock-recruitment models (one model for each of the replicates of the stock in the MSE) is then randomly sampled from the 3 sets of 1000 models, proportionally to the probability of each functional form.

In the case of jack mackerel, there was no clear indication from the data for a specific functional relationship. Fitting the hockey stick, Ricker and Beverton and Holt models with a Bayesian parameter estimation (assuming normally distributed residuals) shows that there is a large uncertainty in parameter estimates (figure 2). The most likely relationships are Beverton and Holt (50%) and Ricker (40%).

For each of the replicates of the stock in the MSE, the recruitment model is defined by the functional form, the two parameters defining the shape given the functional form, and Sigma, the residuals standard error. Recruitment for a given year *y* in the simulation is hence modelled by the following formulae :

$$R_{y,k} = rnorm\left(mu_{y,k}, sigma_k\right)$$
$$\text{and} \qquad mu_{y,k} = SRR_k\left(SSB_{y-rec\,age,k}\right)$$

Where SSR_k is the stock recruitment model for the k^{st} replicate of the stock, $sigma_k$ is the corresponding residuals standard error and rec age is the age at recruitment. The function *rnorm()* means sampling one value from a Gaussian distribution with defined mean and variance.

In order to check whether the proposed modelling framework gives an appropriate description of the distribution of recruitment values, 40 000 recruitments where simulated using this method, based on the historical SSB values. The strong similarity in the cumulated distribution of the simulated values and the observed values (figure 3) indicated that the distribution of recruitment values was correctly represented by the Bayesian approach.

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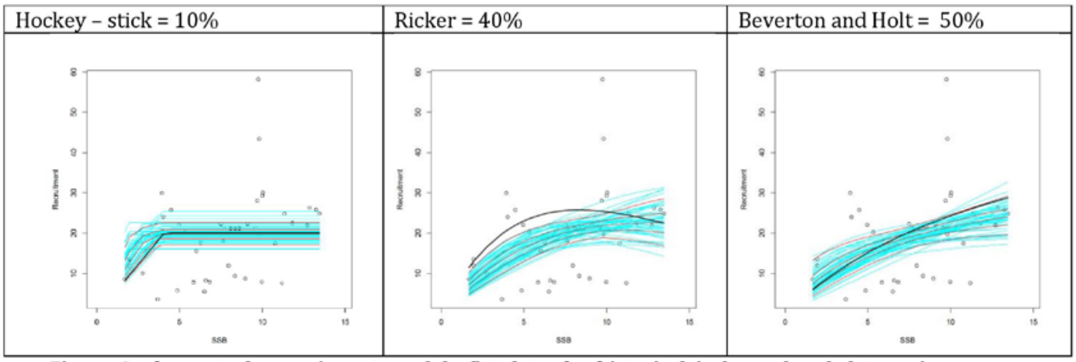

Figure 2: three stock recruitment models fitted to the historical jack mackerel data, using a Bayesian estimation. The blue lines represent a sample from the 1000 models taken on the MCMC chains for each functional relationship (with the 5%, 25%, 50%, 75% and 95% percentiles of the predicted recruitment values in red). The black line is the maximum likelihood estimate. The probability of each functional relationship is also given.

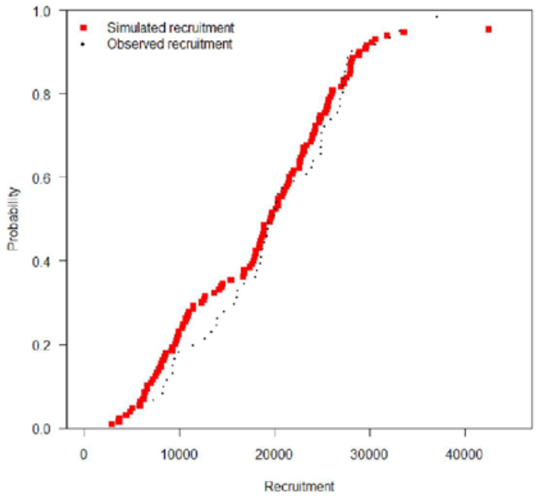

Figure 3 : comparison of the cumulated distribution of simulated recruitment based on the Bayesian approach and of the observed recruitments

Recruitment simulation based on Fourier surrogates

The Fourier surrogates method (see example of application in Planque and Buffaz, 2008) is based on a Fourier decomposition of the original recruitment time series (decomposition of the original time series into a sum of simple periodic functions). The surrogate recruitment time series are constructed by adding random phases in $[0,2\pi]$ to the Fourier decomposition of the observed recruitment time series, and then computing its inverse Fourier transform. This procedure is known as phase randomization (see e.g. Schreiber & Schmitz 2000). The resulting surrogates recruitment time series are Gaussian and have the same mean, variance and power

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spectrum as the original data time series. However the general trend can be quite different (figure 4) with some simulated series remaining at low level for the first 20 years and increasing thereafter (e.g. green series) while others first increase and then decrease (e.g. black series).

Using the surrogates recruitment time series in the simulation implies that the strength of a year class is not related to the size of the spawning stock from which it originates. This recruitment scenario represents therefore a situation where recruitment would be driven by an hypothetical environmental signal.

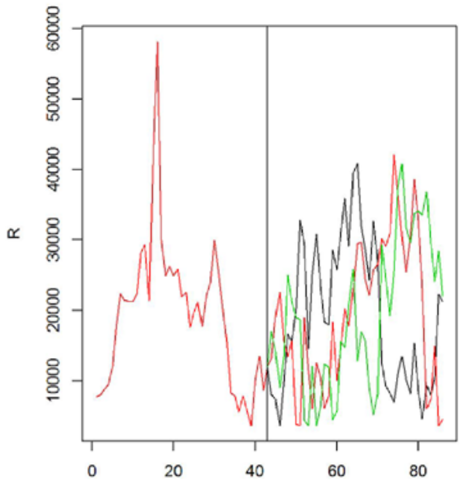

Figure 4 : recruitment simulation using the Fourier surrogates method. The first part of the time series (up to the vertical line) shows the historical recruitment values. In the second part, three Fourier surrogates are shown in red, black and green.

Growth

Preliminary analysis on jack mackerel showed that catch weights at age exhibited a significant degree of temporal autocorrelation. Hence it seemed inappropriate to represent weight at age by purely random variations. Instead an ARMA (auto-regressive moving average) model was fitted to capture the degree of autocorrelation of the variation of the time series. The ARMA models were fitted using the fArma library in R. For each time series, the best model – the optimal set of p and q parameters, being the orders of the autogressive and moving average parts respectively) was obtained by fitting a range of models with varying p and q values and selecting the one with the lowest AIC criteria. Once an ARMA model is fitted to a time series, it can be used to simulate time series with the same characteristics as the original time series.

