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Deliverable D6.10

Report on the DSTs used in case studies for developing MR2

30/03/2022

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Executive Summary

This document contains a report of the Decision support tools used for developing management recommendations (MRs) in each of the FarFish case studies. These tools have been selected in coordination with the production of the version two of the Management Recommendations for each case study. It continues the work program outlined in Deliverable 6.4 and 6.7 in collaboration with other work packages (WPs) of FarFish, mainly WP1, WP4 and WP7. The report shows the outputs of the satellite work in support of compliance. It summarizes the use of the FarFish-DLMtool developed for supporting stock assessment in data limited situations, including implementation, training applications and dissemination beyond FarFish. It also describes how some data limited methods were explored using small pelagics data from West Africa and the plan to use them to understand the effect of the environment on the population.

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Abbreviations

AIS	Automatic Identification System
CS	Case Study
DLM	Data Limited Method
DoA	Description of Action
EEZ	Exclusive Economic Zone
ESA	European Space Agency
GFW	Global Fishing Watch
GT	Gross Tonnage
ICCAT	The International Commission for the Conservation of Atlantic Tunas
ICES	The International Council for the Exploration of the Sea
IOTC	The Indian Ocean Tuna Commission
IUU	Illegal, unreported and unregulated
MPA	Marine Protected Areas
MR	Management Recommendation
NOAA	The National Oceanic and Atmospheric Administration
OT	Outcome Target
RFMS	Responsive Fisheries Management System
TAC	Total Allowable Catch
VHF	Very High Frequency
VIIRS	Visible Infrared Imaging Radiometer Suite
WP	Work Package
WWF	World Wide Fund for Nature

Concepts/definitions

Management Recommendation	In RFMS, the management recommendation (MR) is a formal arrangement between a management authority and operators that specifies the partners in the fishery and their respective roles, the agreed objectives for the fishery, the management rules and regulations that apply, and provides other relevant details about the fishery.
Outcome Target	Outcome targets (OTs) are specific and measurable requirements that are set by an authority to make management goals operational. An OT is a statement of the condition of an indicator relative to a reference point, often in the form of an inequality ('A>B') or a statement of presence or absence of some entity. On the basis of relevant information, this statement can be assessed to be either true or false at a given point of time54. For instance, the management objective that "the fishery should be biologically sustainable" could be expressed in terms of one or more OTs such as 'Catch < 20 000t; 'by-catch < 20%'; SSB > 30 000t; 'a catch reporting system is present', etc.

1 Introduction

The overall objective of work package six (WP6) in the FarFish project is to develop tools that provide added value, relevance and usefulness in support of management and decision making for the actors involved in each of the case studies (CSs). As described in FarFish deliverables 6.4 and 6.7 the relevance and added value was ensured through a consultation process involving both internal (mainly the partners involved in the implementation of the case studies) and external (mainly regional fishery bodies) actors of FarFish. Partnership with other organizations like Copernicus Marine Services, Global Fishing Watch and Google was also incorporated to the exercise. As described in this report, these organizations have provided data and technical support to develop the tools identified as relevant and with added value by internal and external actors while ensuring technical characteristics that make of them useful tools within the context of the Responsive Fisheries Management System (RFMS) applied in FarFish.

As described in the DoA and in FarFish deliverables 6.4 and 6.7, for the tools generated in WP6 to be useful to actors involved in the spiral procedure of applying the RFMS approach, they must accomplish a set of operative characteristics such as:

1) Facilitating an equal footing for the technical dialogue of all actors involved.
2) Guaranteeing all-actors accessibility by working under open-access schemes.
3) Interaction with data, simulation and visualization based on free platforms.
4) Tools remaining once the project has ended.

According to consultation process starting and evolving through the time of the project (see D6.4), the diversity of tool demands was organized into five basic sets, namely:

1) Model implementation to assess stocks.
2) Big-Data analysis from satellite in support of compliance.
3) Oceanographic support to stock dynamics.
4) Tools to differentiate hake stocks in NW Africa.
5) Visualization tools

It is described in this report how these tools have been implemented through the use of free and widely used platforms such as RStudio, Shiny, Copernicus products or Google Earth Engine. This effort has also benefitted from the data work carried out in WP2 (deliverable 2.3 and 2.6), and from the collaboration of WP7 (deliverable 7.10) on delivering training in a hybrid workshop (in person and online) about the use of some of these tools to students from case studies countries.

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In addition to the creation of these tools, the report also describes the use of satellite and big data tools in support of compliance and how to combine the tools and methods available to provide oceanographic and stock assessment support for the Moroccan coast.

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2 FarFish Decision Support Tool for Data Limited stocks

Despite the important economic and social role of fisheries worldwide, only 80% of world catches come from species for whether current catch levels are sustainable (Costello et al 2012). This number claims for tools able to be applied even in conditions where little data (frequently only catch and more rarely effort) and technical expertise are available. A reference for sustainability is available through these tools to managers even in these conditions of poor data and expertise. Which was the situation of several FarFish Case studies as concluded by the stock assessment methods review performed by WP2 (D2.5): "*This review has shown that lack of suitable data for classical stock assessment methods is an underlying theme in all the case studies and that to date, there has been limited use of data-limited models or approaches applied*". Owing to this overall situation, the FarFish data limited tool (FarFish-DLMtool) builds on the methods described in Carruthers et al. (2014) and on DLMtool R package. Although there is a toolkit using this package developed by Carruthers and collaborators, we developed a new version enhancing mainly the data input process and testing it with different students from University of Cadiz, University of Algarve and GRO-FTP fellows including students from all case studies. Short guidelines for data input into FarFish-DLMtool were also developed and distributed to the students in collaboration with LDAC team (included as Annex 1 and 2 in this document). The combination of these guidelines, the two days training workshop on data limited methods and the open access of the tool ensure that it will remain once the project has ended.

The last version of the FarFish-DLMtool (available at https://ffdb.farfish.eu/) has two components: the DLMGui and the SPiCTGui. As explained in D6.8 the DLMGui (Data Limited methods graphical user interface) facilitates the implementation of the methods described in Carruthers et al. (2014), while the SPiCTGui (Stochastic surplus model in continuous time graphical user interface) provides a platform for the implementation of a Stochastic Surplus continuous-time state-space model (SPiCT, Pedersen et al, 2014).

FarFish-DLMtool proved to be useful by providing preliminary stock status estimations and outputs of different management measures for species of interest for the FarFish case studies, on one hand, on selected bycatch species of Indian and Atlantic Oceans, and, on another hand, by going deeper in the methods of the tool for assessing small pelagics status in the Moroccan coast. The first was part of the Mercedes Aramburu's master thesis for the Fisheries and Aquaculture master programme at University of Cadiz (Aramburu, 2021) and the second was developed during a short stay of the PhD student Ghoufrane Derhy from University of Cadi Ayyad at CSIC in Cadiz (Spain) and will be part of Ghoufrane Derhy's PhD thesis.

The tool was also used for training support in an introductory stock assessment workshop organized by WP7 and delivered to GRO-FTP students.

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Another important part for FarFish-DLMtool development was its dissemination in different events. Due to COVID 2019 pandemic, this dissemination was mainly performed through different online events.

2.1 FarFish-DLMtool used for obtaining preliminary stock status estimations and outputs of different management measures using data from bycatch species in Indian and Atlantic Oceans

Common dolphinfish, wahoo and frigate tuna are some of the major pelagic species caught as bycatch by fisheries targeting tropical tuna and swordfish in the Indian and Atlantic Ocean. They are also important species for small scale fisheries and fish processing companies in some island states like Seychelles and Cape Verde, where even some of these companies purchase these species caught by foreign vessels. Understanding the population dynamics and current status of these species would allow us to improve scientific advice and progress towards its sustainable exploitation. Because of the low quality and quantity of the available data, it is difficult to know the status of these species, thus there is a high level of uncertainty about their exploitation rates. Historical catch series, some abundance indices and some life parameters were used as data input into the FarFish-DLMtool to implement some data limited methods including the Surplus Production in Continuous Time model (SPiCT). The results obtained by implementing SPiCT for the common dolphinfish in the Indian Ocean are promising. Model estimates suggest that the resource is under-exploited, and the uncertainty is within acceptable levels, thus these results technically could be used to report on the status of the fishery. This could be an approximation towards adequately regulating the exploitation of these resources and ensuring their conservation and highlights the need to make a great effort to obtain data that allow us to better understand the fishery of these species in the Indian and Atlantic Oceans.

2.1.1 Methods selected and data input:

A SPiCT model was implemented using SPiCTGui feature of FarFish-DLM-tool, as well as the following methods to define management strategies for data limited stocks using the DLMGui feature: AvC (Average catches), CC1, CC2, CC3, CC4, CC5 (Constant Catch management), SPMSY (Surplus Production MSY) y SBT1 (Management applied to Southern Bluefin Tuna).

Catch data and catch per unit of effort (CPUE) as indices of abundance were obtained from the ICCAT databases (t1nc-ALL_20181205 (excel) and t2ce_20181205web (access)) and IOTC (IOTC-2018-DATASETS-NCDBrev2 (excel) and IOTC-2018-WPEB14-DATA04 - CELongline (excel)) both from the edition of 2018, it should be taken into account that these data are continuously being reviewed. For the Common dolphinfish and Wahoo from the Indian Ocean, Seychelles longline catches were used for the periods 1998-2017 and 1985-2017, respectively. CPUE data was obtained from swordfish longliners from La Reunion Island (Reunion from now on), which corresponds to the period 1994-2017. For

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Frigate tuna from the Atlantic Ocean, Cape Verdes's catches were used for the period 1987-2017 together with an abundance index from of the Spanish purse seine fleet (1991-2017). For all species, an average of catches was calculated for the period 2000-2017 from available catch data and the following life parameters were used: natural mortality, mean length at first maturity, rate of annual growth, maximum or asymptotic length, age at length 0 and parameters a and b. Additionally, for the Frigate tuna the maximum age and the size of first catch were also used. All life parameters for Indian Ocean species (Common dolphinfish and Wahoo) were extracted from FishBase. For the Atlantic Frigate tuna, the natural mortality, the mean length of first maturity and the parameters a and b were extracted from FishBase and the size of the first catch, growth rate annual, maximum or asymptotic length, age at height 0 and maximum age were extracted from Fredou et al, 2016.

2.1.2 Results:

2.1.2.1 Common dolphinfish in Seychelles

A list with the main estimated values is presented in Figure 1, showing an estimated MSY of 6.6 tons and, a BMSY and FMSY, of 9.4 and 0.7, respectively. Figure 2 shows the time series of the estimated relative biomass (B/BMSY), where it can be seen that B remains above BMSY. At the same time in Figure 3, where relative fishing mortality time series is presented (F/FMSY), it can be observed that F is below the FMSY. These two results indicate that if the fishing activity continues at this rate, the Common Dolphinfish population would be within sustainable limits. On the other hand, the Kobe plot presented in Figure 4 shows the evolution of the fishery relative to B MSY and FMSY reference points. It shows that the risk of overfishing is minimal during the period 1994-2018 (green region of the plot). Regarding the goodness of fit for the model, if we look at Figure 5, the green color of the titles informs that there weren't relevant deviations regarding the main assumptions of the model.

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Figure 1: Results of the SPiCT model implementation for the Common dolphinfish in the Indian Ocean.

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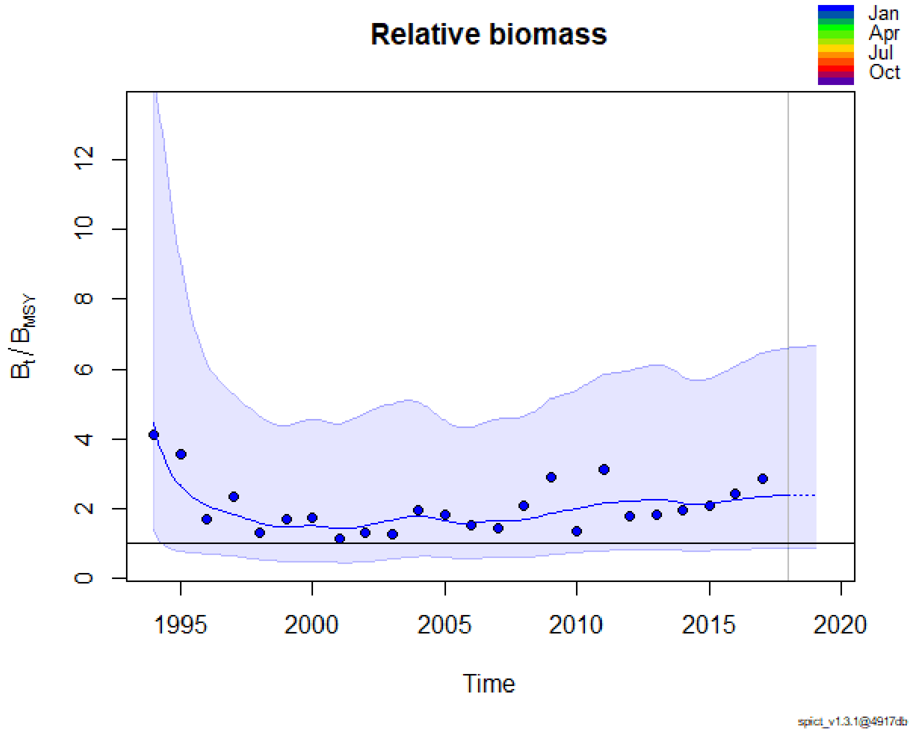

Figure 2: Estimated relative biomass (B/BMSY) for Indian Common dolphinfish (blue line). BMSY reference point is represented by a black line parallel to the x-axis. The gray line parallel to the y-axis represents the end of the range of available data and the blue area corresponds to the 95% confidence interval.

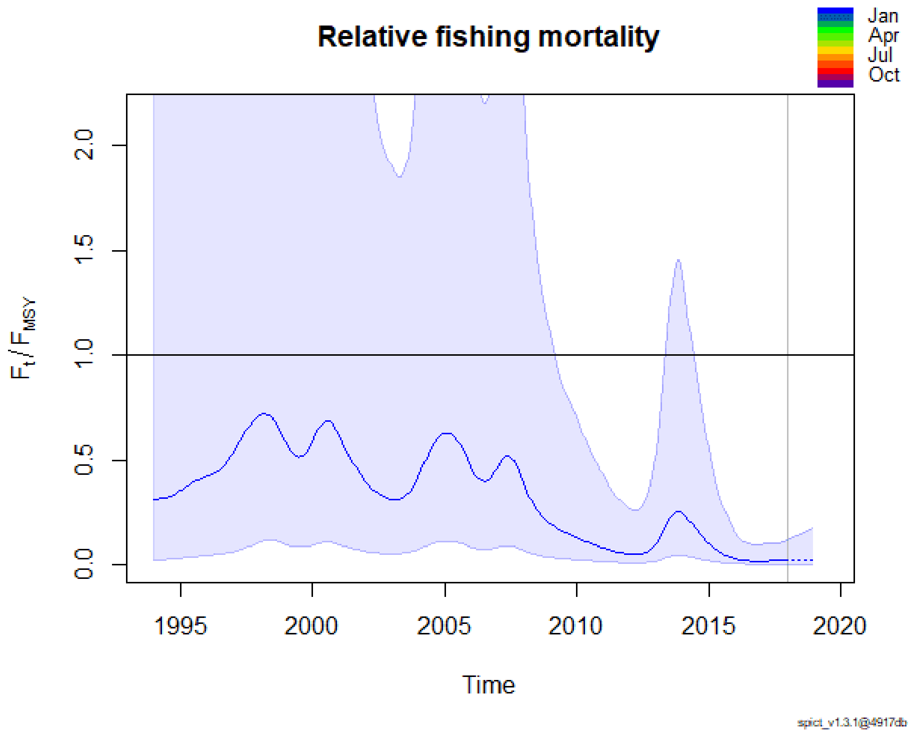

Figure 3: Estimated relative fishing mortality (F/FMSY) for Indian Common dolphinfish (blue line). FMSY reference point is represented by a black line parallel to the x-axis. The gray line parallel to the y-axis represents the end of the range of available data and the blue area corresponds to the 95% confidence interval.

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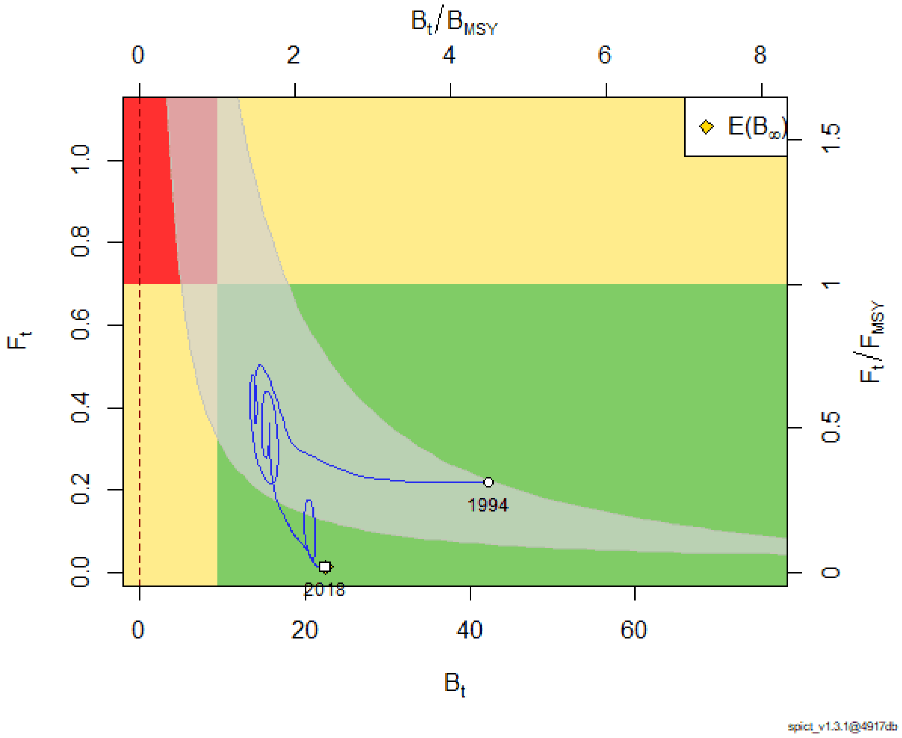

Figure 4: The Kobe plot is divided into four panels: red (upper left) corresponds to the "overfished and overfishing phase", with biomass inferior to BMSY and fishing mortality superior FMSY. The green panel (lower right) is the "no risk" area where fishing mortality is below FMSY and the biomass is above BMSY. The two yellow panels (overfishing and overfished) characterize intermediate situations. Blue line represents the annual trajectory of the Indian Common dolphinfish fishery from 1994 to 2018.