An ARMA model was first fitted to the time series of weights at age 1, and one weight at age 1 time series was simulated for each replicate of the stock. Then, the growth increment during the second year of the fish (i.e. weight at age 2 minus weight at age 1) was modelled by another ARMA model. Time series of weight increments from age 1 to 2 were generated for each replicate of the stock. The weight increments were added to the weights at age 1 of the corresponding cohort to generate the weights at age 2. Weights at age 3 to 12 were generated in

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the same way. By doing so, each cohort has a coherent growth history (e.g. no decrease in weight is possible).

This was done for the two different catch weights matrices (one for the Farnorth fleet, and another for the 3 other fleets). As in the assessment, the weights at age in the stock were calculated as an average of the two matrices, weighted by the historical proportion of the catch taken by the FarNorth fleet compared to the sum of the three others.

Natural mortality and maturity

As in the stock assessment model, constant natural mortality and maturity at age were used in the simulations.

3. Fishery operating model

The total fishing mortality, which is used in the biological operating model to compute at each time step the numbers at age at the start of the new year, is the sum of the partial fishing mortalities of the 4 fleets. Each of these fleets has a given selectivity, which is kept constant over time in the simulation, equal to the selectivity at age estimated by the assessment for the terminal year. The proportion of the total fishing mortality represented by each fleet is also constant in time, which means that any change in the total fishing mortality resulting of a given advice affects the 4 fleets in the same way. This also means that the percentage of the catch realised by each fleet in the simulation is constant and equal to the percentage in 2012.

4. The perceived stock

In the simulations – as in reality - management decisions are based on the perception of the real stock provided by a stock assessment. Stock assessment gives a perception of the real stock which can deviate from the real stock for a number of reasons : inaccuracy of the catch data, sampling uncertainty, noise in the survey indices, assessment model mis-specification, assessment model fit uncertainty.

At each new year in the simulation, a new perception of the stock has to be generated, in a way that mimics as closely as possible the uncertainty related to stock assessment. The approach taken for the jack mackerel MSE consisted in adding an error term to the output – abundance and fishing mortality at age - of the biological operating model. This error term was defined as the product of cohort-specific normally distributed deviations and an error amplitude proportional to the assessment uncertainty of the corresponding estimate.

The cohort specific deviations were generated by sampling a random number from a standard normal distribution for each cohort of the projection period, and propagating this value to all the ages for each cohort (figure 5). One matrix of cohort-specific normal deviations was generated for each replicate of the stock.

The amplitude of the error on numbers and fishing mortality at age was calculated from the 200 replicates of the biological stock at the start of the simulation (see section starting points). These replicates were generated by resampling parameters from the stock assessment based on the variance-covariance matrix and therefore the inter-replicate variability of a given estimate represents the uncertainty in the assessment output. A matrix of CV representing the amplitude of the assessment uncertainty was calculated for numbers and fishing mortality at age by computing the standard deviation of a given estimate (N or F at a given age, for a given number of years before the terminal assessment year) across all 200 replicates and dividing by the mean.

The final error was calculated by multiplying the cohort specific deviations by the uncertainty variance, calculated as square of the product between the CV and the estimate from the biological model (figure 5).

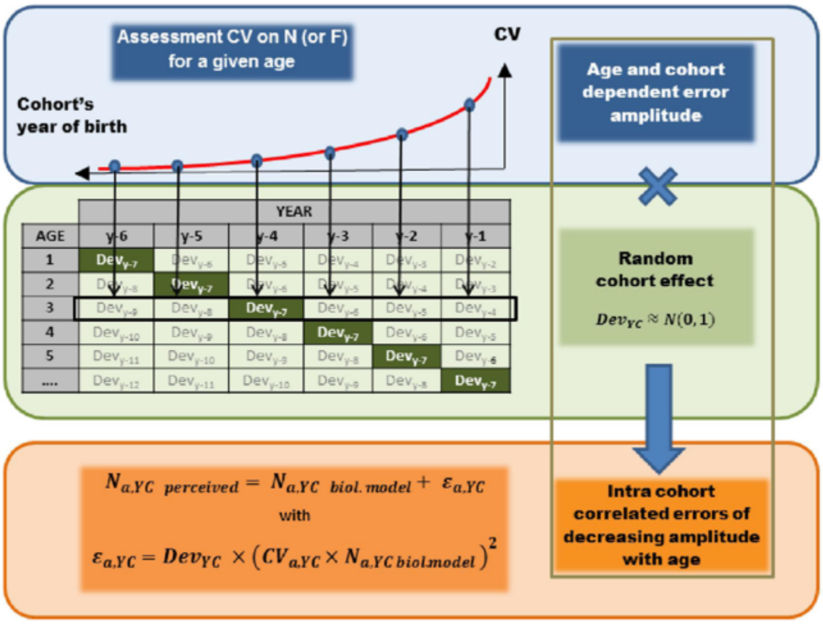

Figure 5 : simulation of assessment errors. Assessment errors are the product of a cohort effect normally distributed and an age and cohort dependent amplitude, representative of the uncertainty in the assessment, derived from on the variance-covariance matrix of the assessment parameters.

5. Implementation of the management rule

At each step of the simulation, a TAC advice is formulated based on the results of the latest assessment. The procedure which is implemented here is similar to the standard ICES procedure, where in a given year *y*, the TAC advice is given for the following year *y+1*, based on a perception of the stock in the previous year *y-1* (figure 6). In order to give a TAC advice, a short term projection of the stock is necessary to get the stock abundance in the advice year *y+1*. The short term forecast is based, as in reality, on the perceived stock.

Here, the survivors at the start of the current year, *y*, are projected forward to the start of the next year, *y+1*, using the assumption that the catch of the current year *y* is equal to the TAC for the same year *y*. Then, based on the numbers at age at the start of the year *y+1*, the harvest control rule is applied : such rule give the value of Fbar which should be applied in the year *y+1* given the value of SSB in *y+1*. The advised TAC in year *y+1* is calculated based on this value of Fbar. In this MSE, it is assumed that the actual catch in a given year is equal to the advised TAC, i.e. that the quotas are fully used and not overshot.

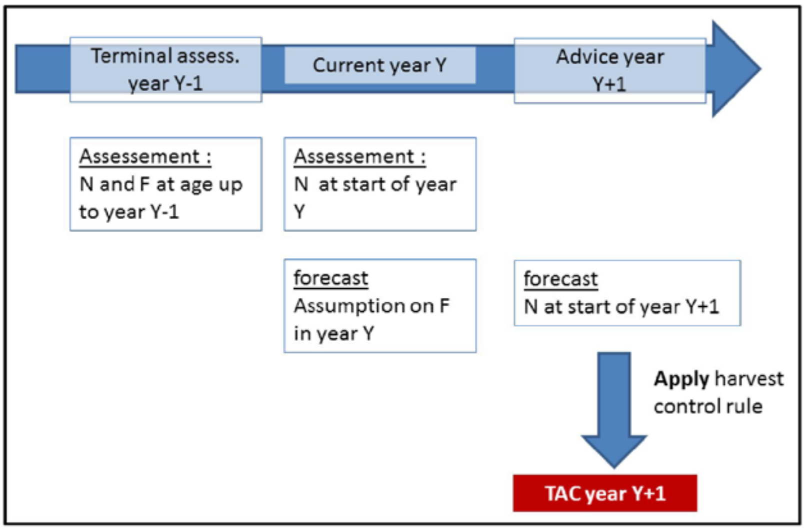

Figure 6 : time line of the advisory process implemented in the MSE. In year y, advice is given for the catch of year y+1 based on a short term forecast of the stock 2 years ahead of the final year estimated in the assessment, y-1.

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III. Application of the MSE tool to estimate MSY

A first set of simulations were run to investigate the link between SSB, Yields and fishing mortality at equilibrium. These simulations were run by imposing a constant Fbar value over the simulation period (2013 to 2040) directly in the biological operating model (i.e. not based on the perceived stock, and not implementing any management rule). The aim of these simulation at constant F is to reach a "dynamic" equilibrium, where the stock would be on average at an equilibrium situation corresponding to the level of F imposed, but will still fluctuate around this equilibrium due to the stochastic variability in the model. The equilibrium state is defined by computing the mean of SSB and Yield over the period 2030 to 2040. Inspection of the stock trajectories confirmed that equilibrium was usually reached in 2030. The simulations were run using 200 replicates (generated as explained above) of the stock for each value of Fbar. Hence, for a given Fbar, the variability in mean SSB and mean Yield at equilibrium is the result of the difference in the stock-recruitment models (functional form and parameter values) between replicates.

The results of the simulations using the Bayesian stock recruitment models are show on figure 7 and the results of the simulations using the Fourier surrogate time series are show on figure 8.

For the recruitment scenario based on the Bayesian stock-recruitment models, Fmsy was estimated at F=0.14, corresponding to a yield of around 2 mt, and an SSBmsy of 10.6mt. These estimates are in the line with previous estimates obtained by a range of different methods (Hintzen and Canales, 2012), giving Fmsy in the range of 0.13 to 0.17, MSY between 1.9mt to 2.2mt and Bmsy between 9.3mt and 12.1mt.

The determination of MSY for the recruitment scenario based on the Fourier surrogates was inconclusive. The yield increased with fishing mortality until around F=0.20, and was stable thereafter, with no sign of decrease at high F values. At the same time, the SSB decreased continuously with increasing fishing mortality.

The concept of MSY is based on the principle of density dependent productivity in fish stocks: starting to exploit a virgin fish population relaxes the strength of density dependent mechanisms, and thereby increases the productivity of the stock. Further increasing the exploitation level leads to overexploitation, a situation where the productivity is reduced (starts affecting recruitment, does not let the fish growth to the optimal size). The MSY is the limit between these two states. In the simulations using the Fourier surrogates, there is no link between recruitment and stock size, and hence no density dependence is present in the model. The concept of MSY has no meaning in this case, since the productivity of the stock is governed entirely by extrinsic factors.

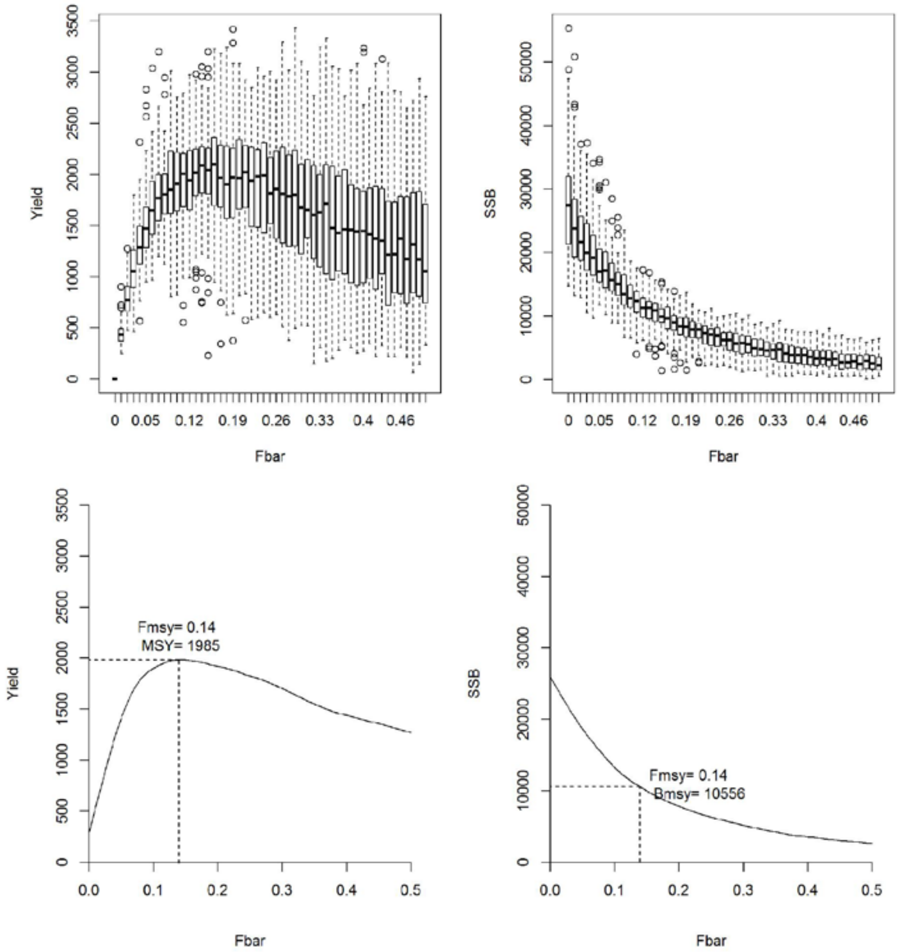

Figure 7 : determination of Jack mackerel MSY based on the Bayesian stock-recruitment models. The plots show the mean yields and SSB over the years 2030-2040 in relation to the Fbar value. Top panel : the boxplot represent the variability of the mean Yield and SSB across the 200 replicates ; bottom panel : relationship between the median value of Yield and SSB and Fbar (smoothed using a lowess smoother), and determination of the MSY.