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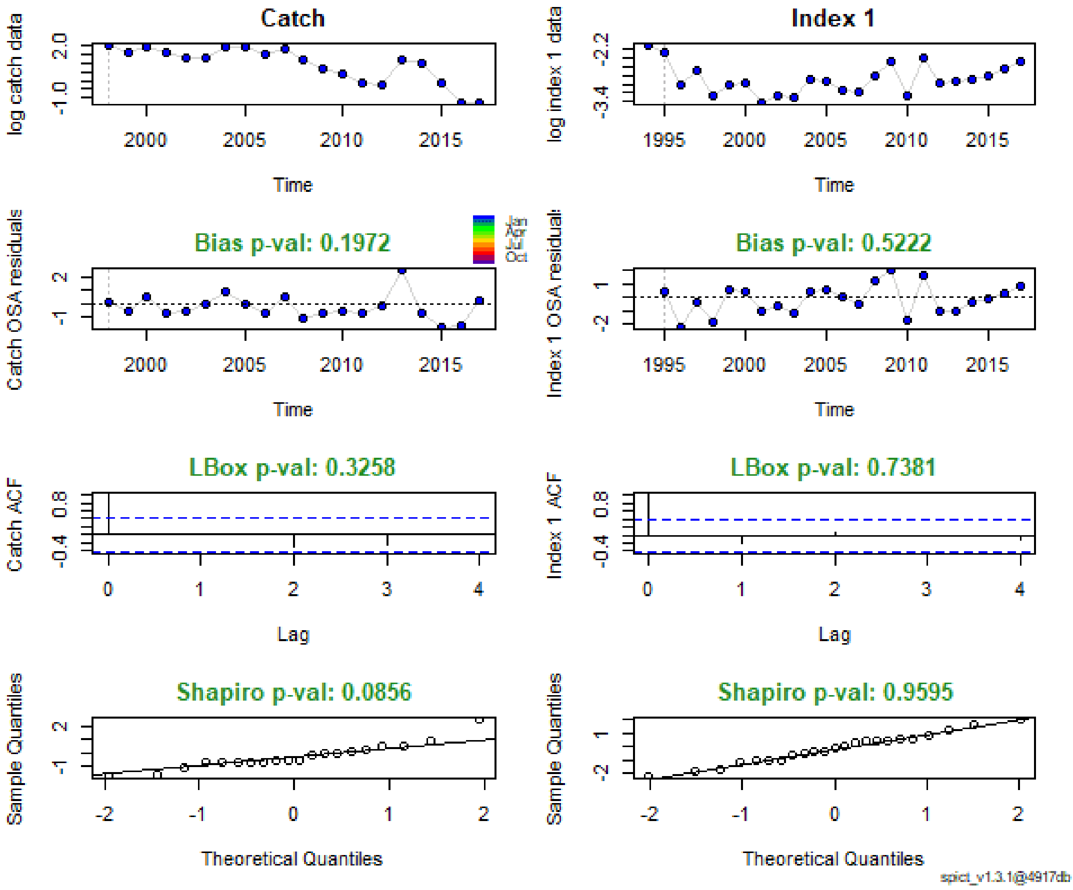

Figure 5: Plots for diagnostics on model assumption violations. Green tittles stand for no model assumption violations.

2.1.2.2 Wahoo in Seychelles

A list with the main estimated values is presented in Figure 6, showing an estimated MSY of 3.7 tons and, a BMSY and FMSY, of 2.6 and 1.1, respectively. Figure 7 shows the time series of the estimated relative biomass (B/BMSY), where it can be seen that B remains below BMSY. At the same time in Figure 8, where relative fishing mortality time series is presented (F/FMSY), it can be observed that F is above the FMSY. However, it must be taken into account for this case, that the estimated uncertainty is very high, as it is represented by a great blue area in Figures 7 and 8. On the other hand, the Kobe plot presented in Figure 9 shows the evolution of the fishery relative to BMSY and FMSY reference points. It shows that during the period 1985-2018 the fishery was not exploited sustainably as B is below BMSY and F above FMSY. The red color titles in Figure 10 show that they have been found relevant deviations from the assumptions of the model that must be taken into consideration.

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[42] " B_2017.94/Bmsy  0.1775424 0.0000000 4.714228e+13 -1.7285458  "
[43] " F_2017.94/Fmsy  4.9756326 0.0000000 1.245310e+39  1.6045525  "
[44] ""
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[48] " F_2019.00        5.5067359 1.5588793 1.945253e+01  1.7059720  "
[49] " B_2019.00/Bmsy   0.1773844 0.0000000 4.755670e+13 -1.7294364  "
[50] " F_2019.00/Fmsy   4.9756335 0.0000000 1.246569e+39  1.6045527  "
[51] " Catch_2018.00    2.5272892 1.6889594 3.781731e+00  0.9271473  "
[52] " E(B_inf)         0.1362679        NA           NA -1.9931328  "
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Figure 6: Results of the SPiCT model implementation for the Wahoo in the Indian Ocean.

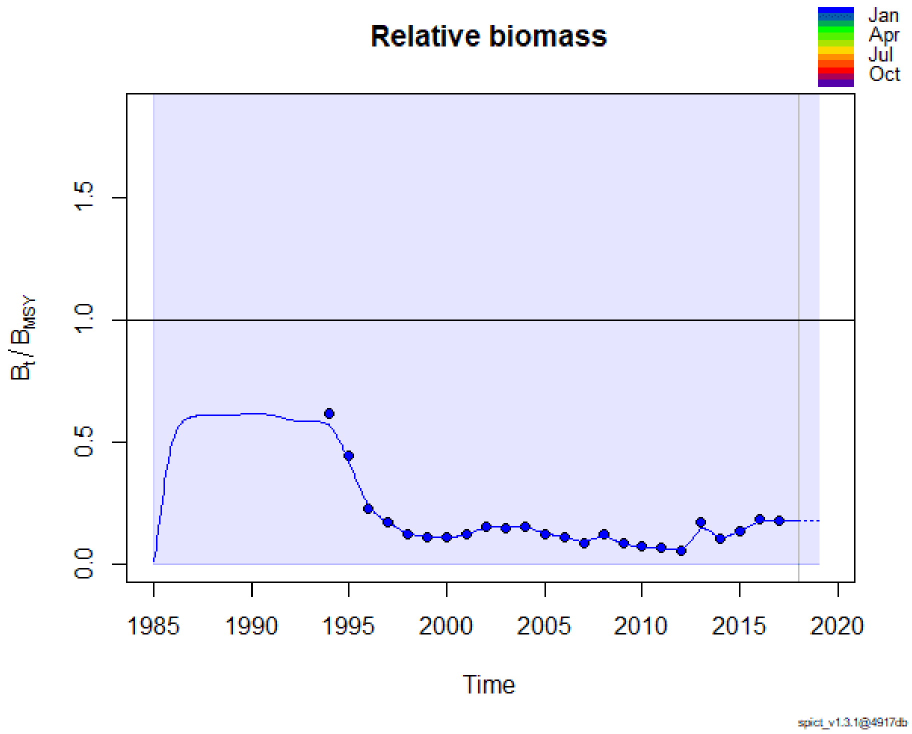

Figure 7: Estimated relative biomass (B/BMSY) for Indian Wahoo (blue line). BMSY reference point is represented by a black line parallel to the x-axis. The gray line parallel to the y-axis represents the end of the range of available data and the blue area corresponds to the 95% confidence interval.

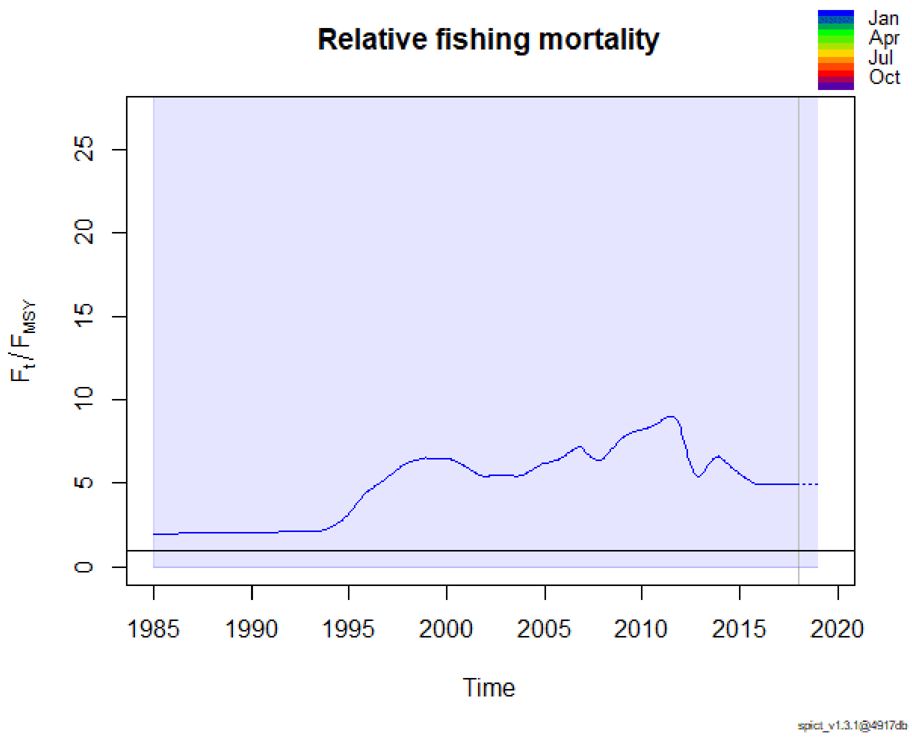

Figure 8: Estimated relative fishing mortality (F/FMSY) for Indian Wahoo (blue line). FMSY reference point is represented by a black line parallel to the x-axis. The gray line parallel to the y-axis represents the end of the range of available data and the blue area corresponds to the 95% confidence interval.

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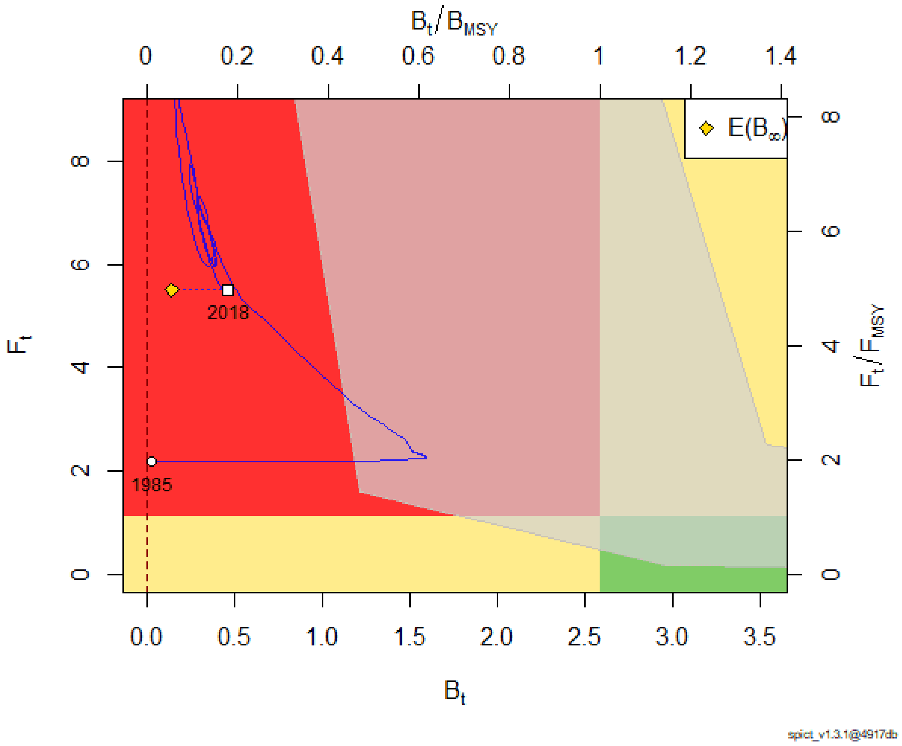

Figure 9: The Kobe plot is divided into four panels: red (upper left) corresponds to the "overfished and overfishing phase", with biomass inferior to BMSY and fishing mortality superior FMSY. The green panel (lower right) is the "no risk" area where fishing mortality is below FMSY and the biomass is above BMSY. The two yellow panels (overfishing and overfished) characterize intermediate situations. Blue line represents the annual trajectory of the Indian Wahoo fishery from 1994 to 2018.

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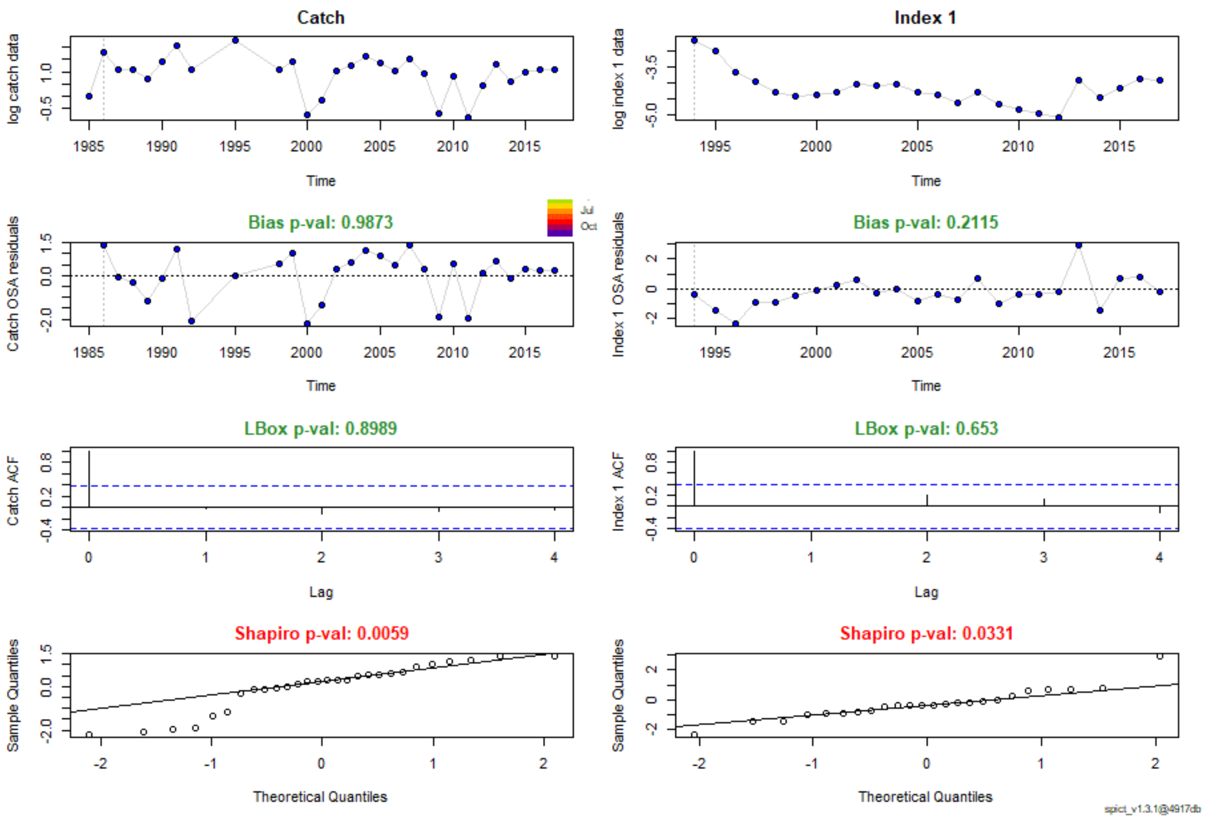

Figure 10: Plots for diagnostics on model assumption violations. Red tittles stand for model assumption violations.

2.1.2.3 Frigate tuna in Cape Verde

A list with the main estimated values is presented in Figure 11, showing an estimated MSY of 7 tons and, a BMSY and FMSY, of 3.1 and 2.2, respectively. Figure 12 shows the time series of the estimated relative biomass (B/BMSY), where it can be seen that B remains above BMSY from 2007 onwards. At the same time, it can be seen that F is below the FMSY during the whole period (Figure 13) but with a huge uncertainty, as it can be seen by the size of the blue shaded region in Figure 13. Figure 14 shows the evolution of the fishery through a Kobe plot showing that frigate tuna fishery goes from left down yellow region where B is below BMSY and F is below FMSY, to green region, where risk of overfishing is minimal during period 1987-2018. Regarding the goodness of fit for the model, in Figure 15 red color titles show that relevant deviations from the assumptions of the model have been found and that must be taken into consideration.