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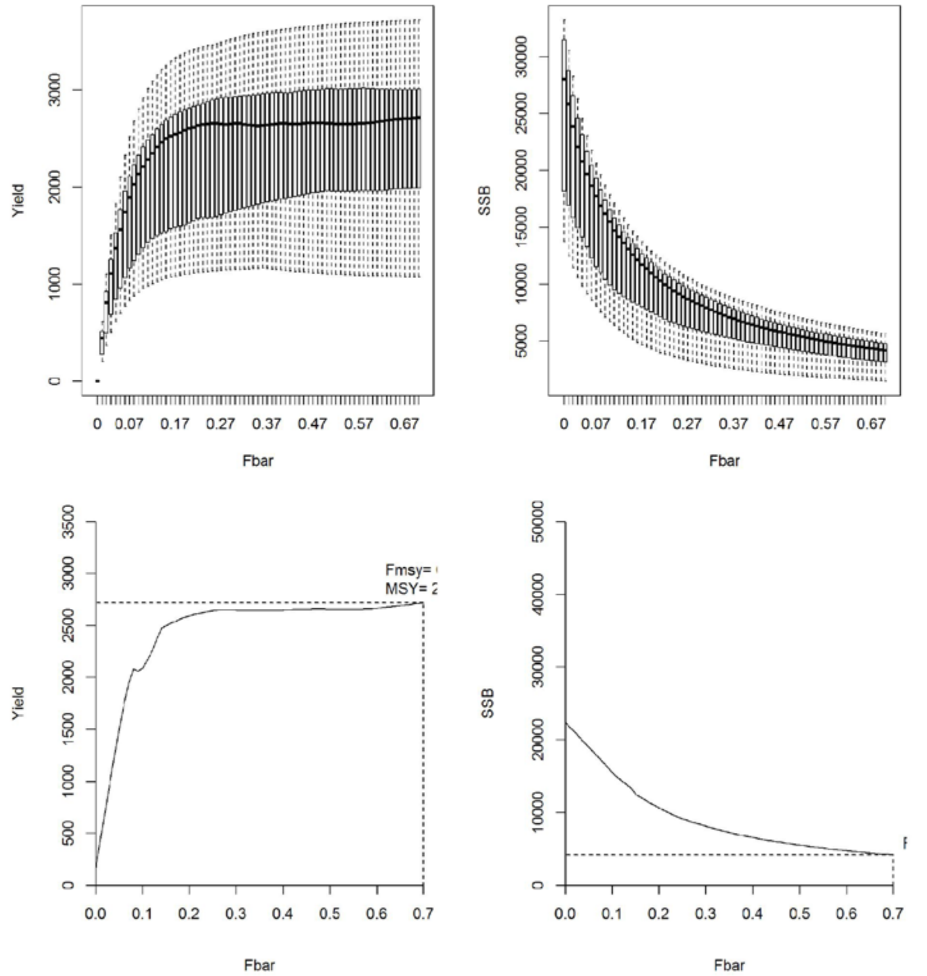

Figure 8 : determination of Jack mackerel MSY based on the Fourier surrogate-recruitment time series. The plots show the mean yields and SSB over the years 2030-2040 in relation to the Fbar value. Top panel : the boxplot represent the variability of the mean Yield and SSB across the 200 replicates ; bottom panel : relationship between the median value of Yield and SSB and Fbar (smoothed using a lowess smoother), and determination of the MSY.

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IV. Example of evaluation of the performance of management strategies

In order to illustrate how the simulation tool can be used to evaluate the performance of a management strategy, simulations were run applying different example management scenarios. Diagnostics of the performance of these management scenarios were derived from the output of the simulation.

Since these simulations are only carried out for the purpose of illustration, the Bayesian stock-recruitment scenario was chosen arbitrarily.

1. Management scenarios

Proposed reference points

The table below gives the values of the proposed reference points for the management of the jack mackerel, together with their definition and origin.

	Value	Description	Origin
Biomass reference point			
Bmsy	10.6 mt	Biomass at MSY	Simulations using the Bayesian SR models (see above)
Blim	2.8 mt	Biomass under which recruitment may be impaired	Median of the breakpoint of the 1000 hockey-stick stock recruitment models fitted with the Bayesian approach
Bpa	3.9mt	Biomass below which there is a risk to fall below Blim, given the uncertainty in the assessment	Bpa=Blim * exp(1.645 σ) with σ being the standard error of the SSB estimate, here equal to 0.2 (see ICES, 2007)
Fishing mortality reference point			
Fmsy	0.14		Simulations using the Bayesian SR models (see above)

Scenario 1 : constant fishing mortality "F target" scenario.

The TAC is set so that the fishing mortality in the advice year is equal to a target value. Here the value Ftarget was set at Fmsy=0.14.

Scenario 2 : recovery plan

Given that the stock is currently at a low level, special management measures, aiming at rebuilding the stock to higher levels, could be implemented. Simulations were also run to test the efficiency of a stock recovery management strategy in which :

- F should be annually decreased by 25% until the stock recovers to a level above Blim,
- When Blim is reached, F should be annually decreased by 15% per year until the stock is above Bpa,
- When the stock has recovered at above Bpa, F should be equal to Fmsy.

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Scenario 3 : hockey-stick harvest control rule

This harvest control rule aims at maintaining the stock close to MSY. When the stock is at Bmsy or larger, it should be exploited at F=Fmsy. When the SSB falls below Bsmy, F should be reduced from Fmsy proportionally to the decrease of SSB compared to Bsmy (figure 9).

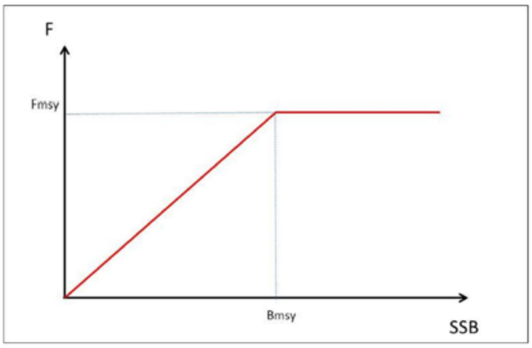

Figure 9 : the hockey-stick harvest control rule

2. Simulation set up and performance diagnostics

The simulations were run with the following set-up :

- simulation first year : 2013
- simulation last year : 2040
- number of replicates : 200
- recruitment : Bayesian models (fitted based on SR pairs from 1970 to 2012)

The performance of the HCR was measures of the risk, recovery speed, yield. The risk corresponds to the probability of SSB falling below Blim, defined as the proportion of the stock replicates for which SSB was below Blim at least one year over the period of years of interest (prob2, as defined by ICES 2013). Given that the stock is at around Blim at the start of the simulation, the probability prob2 was calculated excluding the 5 first years of simulation.

The efficiency of the management in term of recovery was assessed by the rebuilding speed expressed as the number of years after the start of the simulation at which the stock first reached a level above Blim and then, Bpa.

The performance in term of yield was assessed by the mean yield in the short (2013-2017), medium (2018-2027) and long (2027-2040) term. The yield variability was also calculated as the average of the absolute percentage of change between two consecutive years.

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3. Simulation results

The figure 10 shows the simulated stock trajectories for the three management strategies implemented. The diagnostics are presented in table 1. SSB trajectories are very similar for the three management scenarios, with an instantaneous increase at levels above Blim, and with Bpa being reached within less than 2 years for the hockey-stick HCR, to 3 years for the F target management. In the long term, SSB reaches Bmsy, and even goes slightly above for the hockey-stick HCR. The risk with respect to Blim is never higher than 1% in the mid and long term. Minor differences are found for fishing mortality, with Fbar going immediately to Fmsy in the F target management, decreasing slightly in 2014 but then going to Fmsy for the recovery strategy, and declining abruptly in 2014 and slowly increasing towards Fmsy for the hockey-stick HCR. In all cases, Fbar is close to Fmsy in the long term. The hockey-stick HCR leads to higher yields in the mid and long term, but at the price of lower yields in the short term and of a slightly higher yield variablity. In all cases, the discrepancies between real and perceived stock are small. Assessment errors are similar in the three cases, with a small imprecision on SSB with no bias, and a small but minor bias on Fbar.

Table 1 : diagnostics of the simulations.

	Management scenario		
Diagnostics	**F target**	**Recovery plan**	**Hockey stick HCR**
Risk	proportion of the stock replicates falling at least once below Blim		
Mid Term	1%	0%	0%
LongTerm	1%	1%	0%
recovery time	Average number of years to go above the specified SSB level		
to Blim	0.33 yr	0.19 yr	0.18 yr
to Bpa	3.02 yr	2.65 yr	1.79 yr
SSB	Average SSB		
Long Term	9.9 mt	10.4 mt	11.0 mt
End	10.7 mt	10.8 mt	11.6 mt
Fishing mortality	Average Fbar		
mean	0.141	0.140	0.126
Long term	0.143	0.142	0.136
End	0.143	0.143	0.138
Yield	Average yield		
Short Term	578 t/yr	555 t/yr	444 t/yr
Mid Term	1269 t/yr	1338 t/yr	1453 t/yr
Long Term	1909 t/yr	1942 t/yr	2071 t/yr
Yield Variability	Mean absolute yield difference between two consecutive years		
	9.6%	10.0%	11.6%
Assessment errors	Difference between real and perceived stock relative to the real stock		
SSB (absolute bias)	4.3%	4.3%	4.0%
SSB (bias)	-0.2%	-0.3%	0.1%
Fbar (absolute bias)	2.1%	2.1%	2.1%
Fbar (bias)	2.0%	2.0%	2.0%

F target **Recovery strategy** **Hockey stick**

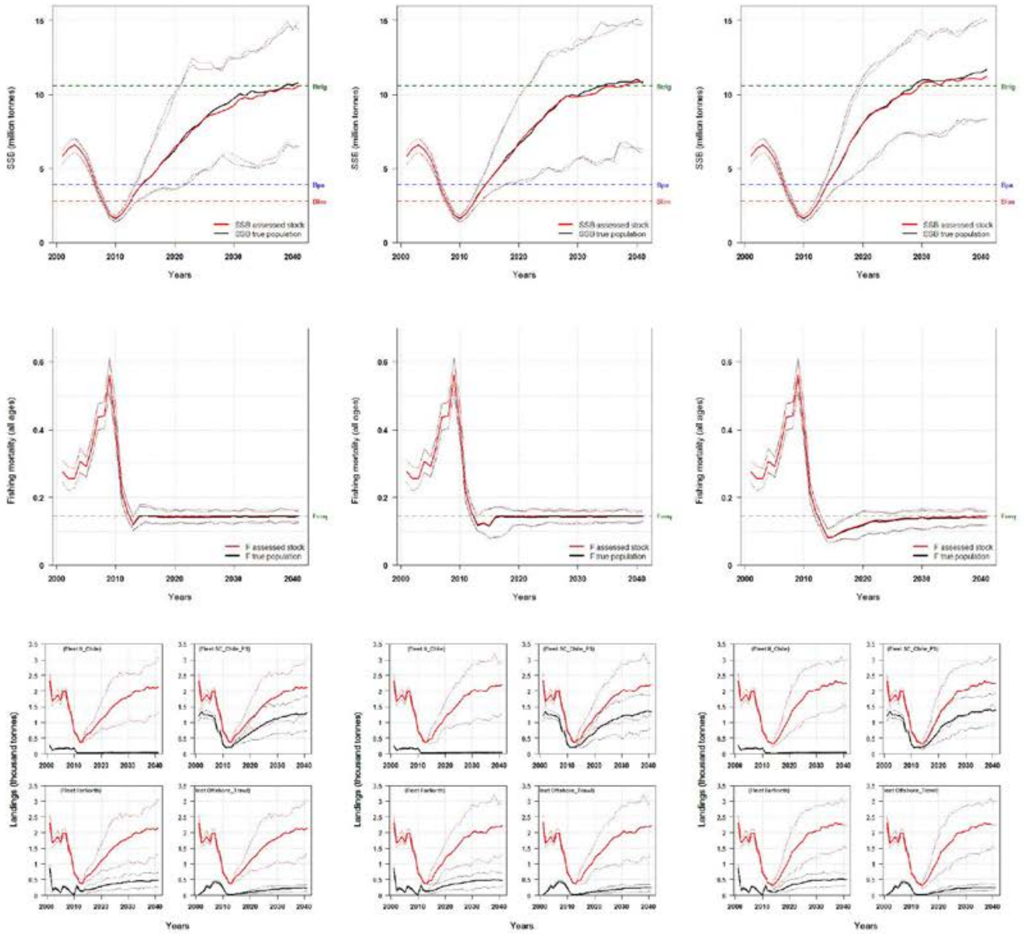

Figure 10 : simulation output for three management scenarios. Jack mackerel SSB (Top panels), fishing mortality (medium panels) and Yield (bottom panels) trajectories (solid lines : median values ; dashed lines : 5% and 95% quantiles of the inter replicates distribution)

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V. Concluding remarks

This document presents a methodological framework to test different management strategies for jack mackerel. Here, only a couple of management strategies were implemented for the purpose of illustration. The next step toward the instauration of a management plan for jack mackerel is the definition of management goals by the stakeholders. Real candidate management strategies should then be defined to fulfil these goals and eventually evaluated using this MSE framework.