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```
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 [3] "Euler time step (years):  1/16 or 0.0625"
 [4] "Nobs C: 31,  Nobs I1: 27"
 [5] ""
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 [8] " logalpha  ~  dnorm[log(1), 2^2]"
 [9] "  logbeta  ~  dnorm[log(1), 2^2]"
[10] ""
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[14] " beta   1.784917e-01  0.0252199 1.263257e+00 -1.7232132  "
[15] " r      1.478066e-01  0.0351074 6.222845e-01 -1.9118506  "
[16] " rc     4.097773e-01  0.1205256 1.393209e+00 -0.8921413  "
[17] " rold   5.305326e-01  0.0675121 4.169102e+00 -0.6338739  "
[18] " m      8.664500e+03  1.6500590 4.549751e+07  9.0669895  "
[19] " K      1.365478e+05 23.6458004 7.885253e+08 11.8244303  "
[20] " q      2.195000e-04  0.0000000 2.029815e+00 -8.4243108  "
[21] " n      7.213996e-01  0.5471059 9.512186e-01 -0.3265621  "
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[23] " sdf    8.982914e-01  0.6246548 1.291797e+00 -0.1072608  "
[24] " sdi    7.519424e-01  0.5165213 1.094664e+00 -0.2850956  "
[25] " sdc    1.603376e-01  0.0262757 9.783979e-01 -1.8304740  "
[26] " "
[27] "Deterministic reference points (Drp)"
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[29] " Bmsyd 4.228882e+04 7.2806999 2.456281e+08 10.652278  "
[30] " Fmsyd 2.048887e-01 0.0602628 6.966047e-01 -1.585289  "
[31] " MSYd  8.664500e+03 1.6500590 4.549751e+07  9.066990  "
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[33] "          estimate     cilow        ciupp    log.est rel.diff.Drp  "
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[35] " Fmsys 2.184993e-01 0.0686472 6.954684e-01 -1.520972   0.06229142  "
[36] " MSYs  6.982087e+03 1.2388758 3.934982e+07  8.851103  -0.24096136  "
[37] ""
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[39] "                  estimate      cilow        ciupp   log.est  "
[40] " B_2017.94        1.410302e+05 13.4097270 1.483215e+09 11.856729  "
[41] " F_2017.94        1.096860e-02  0.0000010 1.180872e+02 -4.512715  "
[42] " B_2017.94/Bmsy 4.510333e+00  0.9941850 2.046210e+01  1.506371  "
[43] " F_2017.94/Fmsy 5.019990e-02  0.0000047 5.345713e+02 -2.991742  "
[44] ""
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[49] " B_2019.00/Bmsy 4.027317e+00   0.8536053 1.900091e+01  1.393100  "
[50] " F_2019.00/Fmsy 5.020060e-02   0.0000040 6.373160e+02 -2.991727  "
[51] " Catch_2018.00  1.460117e+03 295.2558593 7.220657e+03  7.286272  "
[52] " E(B_inf)       7.080554e+04          NA           NA 11.167693  "
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Figure 11: Results of the SPiCT model implementation for the Frigate tuna in the Atlantic Ocean.

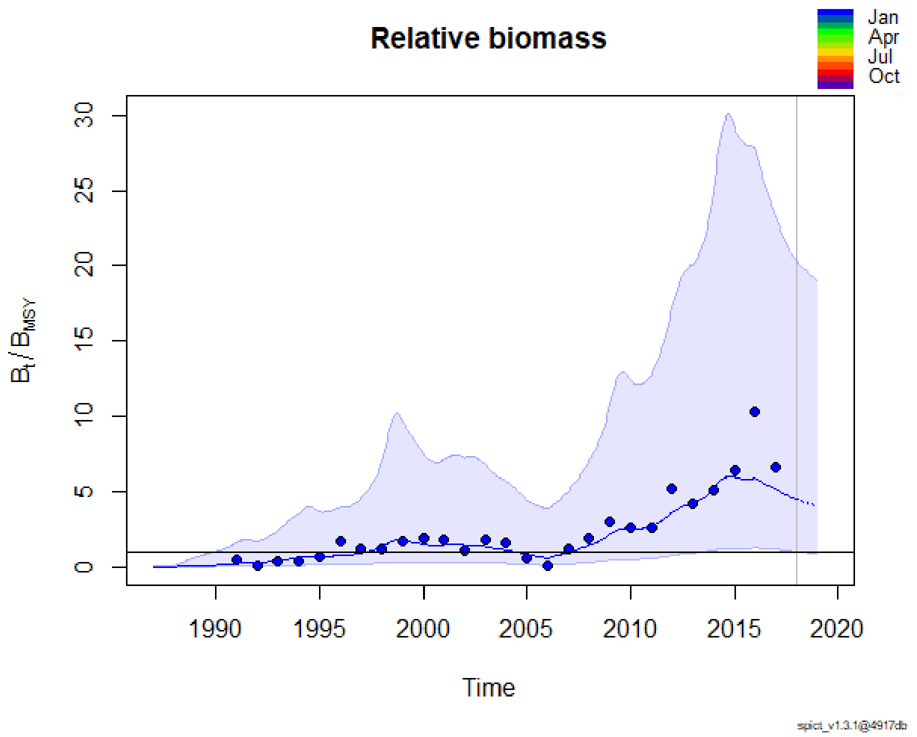

Figure 12: Estimated relative biomass (B/BMSY) for Atlantic Frigate tuna (blue line). BMSY reference point is represented by a black line parallel to the x-axis. The gray line parallel to the y-axis represents the end of the range of available data and the blue area corresponds to the 95% confidence interval.

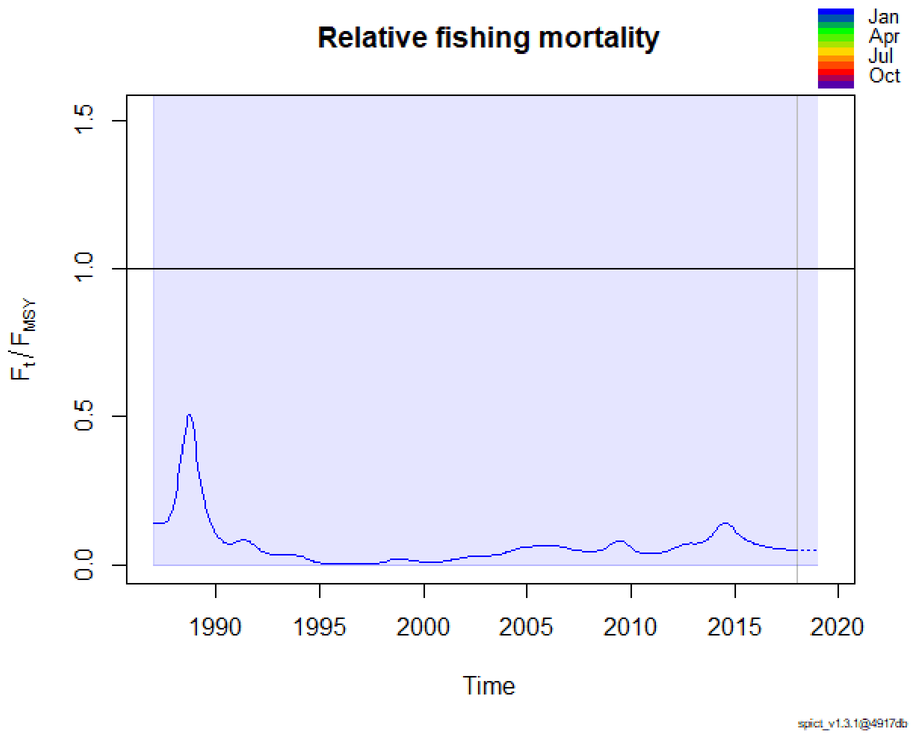

Figure 13: Estimated relative fishing mortality (F/FMSY) for Atlantic Frigate tuna (blue line). FMSY reference point is represented by a black line parallel to the x-axis. The gray line parallel to the y-axis represents the end of the range of available data and the blue area corresponds to the 95% confidence interval.

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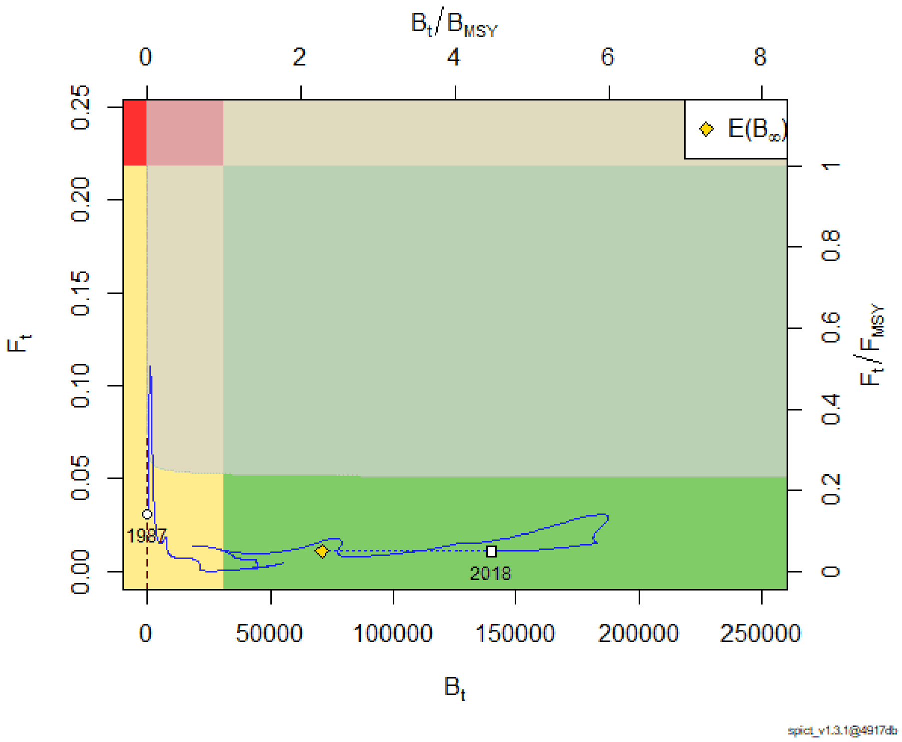

Figure 14: The Kobe plot is divided into four panels: red (upper left) corresponds to the "overfished and overfishing phase", with biomass inferior to BMSY and fishing mortality superior FMSY. The green panel (lower right) is the "no risk" area where fishing mortality is below FMSY and the biomass is above BMSY. The two yellow panels (overfishing and overfished) characterize intermediate situations. Blue line represents the annual trajectory of the Atlantic Frigate tuna fishery from 1987 to 2018.

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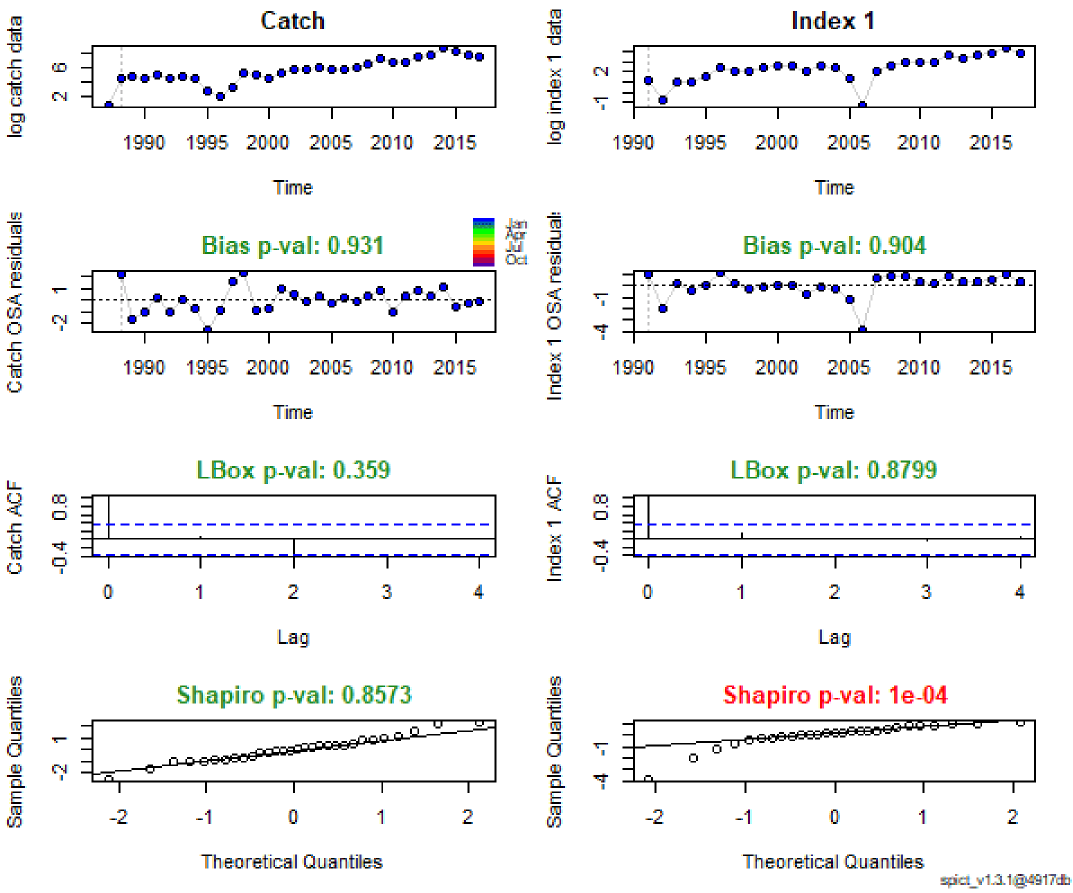

Figure 15: Plots for diagnostics on model assumption violations. Red tittles stand for model assumption violations.

2.1.2.4 Comparison between management measures defined with SPiCT and other data limited methods

Table 1 shows the calculated medians of the quotas for each of the methods applied (rows) to each of the species (columns). We perform a comparison by calculating the difference between each of the medians of the quotas calculated by the methods AvC, CC1, CC2, CC3, CC4, CC5, SPMSY and SBT1 and the quota calculated using the SPiCT model (multiplying FMSY value by the last year estimated biomass), that was used as a reference.

For the Atlantic tuna, we observe that SBT1, a management rule that was formulated within the framework of the recovery plan for the southern bluefin tuna fishery (Hillary et al, (2012), was the rule with a closer value to the reference, 26260.77 tonnes compared with 30815. At

In the case of the Indian Wahoo, the best performance was found with CC5, that estimated a value of 1.67, and that was the smallest difference with respect to the reference value of 0.5082839. For the Common dolphinfish, we consider that the differences between the medians of the quotas of the AvC, CC1, CC2, CC3, CC4, CC5, SPMSY and SBT1 methods and the reference value 15.65737 are too large and it is not possible to identify which method is showing the best performance.

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	Common dolphinfish	Wahoo	Frigate tuna
SPiCT (Referencia)	15.65737	0.5082839	30815
AvC	3.38	3.13	767.62
CC1	1.42	2.79	3075.85
CC2	1.28	2.51	2773.64
CC3	1.14	2.24	2461.45
CC4	0.99	1.95	2146.68
CC5	0.85	1.67	1841.9
SPMSY	NA	NA	438.12
SBT1	0.28	2.86	26260.77

Table 1: Median quota values calculated for the methods applied to each of the selected species. The NA code represents those cases in which any of the methods could not be applied because the minimum requirements were not met.

2.1.3 Discussion:

Common dolphinfish, wahoo and frigate tuna are bycatch species commonly caught by tuna fisheries in the Indian and Atlantic Oceans, however the quantity and quality of available data is limited and it is currently difficult to know the status of their populations. In order to improve knowledge about the status and level of exploitation of these bycatch species, methods for data-limited fisheries were used.

The SPiCT model is the most robust method that we have used for this exercise and proof of this is that it is the most used currently for stock assessment compared to the others. For example, it is used for assessment of *Brosme brosme* (ICES, 2020) and *Isurus oxyrinchus* (Maguire & Berg, 2020).

In the case of its application to Common dolphinfish, as already mentioned, we used catch data from the Seychelles and CPUE from Reunion Islands, so the quality of the data on this species is limited. However, the CPUE choice of Reunion longliners may be reinforced by the fact that this fleet, which fishes near the Seychelles, is highly representative in the region (Coelho et al. 2014) and routinely catches this species (Miossec & Taquet, 2004, Romanov et al. 2013, Sabarros et al. 2013). The results of this model are of special interest since for this species the estimates obtained for biomass and fishing mortality could be used to inform about the state of the fishery (figure 2 and 3) since the associated uncertainty to them is within acceptable levels (Mildenberger et al. 2019).

In the case of wahoo, some of the SPiCT model estimates present high uncertainty, as can be seen in Figures 8 and 9, which show biomass and fishing mortality estimates, respectively, and like for the dolphinfish, studies on this species in the Indian Ocean are extremely scarce. On the other hand, advances have been observed regarding the study of this species in the Atlantic. For Northwest Atlantic wahoo, for example, Mourato et al (2019) identified the most acceptable fishery management methods through a rigorous management strategy evaluation process. The results of that work indicated that the AvC and CC1 methods, based on catches, were the most acceptable. Contrary to these results, in the present work the most acceptable fishery management method for wahoo, using the SPiCT results as a reference, was CC5, also based on catches. Although we do not have other more complete studies on the Indian wahoo to be able to compare with our results, new knowledge on this species indicate that the wahoo could be the first vertebrate with a single globally distributed population, which may represent a challenge from the point of view of the worldwide cooperation of tuna RFBs and agents involved to know their status and ensure their sustainable exploitation (Theisen et al. 2008).

In the case of frigate tuna, the estimates of biomass and fishing mortality that we obtained also present a very high uncertainty, as can be seen in figures 13 and 14 respectively, however, it is important to mention that in the ICCAT reports, it was mentioned that it was not possible to know the status of their populations from the information available at that moment (Valeiras & Abad, 2006).

This exercise show that SPiCT implementation can help to estimate population status regarding reference points, but only the results of the model for common dolphinfish could be considered for an assessment, with lot of limitations considering the data used. It highlights the need to make a great effort to obtain data that will allow us to better understand the situation of these species.

2.2 DLM used for preliminary stock status estimations for small pelagics in the Moroccan coast.

Small pelagic are considered as essential resource in the marine ecosystem, which occupy an intermediate level in the trophic web (Philippe Cury et al. 2000). In economic terms this group is the main harvested fish group, representing approximately 39 million tons (FAO, 2016) and playing a crucial role in the oceans food chain (Brochier et al. 2018). In Morocco, the exploitation of this group occupies an important place in the Moroccan fisheries sector, with a production exceeding 80% of the total landing in 2018 (INRH, 2019). In 2017, the Moroccan Atlantic coast was characterized by generally favorable hydrological conditions resulting an increase in the small pelagic abundance with 7.59 million tons assessed in the autumn season. The main targeted small pelagic resources in this area are sardine (*Sardine pilchardus*), chub mackerel (*Scomber colias*), anchovy (*Engraulis encrasicolus*), horse mackerel (*Trachurus trachurus* and *Trachurus trecae*). However, the increasing catches of these resources and the diagnosis of the size structures landed in certain areas of Morocco require knowledge on these stocks status and some caution regarding the level of fishing pressure, particularly because of their high instability in relation to hydro-climatic changes (INRH, 2017; FAO, 2020). This section presents a preliminary exploration of the most used data limited approaches (mainly SPiCT and LBSPR models)

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implemented for three important stocks in Morocco and based on different available fisheries and biological data.

2.2.1 Anchovy in the Moroccan Coast

The SPiCT model was applied for the anchovy harvested in the whole Moroccan coast. Two main data sets were used in this study: the FAO landings time series from 1995-2018 and biomass index from a survey conducted by the research vessel Atlantida (1995-2018) (FAO, 2018).

The Figure 16 illustrates the most important outputs of the SPiCT model for the Moroccan anchovy stock. The main results of this figure show that the estimated biomass for the anchovy stock is quite stable in the last part of the time series. A significant decrease in fishing mortality (F) has been observed since 2006, but the model is considered a bit optimistic: F/FMSY=1.31 B/BMSY=0.41.

In addition, to ensure no model assumptions violations and consistency of data/model, diagnostics residuals and a retrospective analysis were performed (Figures 17 and 18).

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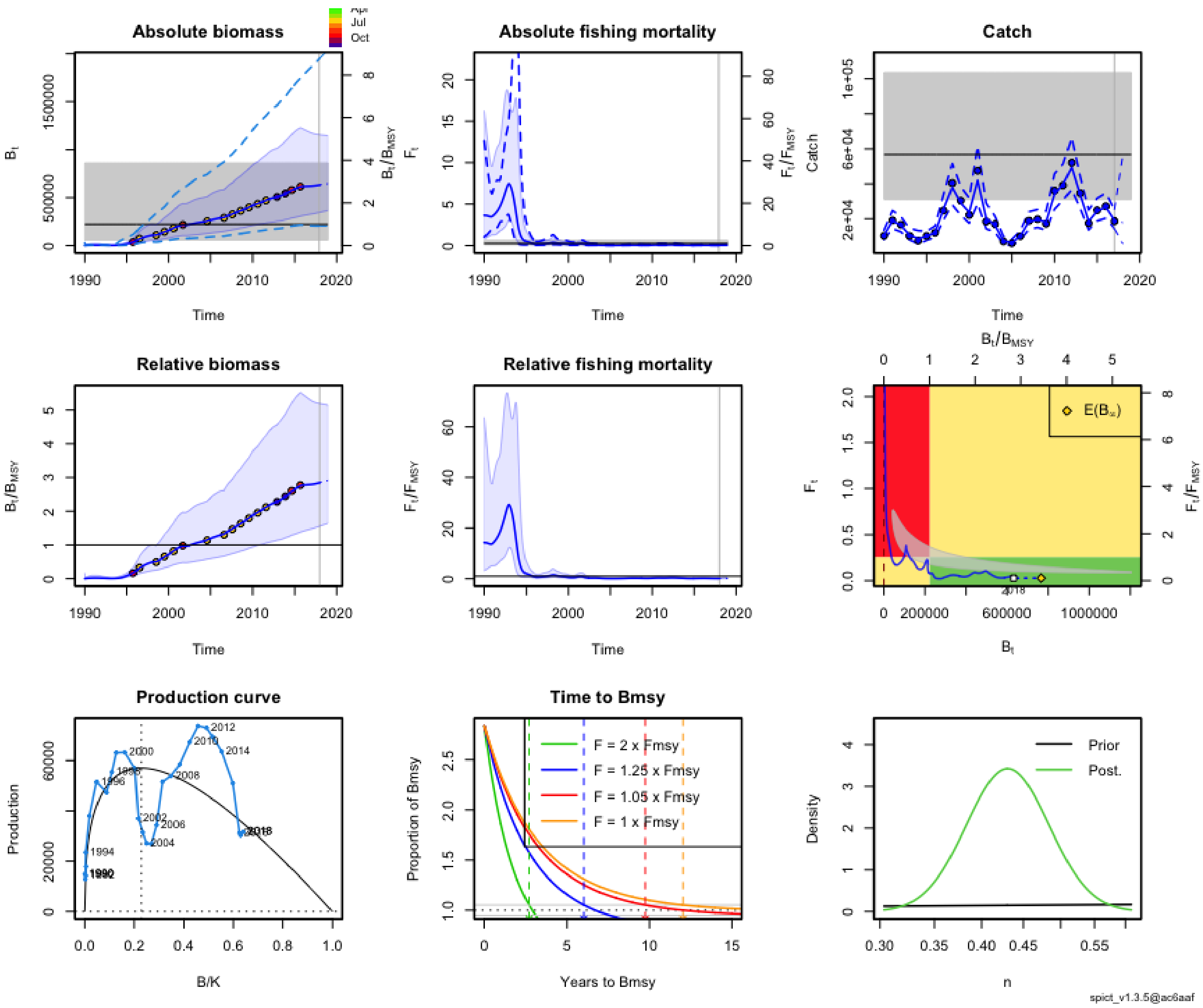

Figure 16: Summary of SPiCT results for anchovy stock in Moroccan Atlantic coast

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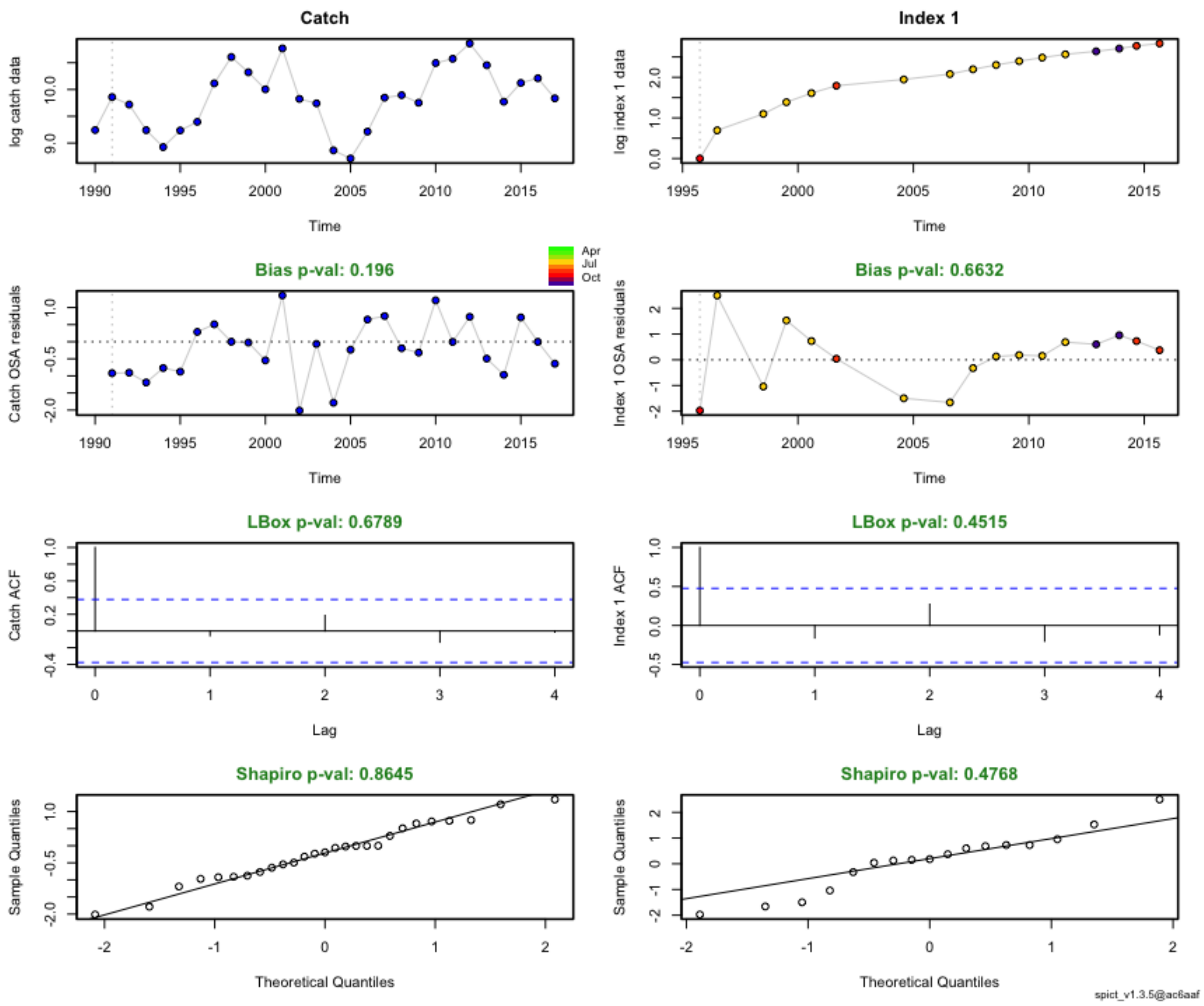

Figure 17: Summary diagnostics for violation of the anchovy model

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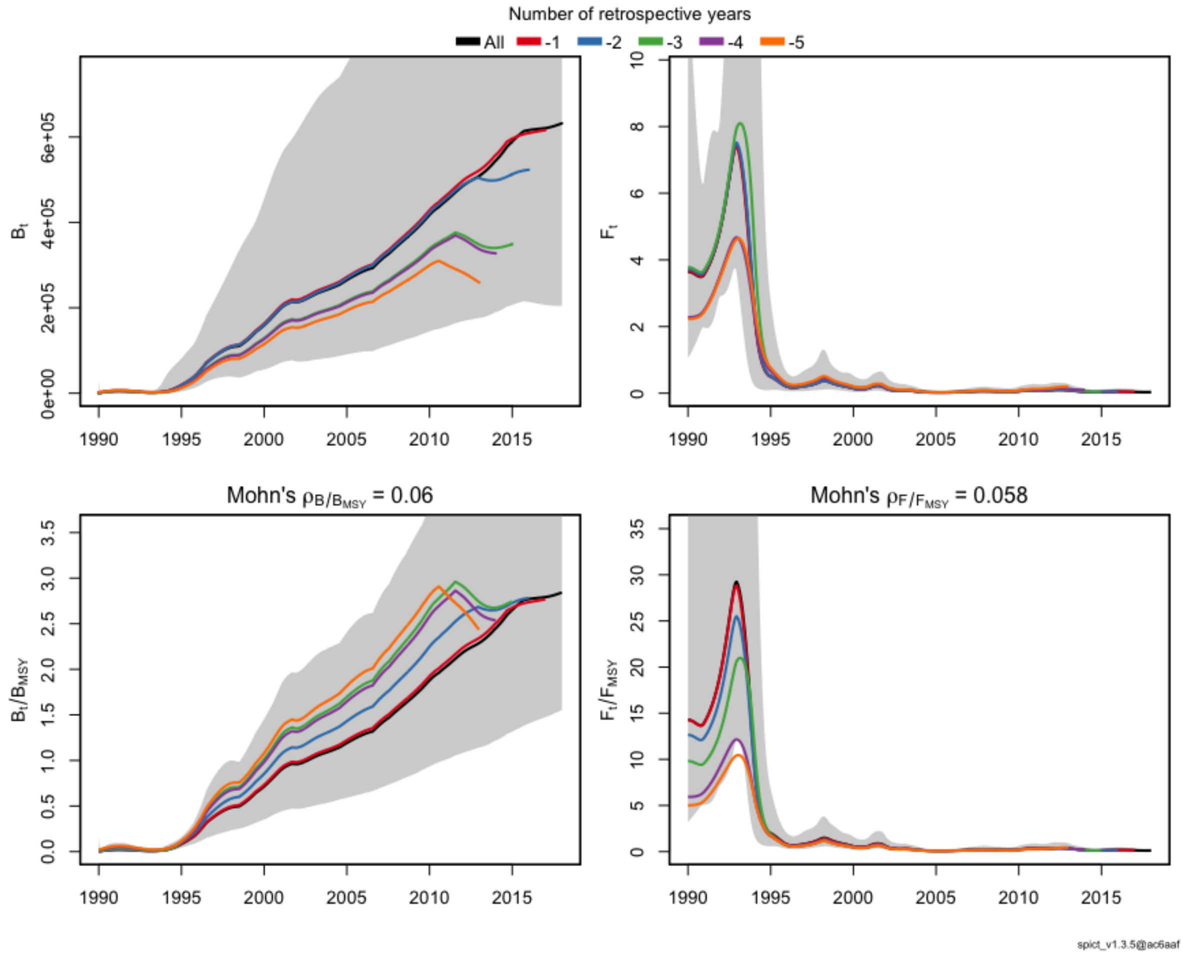

Figure 18: Retrospective plots for the anchovy model

According to the Figure 17, these data do not show significant violations of the assumptions, which increase our confidence in the results. The retrospective analysis results show a high consistency in all runs allowing us to say that this preliminary implementation of the SPiCT model suggests that this anchovy stock is been exploited sustainably.

2.2.2 Sardine in the Moroccan coast using LBSPR model

The Length-based Spawning Potential Ration (LBSPR) method has been developed also for data-limited fisheries, where few data are available other than a representative sample of the size structure of the vulnerable portion of the population (the catch) and an understanding of the life history of the species. The LBSPR method does not require knowledge of the natural mortality rate (M), but instead uses the ratio of natural mortality and the von Bertalanffy growth coefficient (K) (M/K), which is believed to vary less across stocks and species than M (Prince et al, 2015). The LBSPR model described by (Hordyk et al. (2015 a, b)), and tested in a MSE framework (Hordyk,2015c), use a conventional age-structured equilibrium population model. An important assumption of this model structure is that selectivity is age-based not length-based.

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This model was fitted for the Moroccan sardine stock using length composition data for the period 2006-2017, derived from a biological sampling of Moroccan vessels operating in both the central and the southern areas, and the length distribution of sardine was estimated on the basis of Moroccan and Russian catch data for the zone Cape Bojador-Cape Blanc. The required growth input parameters used were estimated by INRH scientists for both stocks of sardine (central and southern).

The LBSPR package uses a Kalman filter and the Rauch-Tung-Striebel smoother function to smooth out the multi-year estimates of SPR, F/M, and selectivity parameters. With the life history parameters and the length composition data from CECAF reports, the LBSPR model estimated the selectivity sizes at 50% and 95% (SL50, SL95, the relative fishing mortality rates (F/M) and Spawning Potential Ratio (SPR).

The length frequency distributions by year with their corresponding LBSPR model fits are presented in Figure 19. The mean length size in 2006 was 22.5 cm and in 2017 decreased to 19 cm. The histograms of length frequencies by years (From 2006 to 2017) mostly exhibited two modes except for the 2014 with three modes. For most bimodal distributions of length frequencies, the first and highest peak occurs around 20 cm while the second lower is found around 15-25 cm. And for some years (2007, 2011 to 2013) the fish sizes smaller than the sizes at maturity (L50=15.8 cm and L95=21.3 cm) were found in a high proportion of the catch.

Other results are presented in Figure 20 showing the evolution of estimated maturity and selectivity at length. According to this figure we can suggest that the majority of sardine captured in this fishing area are adults, the estimated selectivity curves are not all the time above the maturity curve.

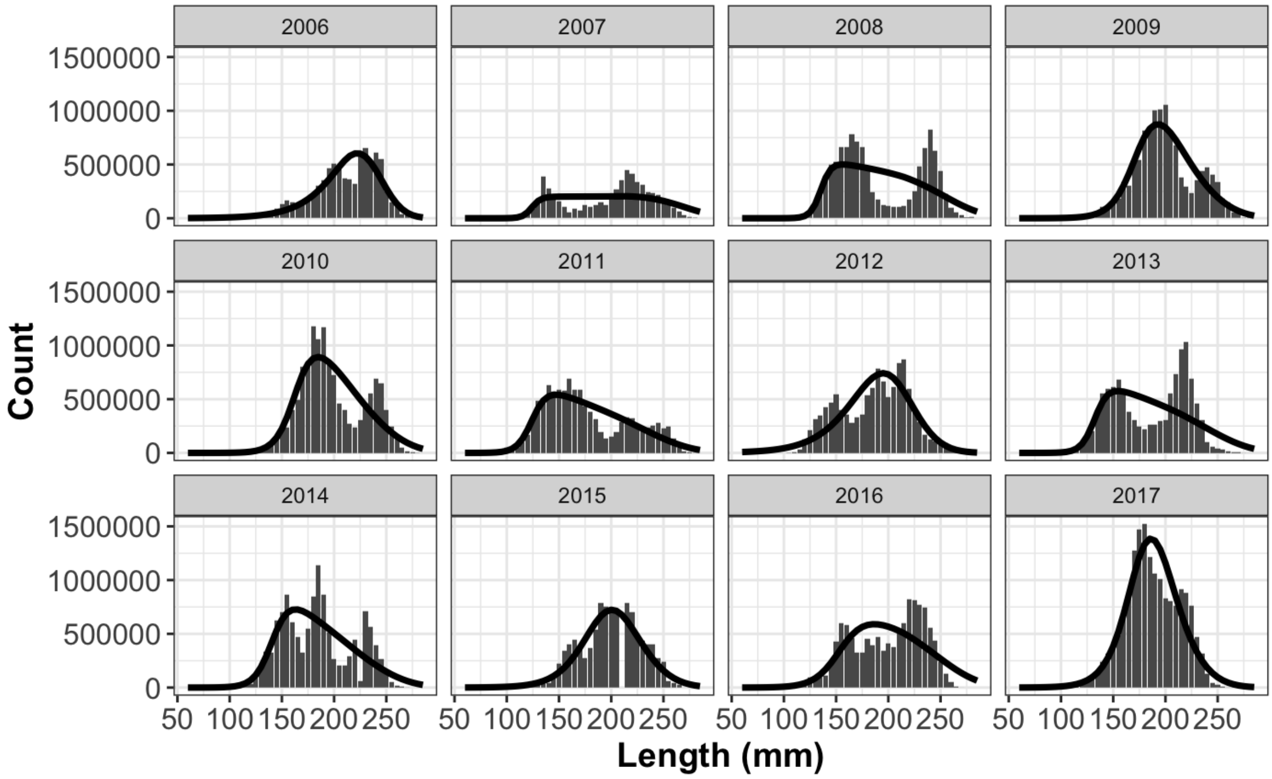

Figure 19: Length composition distributions for Sardine with curves fitted by length based SPR model