The key element in these simulations is the representation of jack mackerel recruitment. All the projections shown here are based on the Bayesian stock recruitment models. It is hence expected that recruitment will increase if SSB starts to rebuilt. However, the decrease in recruitment to low levels in the recent years is quite likely to be associated to environmental drivers, which may have acted in combination with overfishing. The stock recruitment models being fitted based on the historical time series, they do not take account specifically of the recent low productivity of the stock. It is not known whether recruitment can rebuilt to level as high as in these simulations if the SSB start rebuilding.

More research on the environmental determinism of jack mackerel recruitment is needed to build a better knowledge. Until such knowledge is available, MSE simulations based on the Stock-recruitment models should be considered with caution. The reasons for the current low productivity regime are unidentified, and it is impossible to make an assumption on its duration. Therefore, it is uncertain whether the stock can be expected to rebuild as in the simulations shown in this document.

In absence of any knowledge on the drivers of jack mackerel recruitment, the Fourier surrogates time series could be useful to represent a range of potential environmentally-driven recruitment scenarios. Further decisions will have to be made as to whether the surrogates are considered to be an appropriate basis to represent recruitment in jack mackerel MSEs. In any case, simulations should be run using the Fourier surrogates, at least to test the robustness of management strategies to this alternative recruitment scenario.

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Annex

Annex 1 : overview of the jack mackerel MSE

	Background	
Motivation	Jack Mackerel is fished both in international waters and in nationals waters from Ecuador to Chile. The stock is assessed annually by SPRFMO, but there is no management plan in place.	
Objectives	Evaluate a set of candidate management strategies for Jack Mackerel in the Southeast Pacific	
Formal framework	Task of WP4 in the EU project "hydrography and Jack Mackerel in the south pacific"	
Authors	Thomas Brunel and Niels Hintzen IMARES / the Netherlands	
	Method	
Software	Ad hoc software, written in R/FLR, assessment model in AD model builder. Age structure model, HCR applied on a perceived stock (true stock + noise reproducing the uncertainty in the assessment), different recruitment scenario tested	
Type of stock	Pelagic, widely distributed and migratory, medium lifespan	
Knowledge base	Analytic assessment (age based, 4 fleets, 9 indices)	
Type of regulation	In the simulations, the fishery is managed by annual TACs (and potentially also via measures influencing the selection pattern of each fleet)	
	Operating model conditioning	
	Function, source of data	Stochastic? How :
Recruitment scenarios	Bayesian approach[1] fitted on the historical SR pairs (1970-2012). A set of 200 SR models with Bayesian parameters estimation. Proportion of each model (Beverton and Hold, Ricker and Hockey Stick) is based on their respective likelihood.	Stochastic deviations from the SR model normally distributed with a sigma estimated in the SR model fitting
	"Fourier surrogates"[2]: method which generate time series with the same power spectrum as the historical one	Fourier surrogates are by essence stochastic
Growth	Weight at age 1 and annual weights increments from age 1 to 11 modelled by a ARAM (autoregressive moving average) model	Noise (gaussian) on top of the AMRA simulations
Maturity	Same as assessment	Constant in the simulation
Natural mortality	Same as assessment	Constant in the simulation
Selectivity	For the 4 fleets, same as assessment	Constant in the simulations Resampled for each iteration

[1] Simmonds, E. J., Campbell, A., Skagen, D., Roel, B. A., and Kelly, C. 2011. Development of a stock–recruit model for simulating stock dynamics for uncertain situations: the example of Northeast Atlantic mackerel (Scomber scombrus). – ICES Journal of Marine Science, 68: 848–859.
[2] See for instance : Planque B, Buffaz L (2008) Quantile regression models for fish recruitment–environment relationships: four case studies. Mar Ecol Prog Ser 357:213-223.

Initial stock numbers	From assessment	using the varcov matrix Resampled for each stock replicate using the varcov matrix
Decision basis	SSB projected to the advice year	
Number of iterations	200	
Projection time	40 years	
Observation and implementation models		
Assessment in the loop?	No	
Type of noise	Cohort specific deviation * age/year specific effect decreasing with age and time	Cohort effect : N(0,1) Age effect : based on CV on N@age calculated from the varcov matrix of assessment parameters
Comparison with ordinary assessment	Simulated assessment errors have the same CV in the F and N at age in the assessment	
Projection :if yes how ?	Short term forecast 2 years ahead, assuming intermediate year catch is equal to the TAC	
Projection : deviation from WG practice	No catch advice base on short term forecast in the SPRFMO	
Harvest Rules		

Hcr design	Hockey Stick :
	If SSB > Btrigger → F = Ftarget
	If (Blim<SSB<Btrigger) → F = Fmin + (SSB-Blim) * (Ftarget-Fmin)/(Btrigger/Blim)
	If (SSB<=Blim) → F = Fmin
	
	Recovery plan :
	As long as SSB<Blim : reduce F by 25%
	When Blim<SSB<Bpa : reduce F by 15%
	When SSB>=Bpa : apply a Ftarget of 0.15
	
	Target F
	The TAC is set so that F in the advice year is equal to the Target F, set at Fmsy	

Reference points values	Ftarget = Fmsy=0.15 Blim= 2.8mt, Bpa 3.9mt, Bmsy=10.6mt	
Stabilizers	Comparison YES vs. NO stabilizer = max 15% interannual TAC change	
Duration of decision	Annual	
Revision clause	None	
Presentation of results		
Type of diagnostics	Recovery time Risk Fishing mortality Yield Yield variability	
Risk type (and time interval)	Risk : type 2 proportion of the iteration which went below Blim at least once.	
Precautionary risk level	5%	

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Drafting an advice sheet for the SPRFMO Science Committee

By: Niels Hintzen, Francois Gerlotto, Ad Corten
1st Science Committee, South Pacific RFMO

The Science Working Group (SWG) and now the Science Committee (SC) have been asked, on a regular basis, by the Commission to provide advice on, among others, sustainable catch opportunities for Jack Mackerel in the South Pacific. Up till this point, a specific paragraph was devoted in the SWG reports on advice. It is however often heard that the advice is difficult to find and to place the developments of the stock into context with the developments in biology, fishery and historic advice. An advice sheet, specifying the core elements of the status of the Jack mackerel stock and its catch advice, could be communicated through a short and graphical 'advice sheet'. An attempt is made to design such an advice sheet below.