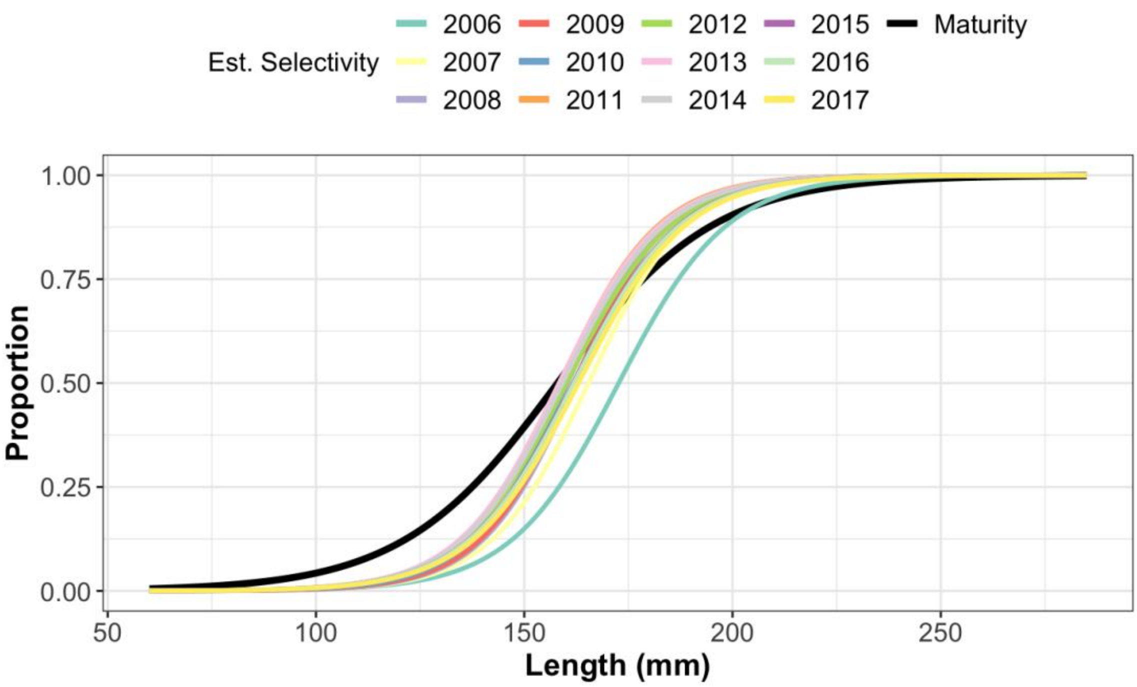

Figure 20: Maturity at length and the selectivity at length curves for Sardine

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Detailed estimated parameters SL_{50}, SL_{95}, F/M ratio and SPR by year are presented in Figures 21 and 22.

```
##          SL50   SL95   FM  SPR
##  [1,] 172.67 211.09 4.29 0.29
##  [2,] 165.41 200.17 3.68 0.30
##  [3,] 162.30 195.62 3.38 0.28
##  [4,] 161.90 195.65 3.29 0.26
##  [5,] 160.35 194.43 3.23 0.25
##  [6,] 158.54 193.54 3.26 0.23
##  [7,] 160.17 197.46 3.42 0.22
##  [8,] 158.35 194.27 3.26 0.22
##  [9,] 159.15 195.35 3.24 0.22
## [10,] 161.77 199.37 3.32 0.22
## [11,] 161.97 199.66 3.33 0.22
## [12,] 163.03 200.95 3.53 0.21
```

Figure 21: The main results of the LBSPR model implementation for the Moroccan sardine stock (the numbers 1-12 represent years from 2006 to 2017)

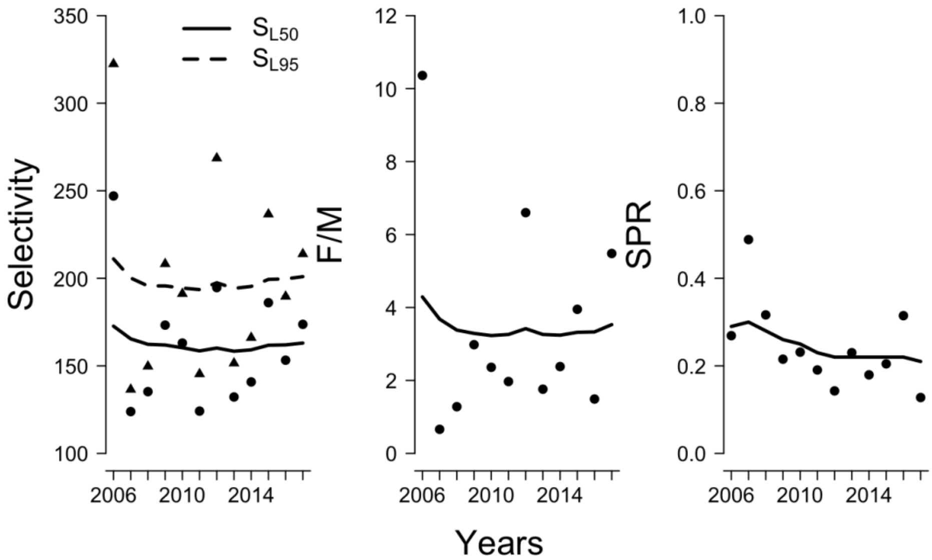

Figure 22: Visual display of estimated quantities (Selectivity, SPR and F/M), the black line corresponds to the smoother line to the estimated points

The results show the variation of observed and fitted values of sizes selectivity (SL_{50} and SL_{95}), from 15,835cm to 17,267cm for SL_{50} and from 19,354cm to 21,109cm for SL_{95}, the estimates selectivity length-at-50% for all years was high relative to length at first maturity. For the selectivity length-at-95% was also above the L_{50} for all years. Most of the SPR values were estimated to be below 0.40 which

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is the proxy for B_{MSY}. These results of LBSPR model with this sardine population suggest that it is sustainably exploited.

2.2.3 Chub Mackerel in the Moroccan Coast using LBSPR model

The model fit to the length distributions landings data of the Moroccan central and southern stock (A=B=C zones) of chub mackerel and the life history parameters were extracted from Fishbase. For this stock different values of the same parameter were available for the same area, therefore two scenarios have been tested (scenario 1: Linf= 39.35, K= 0.25 and scenario 2; Linf= 47.14, K= 0.16).

The Figures 23 and 24 show respectively the LBSPR model fit to the length composition landings data and the specified maturity with the estimated selectivity at length for scenarios 1 and 2. These estimates are equal for both scenarios because the length data input was the same for both scenarios. It can be observed that the length frequency data of the catch for the study area is mainly unimodal in all the years, and the peak of catches by length was mostly found below the length at first maturity (L_{50}).

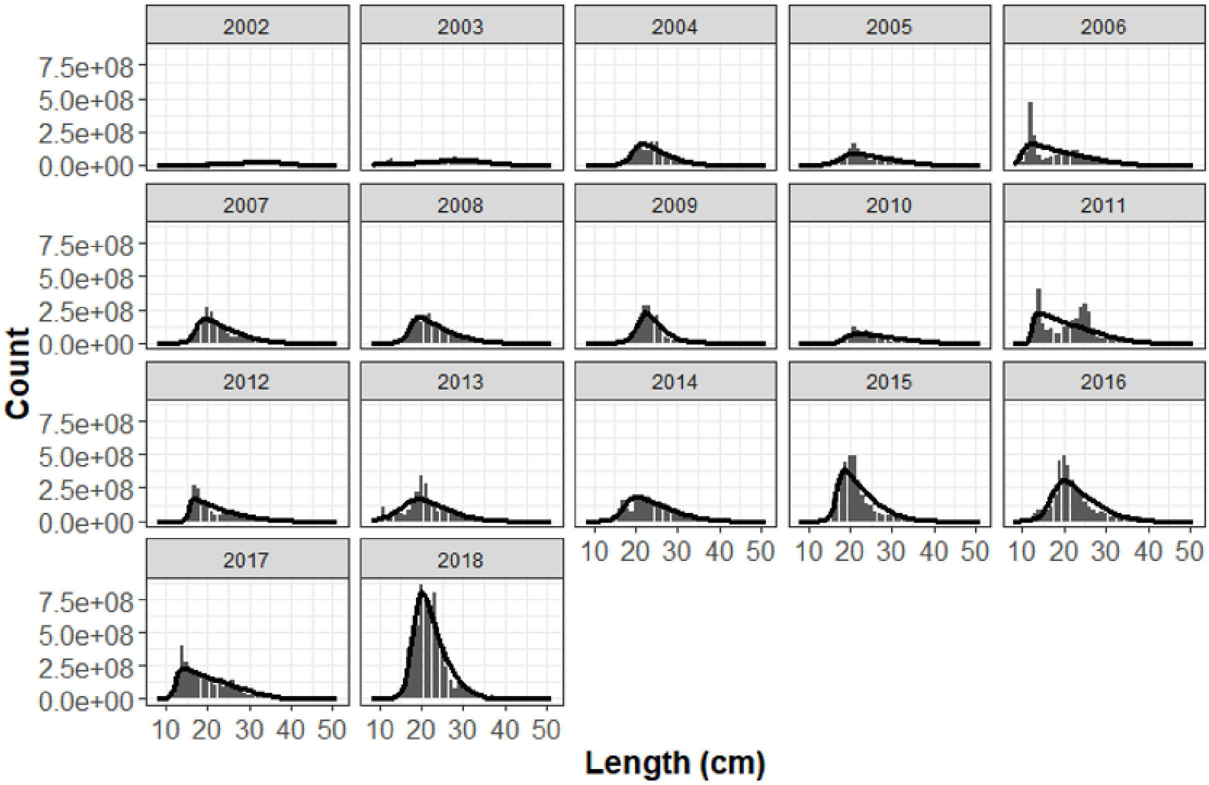

Figure 23: Length composition distribution for Moroccan central and southern chub mackerel stock (bars) and LBSPR model fit (solid black line) for scenarios 1 and 2.

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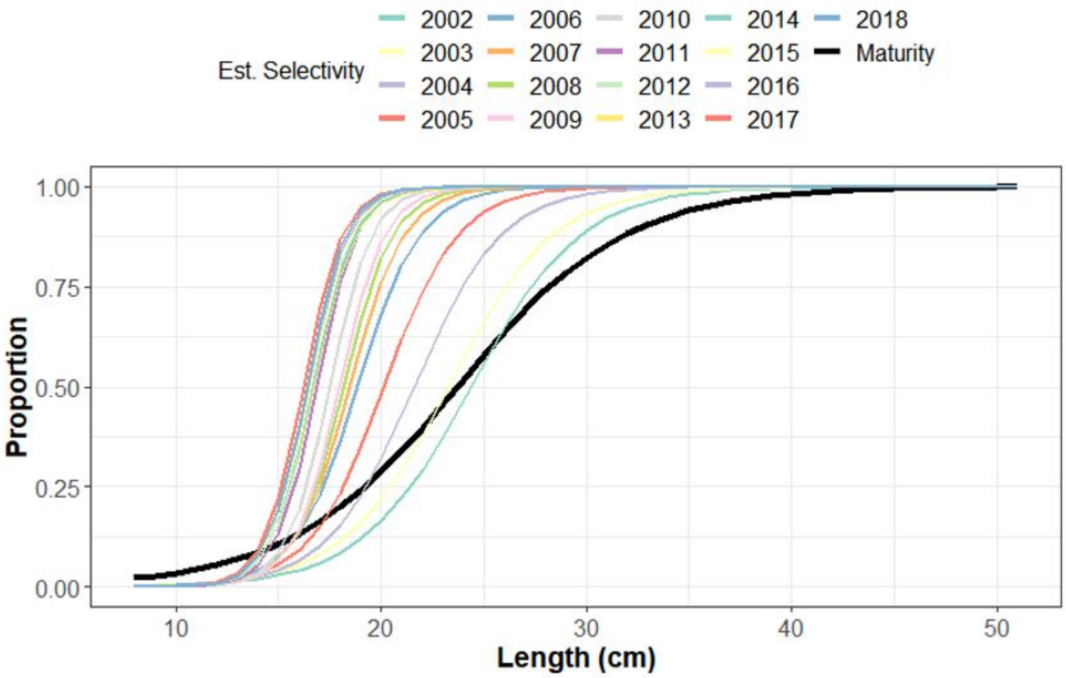

Figure 24: Moroccan central and southern chub mackerel stock: Specified maturity and estimated selectivity at length for scenarios 1 and 2.

The Figures 25 and 26 show the different estimated values for SPR, selectivity and F/M, for scenarios 1 and 2.

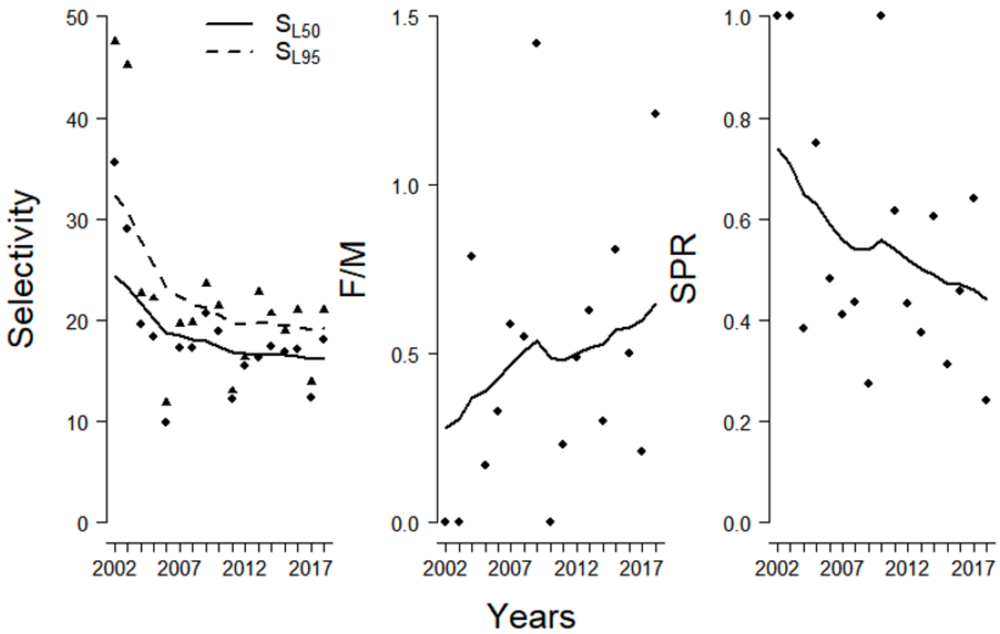

Figure 25: Moroccan central and southern chub mackerel stock: Estimated values for SPR, SL50, SL95 and F/M for scenario 1; the black line corresponds to the smoother line to the estimated points.

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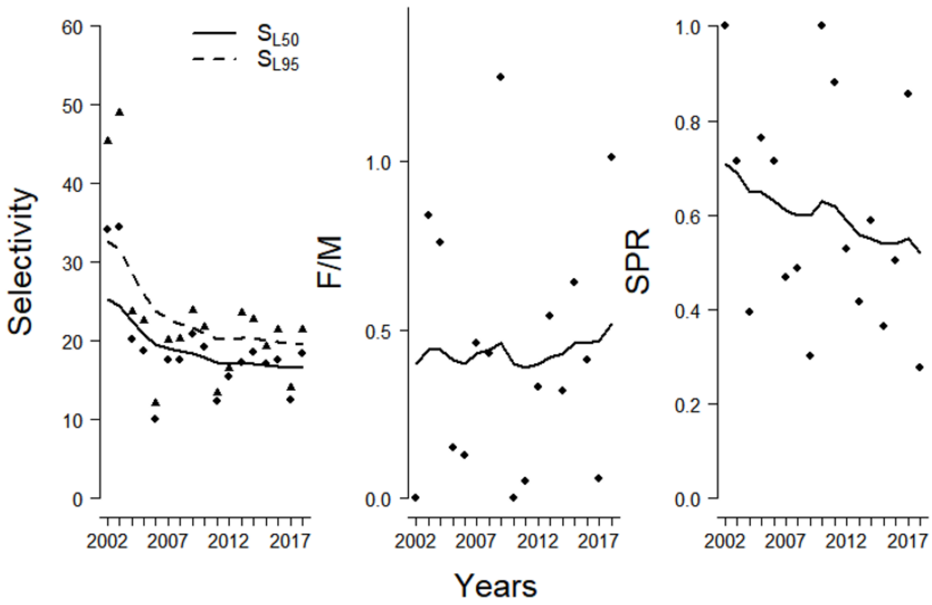

Figure 26: Moroccan central and southern chub mackerel stock: Estimated values for SPR, SL50, SL95 and F/M for scenario 2; the black line corresponds to the smoother line to the estimated points

The length at capture in the level 50% (SL_{50}) and 95% (SL_{95}) were defined as selectivity. The estimated selectivity pattern in the study area decreased over time, indicating that in this region, the proportion of caught smaller fish is increasing. The fitted F/M plots for the first scenario of this model, we notice an increase of relative fishing mortality, and for the second scenario, a slight time variation of this ratio was observed.

The estimated Spawning Potential Ratio (SPR) results for this stock varied above the reference point (0.4) for both scenarios, which are below the 0.4 value of SPR which is the proxy for BMSY. According to these results we can say that an increase of F/M is associated with a decrease in SPR which suggesting in this region an increase of fishing mortality with the subsequent impact on the population reproductive biomass.

2.2.4 Note on SPiCT and LBSPR results

SPiCT results should be contrasted using the technical guidelines for SPiCT (Mildenberger et al. 2021) taking into account that abundance indexes should be an estimation of the exploitable population, here we assume they are but there is no way to verify this assumption with the data available. For LBSPR, it is important to say that the results obtained here are part of an exploratory exercise and they should be interpreted with caution because non-representative length compositions of the stock or violation of the theoretical assumptions of the model (constant mortality and recruitment or logistic selectivity) could lead to unrealistic results (Hordyk et al. 2015). In addition Cousido-Rocha et al. 2022 demonstrate that the accuracy of Linf parameter is indispensable to obtain reliable results in this

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method, and currently we don’t have a reliable way to check the violation of these assumptions with the data available.

2.3 FarFish Data limited methods course in Hafnarfjörður, Iceland

A three day course (September 29th to October 1st, 2021) was delivered at the Marine and Freshwater Research Institute facilities in Hafnarfjörður, Iceland, explaining to the GRÓ-FTP fellows focused on stock assessment and to some scientists from the case study countries (remotely), how to use the FarFish-DLMtool and selected data-limited methods with hands on exercises where they brought their own data and tried to implement some of the methods explained.

First day morning session was open to all the GRO-FTP students (not only to those focused on stock assessment) and remotely to everybody willing to attend just by filling a registration form. During this morning there was a small tutorial in collaboration with EuroSea project connecting the tool and the methods with Oceanographic information obtained from Copernicus Marine System, and also, an introductory session to stock assessment and its evolution through time including the data limited methods more used nowadays. A total of 50 participants attended this open seminar, 30 in person and 20 via Teams.

First day afternoon and the other remaining two days there were two practical sessions, the first one on models using only catches and abundance indices as input with an emphasis on the Surplus Production Model in Continuous time (SPiCT) ,available also through the FarFish-DLMtool (SPiCTGui). Second practical session was about length-based methods with emphasis on the Length based Spawning Potential Ratio (LBSPR) available also through the FarFish-DLMtool (DLMGui). Nine students attended to these practical sessions and each one implemented at least one of these models using data from their own countries in a totally reproducible environment using the R-package RMarkdown.

One of the instructors was the FarFish representative from the Spanish CSIC, Margarita Rincon, who developed the FarFish-DLM tool, and a GRÓ-FTP fellow from CRODT in Senegal, Kamarel Ba, who participated in the 6-month course in Iceland through the FarFish cooperation.

As mentioned before, short guidelines for data input into FarFish-DLMtool were distributed to the attendees (Annex 1 and 2). The combination of these guidelines with the practical sessions ensure that the tool and the knowledge that students obtained from some of the most used data limited methods in Europe will remain once the project has ended.

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2.4 Online dissemination of the FarFish DLMtool

2.4.1 Bycatch Stock assessment

- Poster entitled: “Exploratory implementation of the surplus production model in continuous time (SPiCT) for common dolphinfish in the Indian Ocean” (Figure 27) by Mercedes Aramburu et al. presented at the World Fisheries Congress 2021 (WFC). Held in Adelaide, Australia (20-24 September 2021).
- Poster entitled: Implementación con enfoque exploratorio de un modelo de producción excedentaria en tiempo continuo (SPICT) para el dorado en el Océano Índico by Mercedes Aramburu et al. presented at the Iberoamerican symposium of reproductive ecology, recruitment and fisheries (SIBECORP), held in Santa Marta, Colombia (11-15 October 2021) and at the Iberian Symposium on Modeling and Assessment of Fishery Resources (SIMERPE), held in Vigo, Spain (19-22 October 2021). Available at: https://mervex-group.github.io/SIMERPE/proof/Mercedes%20Aramburu_Exploratory%20implementation%20of%20surplus%20production%20model%20in%20continous%20time%20(SPiCT)%20for%20common%20dolphinfish%20in%20the%20indian%20ocean.pdf

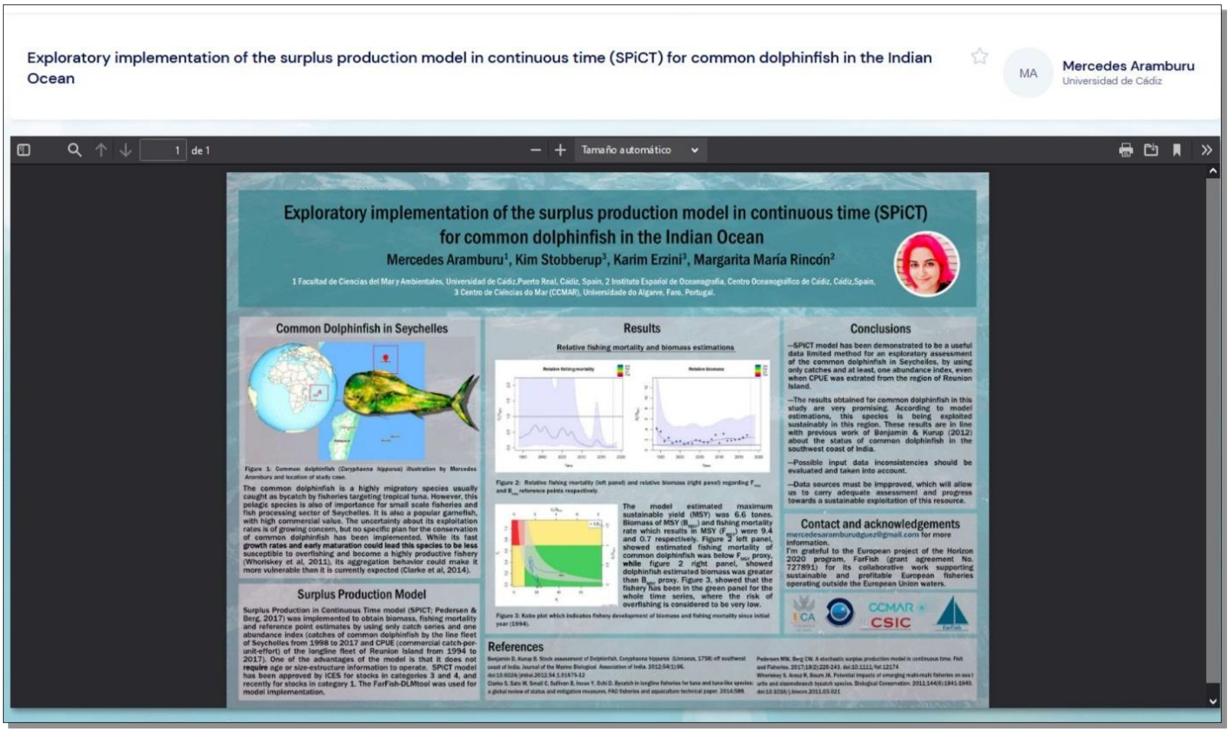

Figure 27: Screenshot from Mercedes Aramburu’s poster presentation at WFC 2021

2.4.2 Dissemination about the tool implementation under a co-creation approach (in person)

An oral communication about the development of the tool under a co-creation approach was presented by Margarita Rincon in the 2019 ICES Annual Science Conference (Gothemburg, 2019). This 2019 conference were the last in person conference before COVID 2019 restrictions.

2.4.3 Tutorial about the last version of the tool for ICES experts and for University of Cadiz

A tutorial on the use of the last version of the tool was provided in the second edition of the ICES Workshop on Data-limited Stocks of Short-lived Species (WKDLSSLS2, September 2020, https://www.ices.dk/community/groups/Pages/WKDLSSLS.aspx). In addition, it was also provided online to master students of the Aquaculture and Fisheries program at University of Cadiz in 2020 and 2021 on the Data Limited Methods session.

2.4.4 Participation on the ICES 2021, Second Workshop on Atlantic chub mackerel

Partcipation of Ghoufrane Derhy and Margarita Rincon in the ICES WCOLIAS workshop as members of the stock assessment group and collaborators for report writing mainly in the stock assessment sections (report available at https://www.ices.dk/sites/pub/Publication%20Reports/Forms/DispForm.aspx?ID=37992).
Data limited methods for different areas were implemented:

- LBSPR model was implemented for The Cantabrian Sea (27.8.c), Portuguese waters (27.9.a.c.n + 27.9.a.c.s + 27.9.a.s.a), Mediterranean Sea – Catalan Sea (GSA6), Madeira island, Canary Islands, North of Moroccan Atlantic coast and Centre (A+B) and south (C) of Moroccan Atlantic coast.
- A SPiCT model was implemented for chub mackerel in the Moroccan coast and a working document was presented. Derhy, G., K. Elkalay, K. Khalil, M.M. Rincón. Stock assessment for chub mackerel in the Moroccan Atlantic coast using SPiCT model.

3 Satellite and big data tools in support of compliance

3.1 Rationale (the why)

According to the EU IUU Fishing Coalition (http://www.iuuwatch.eu/) it is estimated that as many as one in five wild caught fish is fished illegally, representing at least 15% of the world's catches. Illegal, unreported and unregulated (IUU) fishing is widely recognised as a significant environmental, economic and social problem. In addition to being a major threat to marine ecosystems, it also represents a disadvantage for responsible fishermen, and a disruption for the seafood market. Combatting IUU fishing is essential for achieving sustainable management of global fisheries. Although the main cause of IUU fishing is states' failure to control vessels operating under their flag, tackling this problem requires a multi-sided approach. In response to this global phenomenon, the EU adopted the IUU Regulation 1005/2008, which remains to date a unique piece of fisheries legislation worldwide. Its main aim "is to prevent, deter and eliminate trade in fisheries products deriving from IUU fishing into the EU". Prior to the adoption of the IUU Regulation in 2008, approximately 500,000 tonnes of illegal fisheries imports were estimated as entering the EU annually, to a value of approximately €EUR 1.1 billion. Waters beyond national jurisdiction (the "high seas") are particularly vulnerable to IUU since regulation and compliance control is more difficult to enforce in these areas, as they are not subject to direct control by a national authority. In many cases, the national authorities closest to the high sea area even experience difficulties in providing *in situ* control to ensure compliance in their exclusive economic zone (EEZ) waters, which are subject to the specific legal regime established in the United Nations Convention on the Law of the Sea (1982) Therefore, the high seas, including vast sea regions, are frequently in need of stronger compliance control due to insufficient *in situ* resources. In this context, although traditional monitoring methods are essential for effective fisheries management, they can be cost- and time-intensive. Recent advances in satellite technology and machine learning offer powerful, scalable tools that can complement and broaden current approaches by providing cost-effective tools for estimating human activities at sea, including tracking individual fishing vessels in near real time.

3.2 Technical description of the tools implemented (the how)

3.2.1 Automatic Identification System (AIS)

The automatic identification system, (AIS), transmits ships' positions so that all other ships in the vicinity are aware of each other's whereabouts. In fact, this is a requirement established by The International Maritime Organization and other management bodies in order to avoid collisions between large ships, including fishing vessels. According to Global Fishing Watch (GFW), each year, more than 400,000 AIS devices broadcast vessel location, identity, course and speed information. The AIS system was designed for the transfer of very high frequency (VHF) information between ships, so

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it does not depend on satellites for the communication between vessels. Ground stations and satellites pick up this information, allowing the tracking of vessels even in the most remote areas of the ocean.

While AIS has been deployed globally, there is one major limitation which is shared by all VHF communications: the Earth's curvature limits its horizontal range to about 74 km offshore. This means that AIS traffic information is available only near coastal zones or on a ship-to-ship basis. Tracking ships using satellites overcomes this since vessel AIS messages are recorded and decoded by satellites, and subsequently sent to ground stations for further processing and distribution. The European Space Agency (ESA) is promoting a satellite-based AIS (S-AIS) service in partnership with the European Maritime Safety Agency thus supporting the European Commission and Member States in the prevention, for example, of the pollution from ships as well as the tracking of dangerous goods.

Through activities in WP6, FarFish has established a partnership with GFW which has allowed the project to gain access to more than 4 GB of data, including daily data of individual vessels' fishing efforts throughout the ocean for the period between 2012 and 2019.

Despite the new power that has emerged from the global tracking of vessel position, there are drawbacks in the system implemented by GFW. These have been pointed out by other maritime organizations such as Windward (wnwd.com). This organization alerts that vessels engaging in illegal activities are overriding the system and manipulating AIS data. Windward has been detecting this manipulation since 2012 when organizations such as GFW or Marine Traffic, started to openly offer massive AIS data. Windward assessments show that 1% of IMO numbers transmitted by AIS are fake or that the Chinese fishing fleet is responsible for 44% of all GPS manipulations. Windward's main criticism of the GFW products is that their programme only monitors vessels that are willing to be monitored. Moreover, despite the algorithms developed by GFW to detect erratic AIS transmission, a symptom of GPS manipulation, Windward considers that crews are becoming savvier to the various AIS manipulations that can improve their capacity to not be detected.

Therefore, despite the unquestionable utility of the database generated by GFW, for a more complete implementation for compliance purposes, this needs to be complemented with alternative sources of information, either *in situ* or through remote sensing. In this context, the CSIC team has carried out a comparison of two alternative sources of information obtained through satellite: VMS and VIIRS data.

3.2.2 Vessel Monitoring System (VMS)

Vessel monitoring system (VMS) tracks vessels in a similar way to AIS, and is a standard tool used in fisheries monitoring; however, it has historically been restricted to government regulators or other fisheries authorities, and several countries have released their VMS publicly on the Global Fishing Watch map. VMS systems broadcast positions at set intervals and some systems allow operators to increase transmission frequency when needed. Some vessels broadcast both AIS and VMS so information from both systems can be combined to give a higher resolution vessel track.

Europe was the first part of the world to introduce compulsory VMS tracking for all the larger boats in its fleet. The EU legislation requires that all coastal EU countries should set up systems that are compatible with each other, so that countries can share data and the Commission can monitor compliance. The system is compulsory for EU vessels above 15 m (as from of 1 January 2012 – vessels above 12 m). VMS is also compulsory for EU vessels involved in fishing activities of in non-EU waters.

3.2.3 Visible Infrared Imaging Radiometer Suite (VIIRS)

Although the spatial resolution is not as good as Deimos-1 or Sentinal-2 satellites, the Visible Infrared Imaging Radiometer Suite (VIIRS) is a polar orbiting satellite that uses highly sensitive optical sensors to see lights at night. The Earth Observation Group (EOG) at the Colorado School of Mines manages the VIIRs Boat Detection (VBD) database, which identifies vessels in the VIIRs data that use light to attract catch, such as most industrial squid vessels and some types of purse seines.

One of these instruments is the radiometer for visible infrared VIIRS (Visible Infrared Imaging Radiometer Suite) on board the Suomi NPP, which is part of NASA's earth observation system. The spatial resolution of VIIRS is about 750 meters and it offers a daily coverage of the earth. One of VIIRS' spectral channels is DNB (Day Night Band), specifically designed to capture low light levels during the night (Figure 28).

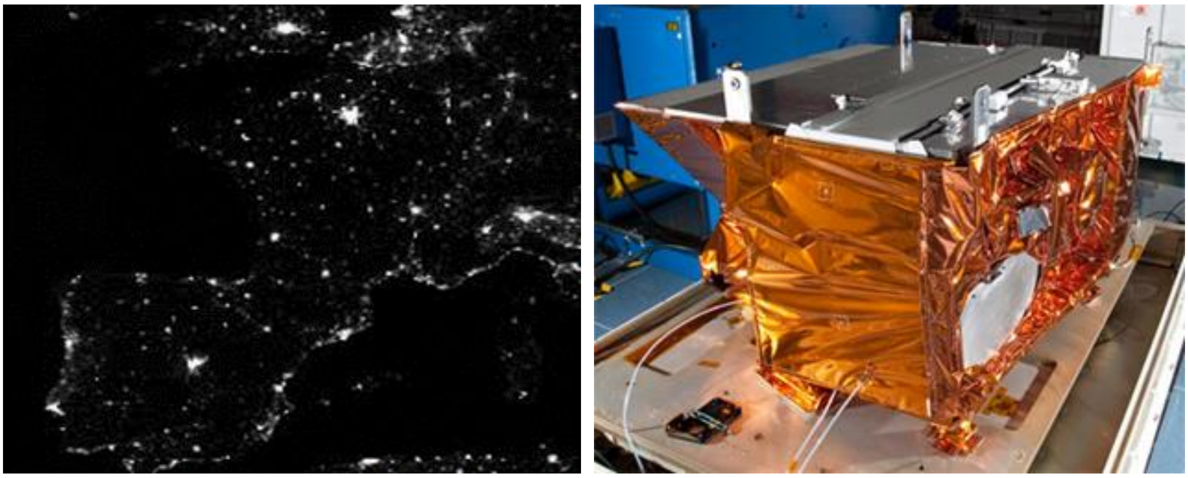

Figure 28: Picture of Radiometer VIIRS on board Suomi NPP (left) and VIIRS image of western Europe at night (right)

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3.3 Open and transparent access to the tool: Google Earth Engine

As identified in the DoA, in addition to relevance and added value, the tools generated by FarFish must include a set of technical characteristics to be useful in the implementation of a Responsive Fisheries Management System, namely:

1) Platforms to host the tools will be free and open access to guarantee reproducibility, interoperability, affordability, and transparency.
2) The tools will ensure full access to all actors in the process.
3) The tools will ensure the immediate capacity of all actors to use it once this has been created.
4) Long-term legacy of FarFish beyond the life-time of the project.
5) The codes generated will be implemented within open code platforms.

These technicalities are more difficult to achieve when the tool is based on the use of massive data obtained from satellites. However, FarFish is not the only initiative facing the need to increase transparency and accessibility to analysis of big data connected to earth functioning and its natural resources. Powerful organizations like Google have already implemented platforms to facilitate this aim and FarFish is making use of this, concretely of Google Earth Engine (GEE).

Google Earth Engine is a cloud-based platform that allows users to run geospatial analysis on Google's infrastructure. It provides a web-based code editor to write and run scripts, including a set of powerful libraries for geospatial analysis. Additionally, GEE is also designed to easily disseminate the results of the analysis to policy makers, NGOs, field operators, and even the general public. Algorithms developed on Earth Engine can be transformed into systematic data products or applications backed by Earth Engine's resources, without needing to be an expert in application development, web programming or HTML. Therefore, the Earth Engine is a platform matching the technical conditions imposed by FarFish for the tools, in particular for those making use of massive satellite data like GFW or VIIRS.

FarFish is already applying Google Earth Engine for the analysis of satellite information in case studies with tool codes that will be open to the public for the use in the cases studies as well as outside the FarFish consortium. The system is composed of the following components:

- Data set from VIIRS images and GFW programme.
- Computational power provided by Google online.
- Application Programming Interface (API) with a programming library provided by Google.
- Code editor provided by Google and codes created in this work package for the analysis of interest to the case studies and FarFish aims.

3.4 Case study implementation

3.4.1 Southwest Atlantic (FAO Major Fishing Area 41)

FarFish has already implemented Google Earth Engine (GEE) in conjunction with Global Fishing Watch (GFW) dataset and available visible infrared imaging radiometer suite (VIIRS) images to test its suitability for assessing compliance from the space. VIIRS-DNB radiance results presented in this work are based on the database and the tools provided by GEE. In the study by Ruiz et al. (2019), the authors selected the case study (CS) Southwest Atlantic, i.e. the Food and Agriculture Organization of the United Nations's (FAO) Major Fishing Area 41, a high-sea fishery where *in situ* surveillance is less feasible thus more prone to illegal practices. In particular, a first test has been conducted to assess the possible manipulation of GPS data to avoid AIS tracking of these activities. Figure 29 shows the VIIRS composite image for the whole period of study (2012 to 2018). In addition to the urban areas of South America, the image also evidences the massive presence of fishing activities beside and outside the EEZ of Argentina. This was clustered in three regions, with R1 in the map tagging the main activity conducted in high seas in connection with the fishing of *Illex argentinux* stock. In the study, the consistency of two time series was analysed of AIS (GFW) and VIIRS-DNB data for one of the main high fisheries of the world's oceans — the jigger fleet squid (*Illex argentinus*) landings in the FAO Major Fishing Area 41. The results show a high level of temporal and spatial consistency between the two signals during the seven years analysed and for the different regions of this area. This suggests that in this particular area and fleet, GFW and VIIRS-DNB are valid tools to assess the temporal dynamics and the spatial structure of these fishing activities.