To the authors opinion, the advice sheet should be short, clear and understandable to a broad public. It should contain graphics that instantly show the status of the stock and indicate potential problems in its assessment and forecast. The core text should be no longer than two pages and supplementary material should only be added if it supports the core text and/or provides important information on historic advice.

Below, an example advice sheet is given. Text and figures are added for illustration purposes only and might therefore not be complete or fully accurate.

South Pacific Regional Fisheries Management Organisation

Advice October 2012

Stock: Jack Mackerel (*Trachurus murphyi*)
Region: SPRFMO convention region, including EEZ of Chile, Peru and Ecuador

Advice for 2013

The SPRFMO Science Committee advises that effort should be maintained at or below 2012 levels. This results in catches for 2013 of no more than 441 000 t.

Stock status

		2010	2011	2012
Fishing mortality in relation to	Target	NA	NA	NA
	Limit	NA	NA	NA
Spawning stock biomass in relation to	Target	NA	NA	NA
	Limit	NA	NA	NA

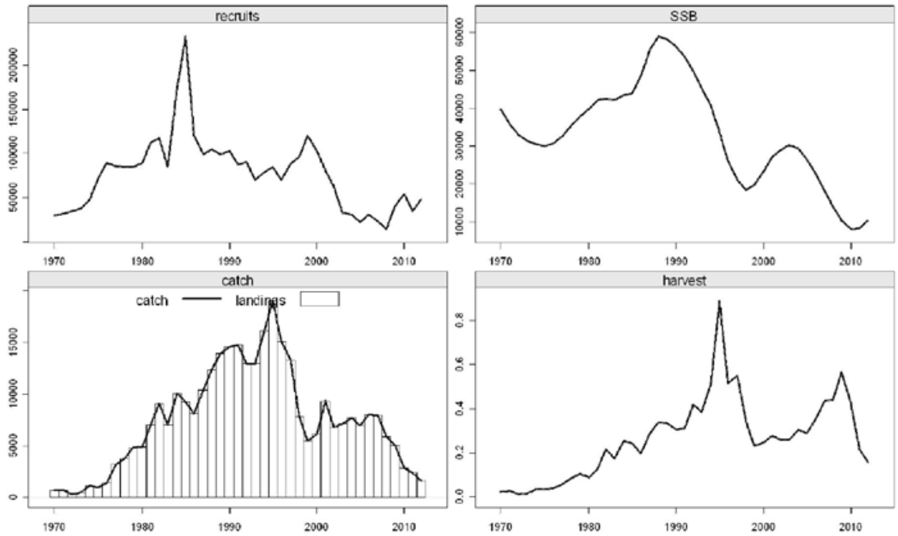

Figure 1. Jack Mackerel in the SPRFMO convention region, including the EEZ of Chile, Peru and Ecuador. Summary of stock assessment. Recruitment is measured in thousands, SSB in thousand tonnes, catch in thousand tonnes and harvest (fishing mortality) as a rate per year.

Management considerations

The Jack Mackerel stock is currently not managed by an agreed management plan or on the basis of reference points.

Biology

Recruitment

Recruitment and population dynamics are influenced by climate variability at a variety of scales from interanual, interdecadal, centenial to millennium. There is large variation in recruitment success from year to year and high uncertainty is associated with its estimation. The predictability of recruitment is low.

Spawning
Two major spawning areas have been identified, respectively south of 30ºS and north of 20ºS. The southern spawning area is most stable in its geographical location and timing of spawning. It is believed to be the most important spawning area in terms of egg abundance. The southern spawning area is located west of the Centre-South zone of Chile, from 100 to 300 NM from the coastline. The northern spawning area is less stable in its geographical location (moving from north to south Peru) and less important in terms of egg abundance. No clear knowledge of a possible offshore spawning area exists (west or 100ºW). Spawning takes place mostly in austral summer (October / November) and fish disperse during the spawning season.

Growth
Jack mackerel is the southern areas is a … growing fish. In the northern areas, it is known to grow faster due to …

Predation and mortality / role in the food web
No major predators for adults Jack mackerel can be identified. There are indications that tunas predate on juvenile Jack mackerel when they overlap in their distribution. In periods of high abundance the Jack mackerel stock can locally deplete the micronekton. Jack mackerel is an opportunistic feeder, where its most important prey are: Euphausids, Myctophids and copepods. Jack mackerel feeds by night in dense schools close to the surface.

Stock structure
4 stock structure hypotheses are listed by SPRFMO. Additional work is needed to identify the most likely structure.

Environmental influences on the stock
Jack mackerel is adapted to the South Pacific high environmental variability and especially to ENSO events. Its distribution and potentially recruitment success are linked to ENSO and decadal variations.

The fisheries

General description of the fisheries
Reported catches of jack mackerel up to the end of 2012 are shown in Figure 1. Historically, the jack mackerel stock has been exploited for more than 40 years, with total catches peaking at 4.700kt in 1995.

Changes in the fisheries
Over the past two years, the spatial and temporal distribution of Jack mackerel catches in the south-eastern Pacific appears to have changed drastically. The observed fish lengths suggests a displacement of juvenile fish from the international waters off Chile towards the EEZ of Ecuador and Chile, possibly as a result of the cooling of the waters (La Niña) or the appearance of a strong year-class in Ecuador and Peru. Chilean catches in 2011 were preliminary taken inside the Chilean EEZ, contrary to the location of the catches in the years before.

The monitoring
Monitoring is based upon 3 activities.

Scientific acoustic surveys have been performed by the 3 main fisheries (Chile, Peru, Russia) since the 1970s and are continued (Chile and Peru: 1 or 2 surveys per year). These surveys cover approximately … % of the Jack mackerel distribution. The surveys provide information on …

Fishing vessels data (excluding catch data) provide informations on the fishing grounds (spatial, dynamic and ecological complexity). Data is collected in all fishing seasons by fishing ships equipped with a digital echo sounder. Data series exist in Peru and Chile since the 1980s for systematic surveys.

Environmental monitoring is obtained from satellite sensors and acoustic information collected on-board fishing vessels. The monitoring data provides information on Jack mackerel habitat, based on relationships between environmental conditions and the distribution of Jack mackerel.

The assessment

The Joint-Jack mackerel stock assessment model has been used to assess the Jack mackerel stock in 2012. Updates to catch data and survey time series were available and have been evaluated.

Quality considerations

A number of changes were made to the model assumptions and data available to assess the status of the stock. These changes have been evaluated stepwise to ensure improvement of the model. Given the current debate on stock structure, two model configurations were tested whereby the Far North fleet was isolated and used in a separate assessment. The results of these model configurations and isolation of the Far North fleet is given in figure 2.