The study's results show a high level of consistency between GFW and VIIRS-DNB signals at different spatial and temporal scales for the jigger fleet at FAO Area 41. No traces of a significant manipulation were detected in the effort data provided by AIS. The results also provide evidence of the increasing power of remote sensing to add transparency to fishing operations in distant and vast zones of the ocean that are difficult to survey.

Details or the study can be found in the article by Ruiz et al. (2019) entitled "Sensing the Same Fishing Fleet with AIS and VIIRS: A Seven-Year Assessment of Squid Jiggers in FAO Major Fishing Area 41"

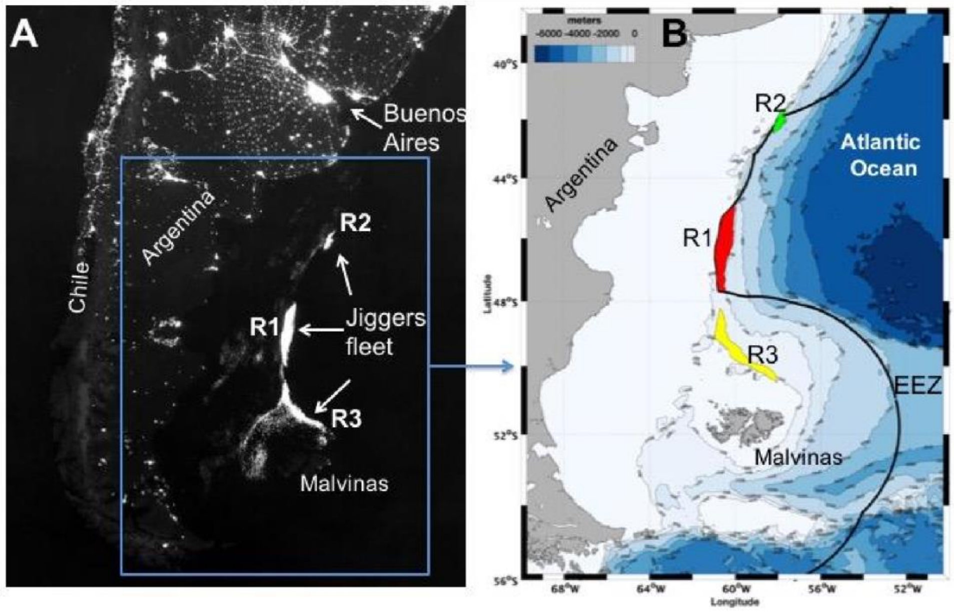

Figure 29: (A) Visible infrared imaging radiometer suite day/night band (VIIRS-DNB) radiance image (entire mission composite 2012–2018). (B) Map showing southwest Atlantic bathymetry. R1, R2 and R3 are the regions of interest. The black line shows the exclusive economic zone (EEZ) of Argentina.

3.4.2 Mauritania

The analysis conducted for the Mauritanian CS uses publicly available AIS data from Global Fishing Watch (GFW), covering the 2012-2016 period. The aim of this research is to study the occurrence of different fleets by country and cross-check with the international public and private agreements, if any, what are the conditions for their presence, and if there are any incongruences.
This study is an exploratory exercise providing an example of what can be achieved with the available public information on marine traffic, as well as test the possibilities of a cross-check verification and validation between different IT tools such as VMS and AIS data. It also aims to serve as a tool to demonstrate the importance of the linkages and interoperability in terms of exchange between scientific and legislative data.

The ICMAN-CSIC project team produced a report (Annex 3) that graphically shows the analysis of daily and monthly apparent fishing effort (in hours), as well as the number of fishing vessels (determined from the Maritime Mobile Service Identity, MMSI), in the EEZ (IMF, 2019) of Mauritania from 2012 to 2018. The analysis was carried out utilizing the Global Fishing Watch (GFW) database (https://globalfishingwatch.org/; Kroodsma et al., 2018). GFW uses the aforementioned automatic identification system (AIS), a GPS-like device that large ships use to broadcast their position in order to avoid collisions, to directly map global fishing activity. From the collected data obtained via satellites and terrestrial receivers, GFW provides information about the type of fishing vessel, its position and the apparent fishing effort (in hours). Only from 2012 to 2016 they tracked more than 70,000 industrial fishing vessels (Kroodsma et al., 2018). VMS data were not accessible for the Mauritania CS.

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A spreadsheet was created containing a list with all the vessels from the GFW data. The document displays information on the ownership in terms of Flag States, the years they were found actively fishing, the peak months of effort and the licenses under which they are allowed to fish, if any. These licenses were found via *whofishesfar* (Oceana/EU FAR-SMEFF) and the ICCAT databases. Once all the info was collected, the trends in the number of vessels per year, for both EU and non-EU vessels were analysed. Next, the fisheries partnership agreements between the Coastal State and the Flag State were identified, checking the availability of the documents and the periods covered by them. Figure 30 shows the countries with vessels present in the Mauritanian EEZ, while Figure 11 explains the percentage of vessels per country.

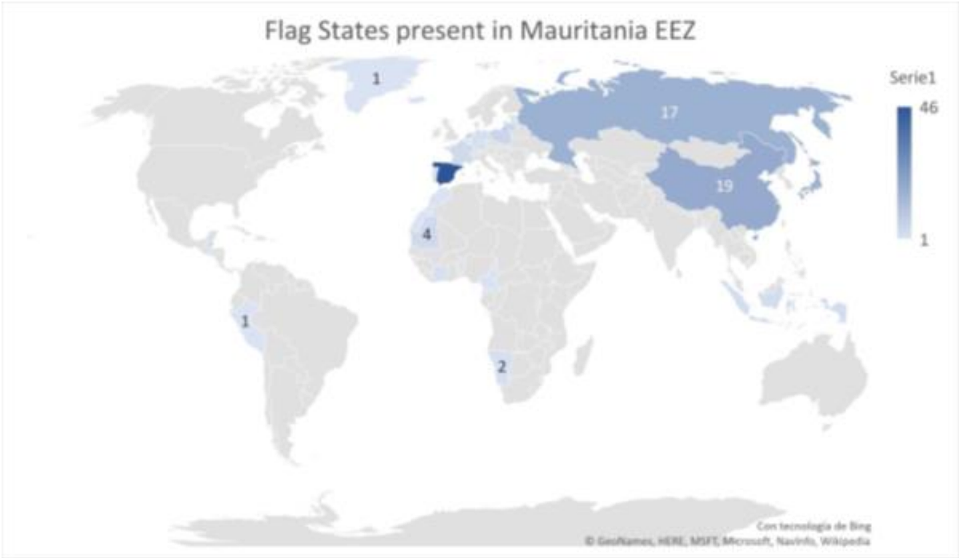

Figure 30: Number of vessels per Flag State present in Mauritanian waters.

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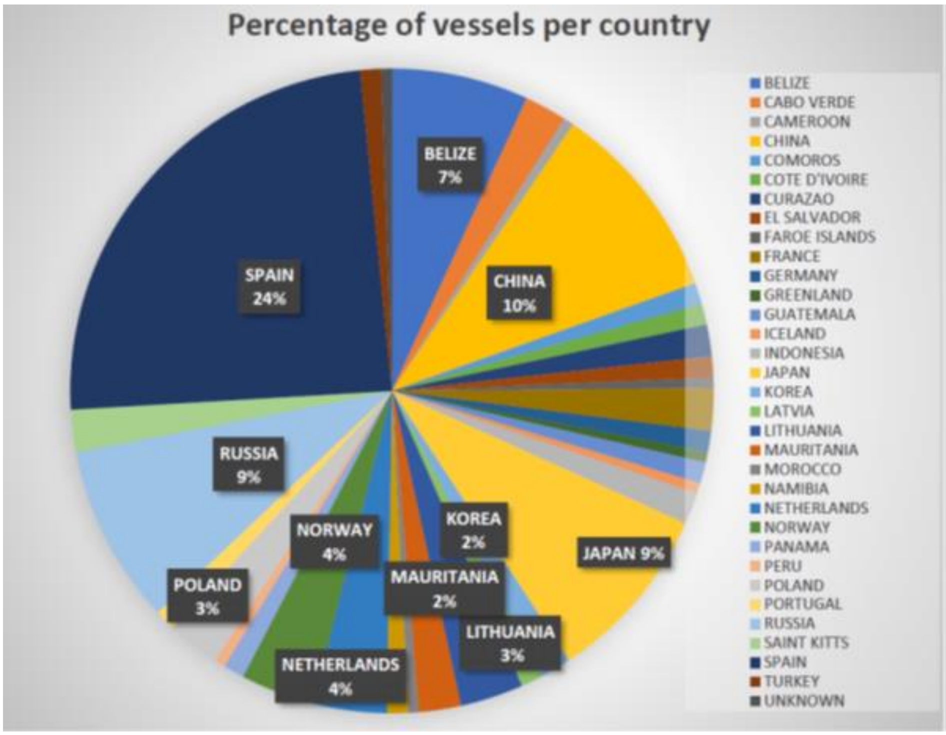

Figure 31: Percentage of total fleet in Mauritanian EEZ per Flag State.

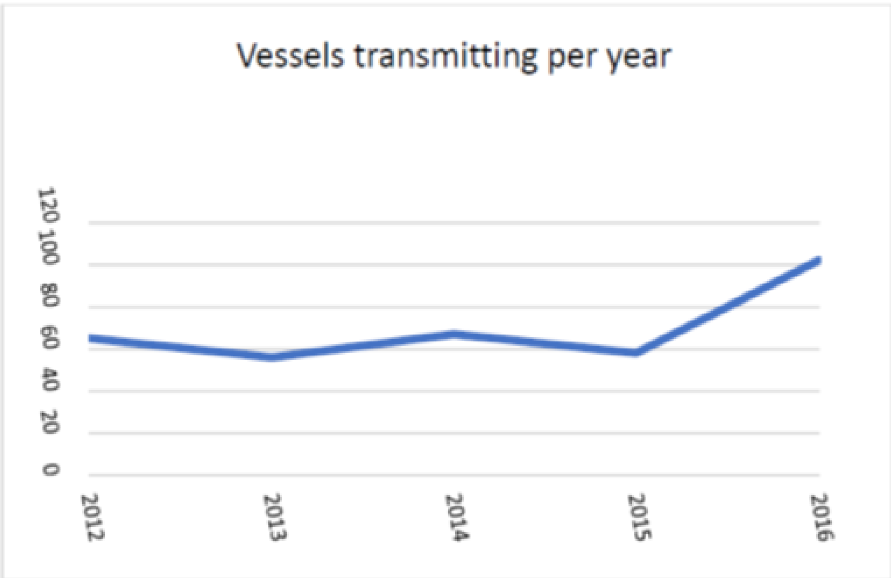

Figure 32: Trend of number of foreign fishing vessels transmitting from Mauritanian waters

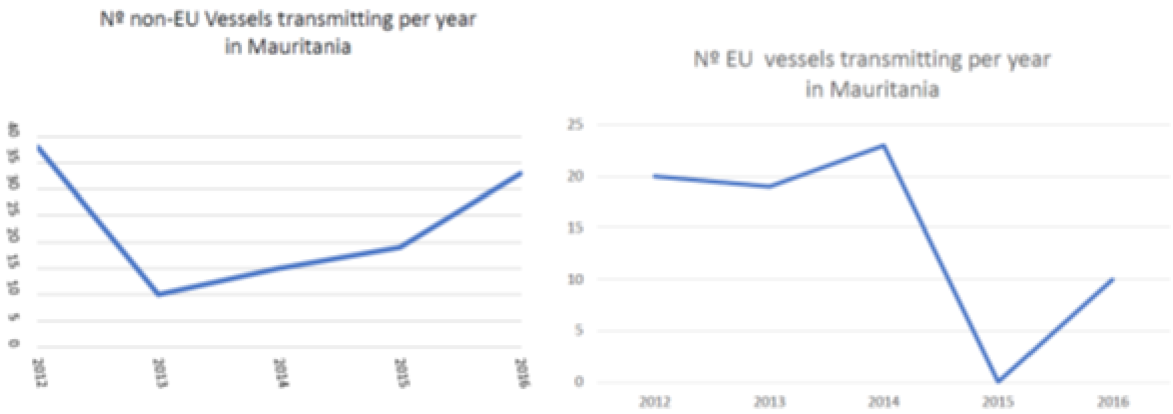

Figure 33: Comparison of trend of fishing fleet size between non-EU and EU fleets

Figure 32 shows the trend on the number of fishing vessels transmitting AIS per year, within the Mauritanian EEZ, while Figure 33 shows the differences in trends between the EU and the non-EU fleets. 7 out of 17 vessels from Japan started their activities (always according to the signal or "ping" transmissions) at the end of 2016. All the other 10 Japanese vessels were fishing in the area in 2012-2013, and came back in 2016. All 3 vessels from Indonesia, and 2 out of 3 vessels from Korea started their activity in 2016. The increase in number of vessels between 2015 and 2016 matches the signing of a new SFPA between Mauritania and the EU (entered into force on November 2015). However, only 10 of those new vessels are from an EU MS (9 from Spain), so this factor alone does not explain the increasing numbers.

3.4.3 Senegal

The analysis conducted for the Senegalese CS uses publicly available AIS data from Global Fishing Watch (GFW), covering the 2012-2016 period (see Annex 4), as well as a list of VMS data transmitting vessels provided by CRODT. These data have been analysed with the aim of looking for inconsistencies between AIS and VMS signals, namely between the signals and data report and the requirements laid out in the maritime legislation in place. Any other additional information that might be useful for the Senegal Case Study has also been considered. It is important to mention that CRODT provided the FarFish consortium with a list of the vessel names for which they have VMS data. That is, they did not provide the actual VMS data.

Regarding the methodology and process, the steps were as follows:

1. The first step was to identify the CRODT listed vessels and match them with their MMSI, so they could then be compared with the GFW data. The Flag State ownership of the vessel was also annotated. This was done checking the names provided in the vessels´ list by Senegal against the publicly available databases such as MarineTraffic or *vesselfinder*.

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2. A spreadsheet was created containing all the vessels, both in the GFW and the CRODT lists. The document contains the Flag States, the years they were found fishing, the peak months of effort and the licenses under which they are allowed to fish, if any. These licenses were found via whofishesfar and the database from ICCAT.

3. Once all the info was collected, the number of vessels per Flag State, the difference between the CRODT list and the GFW list for the Senegalese CS and the trend in the number of vessels per year, for both EU and non-EU vessels, were analysed and cross-checked.

The image in figure 34 shows the countries with vessels present in Senegal EEZ. The legend shows the number of vessels. Figure 35 contains a chart explaining the percentage of vessels per country.

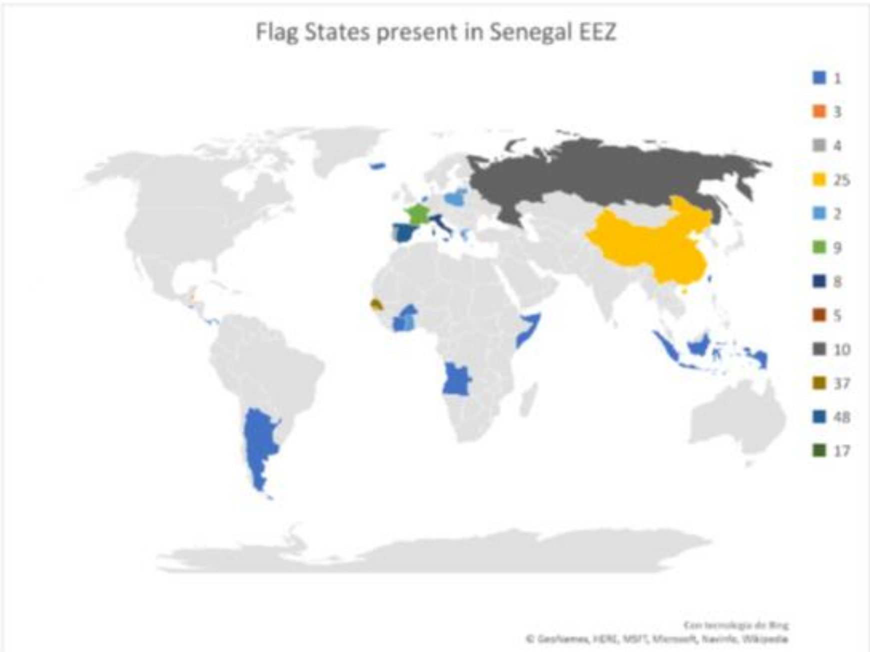

Figure 34: Number of vessels per Flag State present in Mauritanian waters.

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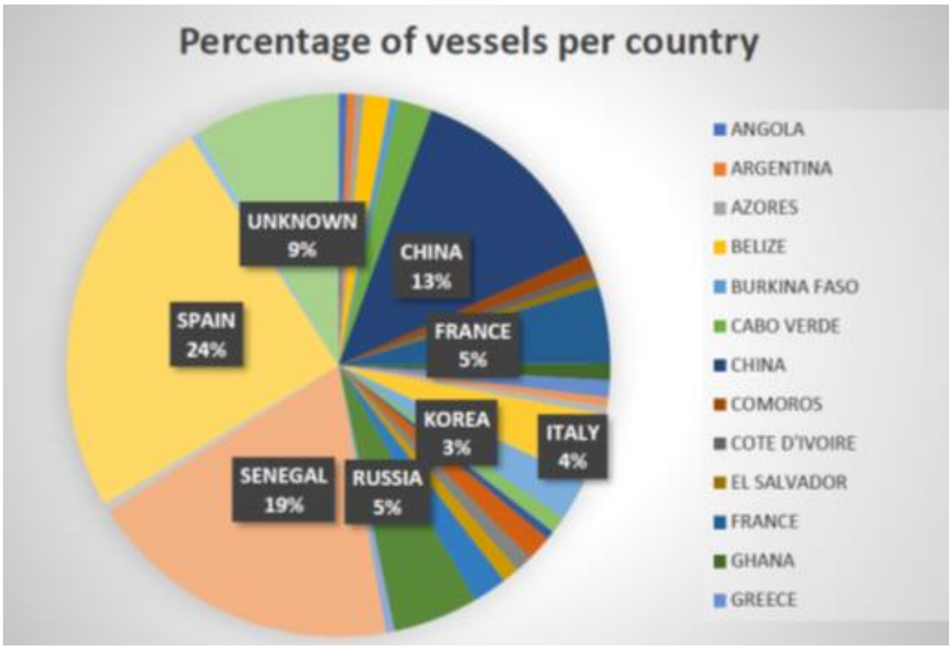

Figure 35: Percentage of total fleet in Senegalese EEZ per Flag State.