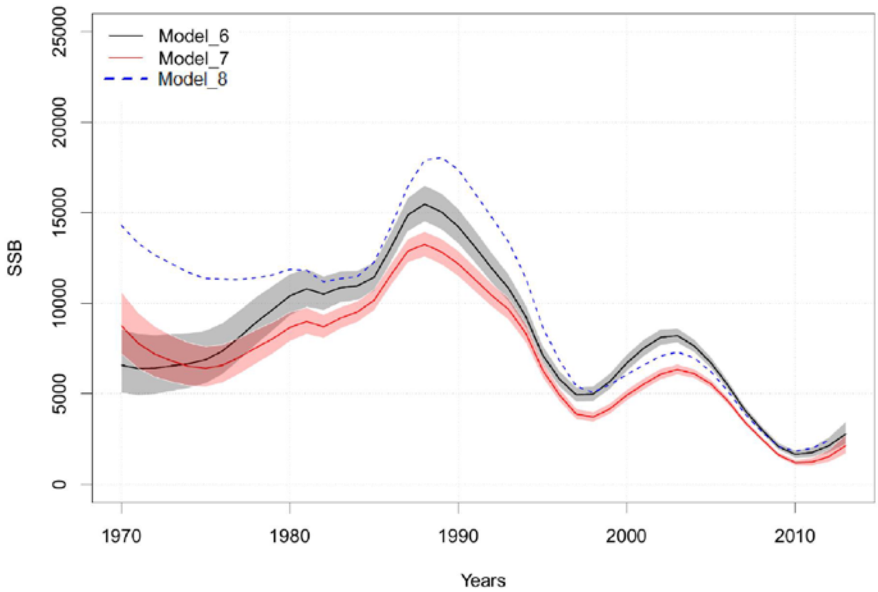

Figure 2: Spawning biomass estimates (t) comparing 3 final model configurations. Model 6 indicates a model configuration assuming a low recruitment regime while model 7 indicates a model configuration with more variability in selection. Model 8 indicates the sum of two assessment models, one based on catch data without the Far North fishery and one based on the Far North catch data only.

Outlook for 2014

Constant fishing mortality scenarios were explored at 100%, 75%, 50%, 25% and 0% of F_{2012} = 0.29. Advice is based on an accepted tentative risk criteria: fishing at a constant mortality rate must ensure that there is a >90% probability that biomass in 2021 > biomass in 2012.

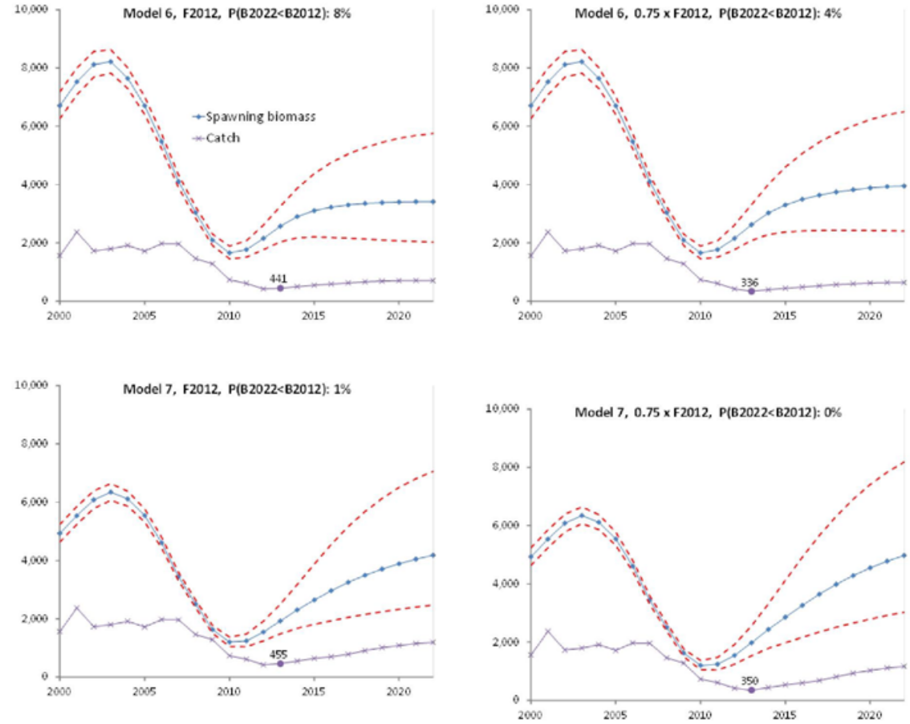

Figure 2: Jack mackerel projections showing catch (lower line) and spawning biomass (dash lines represent 90% confidence bands) for Models 6 (top row) and 7 (bottom row) assuming the same fishing mortality as in 2012 (left column) and at 75% of that level (right column).

Reference points

Currently no reference points have been defined

Catch by countries

	Fleet 1	Fleet 2	Fleet 3 (Far north)					Fleet 4 Trawler fleet off Chile (outside EEZ)											
Year	N Chile (1)	Chile CS (1)	Peru(1)	Ecuador (2)	USSR	Cuba (2)	Subtotal	Belize	Peru	Japan	China	EU	Faroe I.	Korea	Russia /USSR 1)	Cuba	Vanuatu	Subtotal	Total
2002	108727	1357185	154219	604			154823				76261							76261	1696996
2003	142016	1272302	217734				217734				94690			2010	7540		53959	158199	1790251
2004	158656	1292943	187369				187369				131020			7438	62300		94685	295443	1934411
2005	168383	1262051	80663				80663	867			143000	6179		9126	7040		77356	243568	1754665
2006	155256	1224685	277568				277568	481			160000	62137		10474			129535	362627	2020136
2007	172701	1130083	254426	927			255353	12585			140582	123511	38700	10940			112501	438819	1996956
2008	167258	728850	169537				169537	15245			143182	106665	22919	12600	4800		100066	405477	1471122
2009	134022	700905	74694	19834			76629	5681	13326	0	117963	111921	20213	13759	9113		79942	371918	1283474
2010	169010	295681	17559	4613			22172	2240	40516	0	63606	67749	11643	8183	0		45908	239845	726708
2011	23945	194532	257241	69153			326394	0	674	0	32862	2248	0	9253	8229	8	7672	60946	605817
2012	12000	208403	168779	104			168883	0	2996	0	10797	0	0	5492	0	0	8746	28031	417317

Underlined figures have been updated in 2012. 2012 data are preliminary and reflect the best estimates for the year

SPRFMO Advice and Catch / Landings (table)

Year	Advised catch	Agreed catch	Reported catch
2008			1471122
2009			1283474
2010			726708
2011			605817
2012			417317
2013	441000	441000	