Figure 36 shows the trend on the number of fishing vessels transmitting either VMS or AIS per year within the Senegalese EEZ, while Figure 37 shows the trend difference between EU and non-EU fleets. 2014 was the year the last SFPA between Senegal and the EU was implemented (2014-2019). 24 out of 25 vessels from China started their activities (always according to the signal transmissions) in 2015, being the main responsible of the increase of number of vessels between 2014 and 2015.

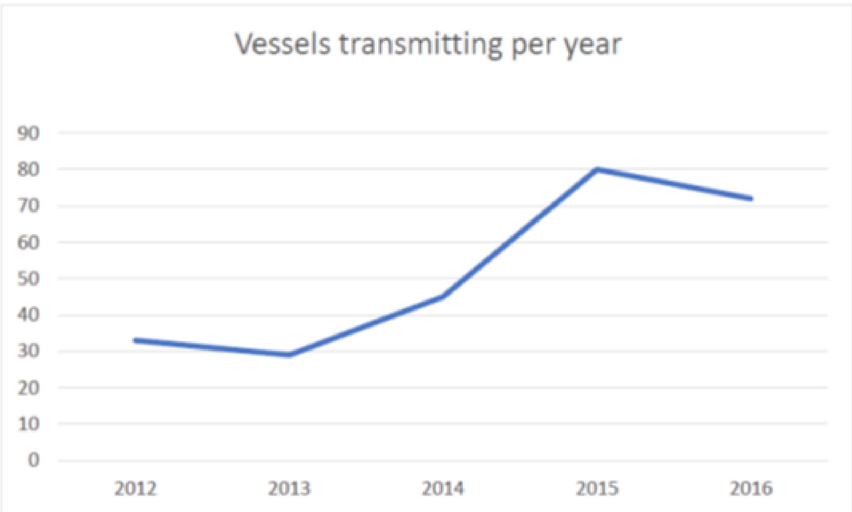

Figure 36: Trend of number of foreign fishing vessels transmitting from Mauritanian waters

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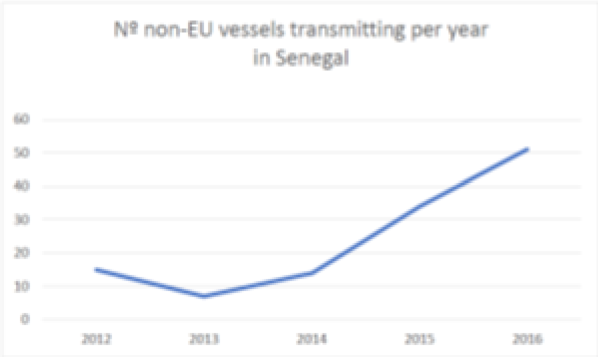

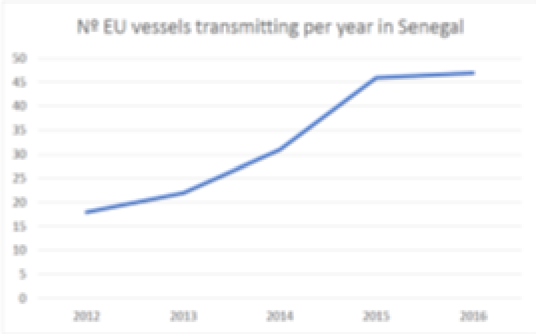

Figure 37: Comparison of trend of fishing fleet size between non-EU and EU fleets

In terms of data gaps, 44 of the vessels from the list provided by CRODT do not appear in the Global Fishing Watch provided data. If entered manually into the GFW search engine, 20 of those vessels do however appear in the map but they only show activity records outside the year gap studied by the CSIC (2012-2016). 7 vessels with identified Flag States (1x Angola, 1x Italy, 1x Argentina, 4x Senegal) are not found via GFW. 17 vessels from the CRODT list are not located via GFW, *vesselfinder* or similar. The assumption to be made is that they might have stopped working. Last, there are neither Chinese nor Russian vessels sending VMS data to the Senegalese authorities. The reasons might be either there are not sending them or that info is not reaching CRODT.

When looking for the agreements under which these vessels operate, 5 out of 9 French vessels are licensed under the Senegal SFPA, but are not listed by CRODT as VMS transmitting boats. This supports the idea that CRODT does not have the full VMS data for all the vessels operating in the area, despite it is mandatory. With CRODT being the main national research institution, this eventual data flow gap is rather important and would need further investigation on underlying reasons. In terms of access to information, there are no documents to be found about a public or private fisheries agreement between China (or Chinese companies and investments) and Senegal. However, there are infrastructures such as fishmeal factories and processing plants funded by China in Senegal. Conditions for their funding, cost-benefits and scale of their fishing activities remain unknown and unclear. The agreement between Russia and Senegal exists, but an official document for the agreement was not found likely due to confidentiality issues.

3.4.4 Southeast Atlantic (SEAFO)

Similar to the previous CSs, an analysis was carried out of daily and monthly apparent fishing effort (in hours), as well as the number of fishing vessels (determined from the Maritime Mobile Service Identity, MMSI), in the South-East Atlantic region, delimited by the South East Atlantic Fisheries Organisation

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(SEAFO), from 2012 to 2018. This analysis was carried out utilizing the Global Fishing Watch (GFW) database (https://globalfishingwatch.org/; Kroodsma et al., 2018) (see Annex 5).
In this case, data related to the following fisheries were analysed: drifting longlines, purse seines, tuna purse seines (pelagic tuna vessels), other purse seines (non-tuna purse seines) and trawlers. (Not enough data were registered for purse seines and other purse seines fisheries). For each of these fisheries, the apparent fishing effort (hours) is represented, as well as the number of fishing vessels (by MMSI) throughout the study period (2012 - 2018) for all the principal subdivisions (e.g., provinces or states) of all countries coded in ISO 3166-2 (see table in supplementary material of the annexed report) that were identified in the 'SEAFO region'. Moreover, for both variables the contribution to the total (%) of apparent fishing effort (hours) is calculated, as well as the number of fishing vessels of each subdivision. In a more detailed analysis, the five subdivisions that exerted the highest fishing pressure are analysed with a daily and monthly resolution. The contribution to the total (%) of apparent fishing effort (hours) and the number of fishing vessels of each subdivision over time is shown. Also shown are the individual apparent fishing effort and the number of fishing vessels of each subdivision. The raw data from these analyses can be found in the excel files. For each fishing gear, there is an excel file for each variable analysed (i.e., the apparent fishing effort and the number of fishing vessels). In each file, the first column refers to the analysed time period (2012 - 2018) with a daily or monthly resolution. The remaining columns refer to the apparent fishing effort or the number of fishing vessels corresponding to all the subdivisions that were identified in the 'SEAFO region'. Thus, each cell represents the sum of each variable (i.e., the apparent fishing effort and the number of fishing vessels) for each day or month of the time period analysed and each subdivision for the 'SEAFO region'

4 Environmental forcing of small pelagics in NW Africa

New scientific Knowledge was also required to understand how environmental forcing creates fluctuation of small pelagics in the West coast of Africa. The exploratory work for this scientific contribution has been developed in collaboration with Cadi Ayyad University in Marrakech to develop the knowledge where small pelagic dynamics in the West Africa can be understood in the oceanographic frame of the region and where vulnerabilities can be assessed. The Moroccan chub mackerel stock was selected to understand the relationship between stock abundance and different environmental covariates. An approach was adopted to achieve our objective, which consisted in estimating the stock abundance using one of the DLM tools (SPiCT model) and based on catch and abundance indices data. The model output (relative biomass trend) representing the stock abundance was then correlated with environmental variables of the studied region obtained by using Copernicus Marine Service products (Figure 38). The results indicated a strong correlation between different environmental forcing in our upwelling ecosystem and population dynamics and allow us to identify factors that may affect the fluctuation of stock abundance mainly salinity, chlorophyll concentration, net primary production, oxygen concentration and nitrate concentration (more details about this work are available in the deliverable 6.11). These variables can be included in this model or in other fisheries management approaches to estimate different scenarios of stock dynamics under different environmental conditions, which can be applied on the other small pelagic stocks of the west coast of Africa.

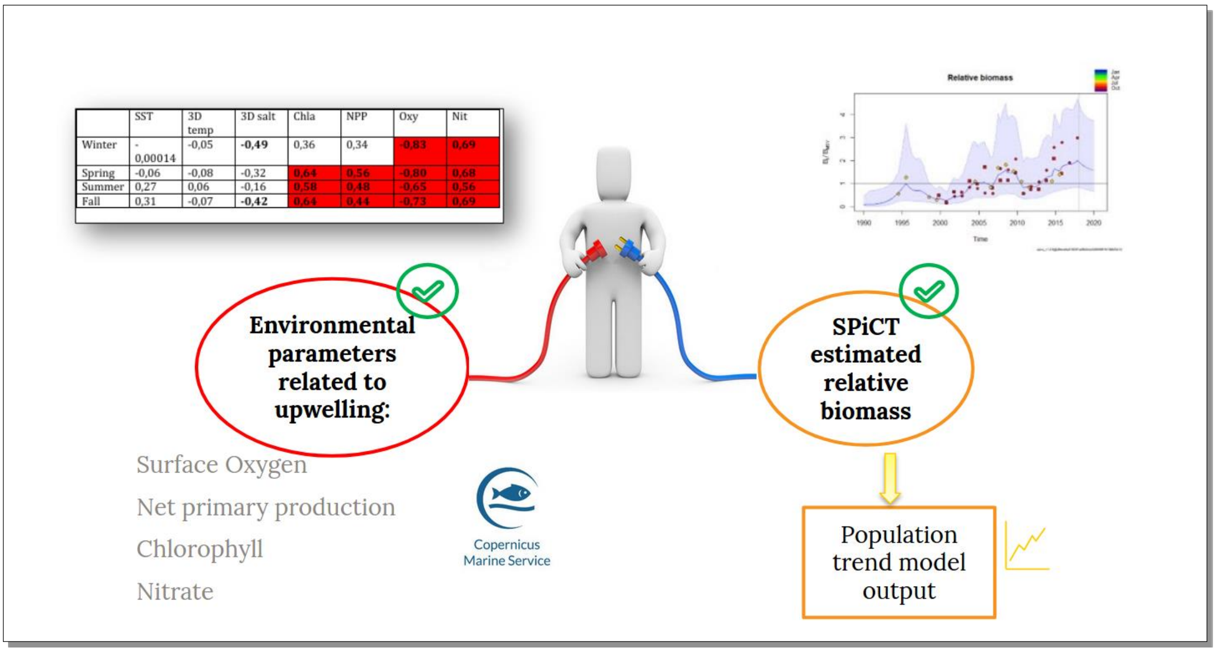

Figure 38: Graphical summary of FarFish contribution to advance in the knowledge about the environmental forcing of small pelagics in NW Africa.

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4.1 Online dissemination

- Oral communication entitled: “Assessing external environmental drivers for the Chub Mackerel Moroccan fishery” (Figure 38) by Ghoufrane Derhy et al. presented at the World Fisheries Congress 2021 (WFC). Held in Adelaide, Australia (20-24 September 2021).
- Oral communication entitled: “Links between the environment and Surplus production model outputs: The case of Moroccan chub mackerel stock” by G. Derhy. et al. the Iberian Symposium on Modeling and Assessment of Fishery Resources (SIMERPE), held in Vigo, Spain (19-22 October 2021). Video available at: https://drive.google.com/file/d/1o8qs9Jpmb7xTUEg692fpYs8U2FVXUtue/view?usp=sharing
- Oral communication on the FarFish Workshop on Small pelagic and climate change in the CECAF area with a presentation entitled: “Links between the environment and population dynamics model outputs: The case of Anchovy in Gulf of Cádiz and first steps with Chub mackerel in Morocco.” By Margarita Rincon, Ghoufrane Derhy and Diego Macias.

Figure 38: Screenshots of Ghoufrane Derhy’s presentation at WFC 2021

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5 Specific use of DST in connection with MR: From MR0 to MR2

Consultation process at the beginning of the project results in the needs and tools specified in Table 1 in accordance with MR0, this table also include a column with the state of the tool at the end of the project, nevertheless needs have been changing with the evolution of the project and they were formalized as outcome targets and the tools have been adapted to the new formulations and demands as can be observed in Table 2.

Table 1: Schematic view of the potential tools to be developed of WP2 and 4, including partners and risks involved from MR0 demands.

Demands from MR0	Demands to WP2	Potential tools	Partners	Risks/achievements at the end of the project
SW Atlantic				
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools		Satellite remote sensing & AIS	CSIC	Not enough sensitivity or resolution -> Tool developed; a manuscript has been published with the results
SE Atlantic				
Analyse current stock assessment methods Improvements using new or existing tools is dependent on the defined CS objectives and OT, making sure that the FarFish contribution is relevant also by consulting SEAFO (FarFish RG).	(1) Data gathering according to the online template in FarFish D6.1-online site and in coordination with D4.1, D4.3 and D4.4	(2) Implement Data Limited Methods	(1) IMR, CCMAR (2) CSIC	Data do not exist or insufficient -> Methods not implemented because there was not data available
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools.		Satellite remote sensing & AIS	CSIC	Not enough sensitivity or resolution -> Only an analysis of GFW data was presented because AIS data was not available.
Cape Verde				
In conformity with ICCAT, collect and analyse data on bycatch of swordfish and blue shark by the EU fleet in the Cape Verde EEZ. If sufficient data is accessible, model scenarios, which may add value to development harvest control rules for these bycatch species. Implementation of biological sampling and data collection programmes (self-sampling protocols)	(1) Data gathering according to the online template in FarFish D6.1-online site and in	(2) Implement DLM for sword fish and blue shark	(1) IMR, CCMAR (2) IMR, UiT	Data do not exist or insufficient -> DLM not suitable for these species, they were implemented for Frigate tuna and Wahoo, but not significant outcomes were obtained.

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	coordination with D4.1, D4.3 and D4.4			
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools.		Satellite remote sensing & AIS	CSIC	Not enough sensitivity and/or resolution-> GFW data was not detailed enough
Senegal				
Improve stock assessment models and tools, developing networks, working groups and knowledge transfer. FarFish aim to add value to present work in CECAF applying new models and tools.	(1) Self-sampling	(1) Tools for hake stock differentiation (2) Automatic Biodim run and visualization (3) Automatic DLM run and visualization	(1) UiT, CCMAR (2) IMR, MATIS (3) CSIC, MATIS	Inexistent data or impossibility to make new operative tools to this aim-> Self sampling was implemented Further formal contacts with CECAF may identify further tools-> LBSPR method implemented for hake by Kamarel Ba, nevertheless stock assessment needs were not identified in posterior versions of MR: MR1 and MR2.
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools		Satellite remote sensing & AIS	CSIC	Not enough sensitivity and/or resolution-> AIS signals have been cross-checked with VMS signals using ISRA-CRODT info as a proxy

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Demands from MP0	Demands to WP2	Potential tools	Partners	Risks
Mauritania				
Advanced knowledge on how the signal of oceanographic processes affects the shrimp stocks and the shrimp fishery will improve assessment and dampen the fluctuations in landings. Given the present capacity of the scientific community to foresee the impact of large-scale climatic oscillations, this might help to rise early warnings and preventive measures to protect the stock and improve long-term profitability of the EU fleet targeting shrimp.		Assess shrimp stock dynamics in an oceanographic context	CSIC CCMAR	No neat assessment is achieved-> This changed into the need of oceanographic support for population dynamics on small pelagics and particularly implemented with chub mackerel in the Moroccan coast
Seychelles				
Contribute to the assessment of non-target species included in recent discard ban (IOTC, 17/04)	(1) Data gathering according to the online template in FarFish D6.1-online site and in coordination with D4.1, D4.3 and D4.4	(2) DLM for bycatch	(1) IMR, CCMAR (2) IMR, UiT	Data do not exist or insufficient->DLM implemented for Wahoo and Common Dolphinfish, obtaining promising preliminary results with the latest.
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools		Satellite remote sensing & AIS	CSIC	Not enough sensitivity and/or resolution-> No AIS or GFW data available

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Table 2: Outcome targets in MR2 connected to the tools developed in FarFish project

Case Study (CS)	Outcome Target (OT)	Tool	Comment
1: High seas: South-West Atlantic fisheries (FAO Area 41)	OT1.2 All vessels transmitting AIS signals	Remote sensing (AIS and VIIRS-DNB) and AIS.	-"The OT achieved the desired impacts, by demonstrating that remote sensing adds transparency to the fishing operations in high seas where enforcement is challenging." -"The data and analyses performed by CSIC allows for assessment of the AIS and remote sensing data and hence contribute to the selected indicator." From Deliverable 5.4
2: High seas: South-East Atlantic fisheries (SEAFO Convention Area; FAO area 47)	OT2.2 All vessels transmit AIS or VMS signals	AIS (annex 5)	No VMS data for EU vessels in the SEAFO system, and AIS data from Global Fishing Watch are not detailed enough, nevertheless, the data available was analysed.
3. Cape Verde	OT3.1 A harmonised catch data protocol in place that facilitate improved reporting of swordfish and blue shark commercial and biological data.	FarFish-DLMtool	This OT could have an impact in improving stock assessment. Nevertheless, the data limited tool currently is not a suitable tool to use with these two species, which assessment is carried out regularly by the ICCAT. The tool was implemented for an important bycatch species as it is the Frigate tuna.
4: Cape Verde	OT3.2: All vessels transmit AIS and/or VMS signals.		Global Fishing Watch data was not detailed enough
5: Senegal	OT4.3: VMS and/or AIS signals are transmitted	AIS (annex 4)	Connected to I_10_CS4: AIS signals have been cross-checked with VMS signals using ISRA-CRODT info as a proxy, and I_11_CS4: The comparison between AIS and VMS signals is an accurate and useful method to identify if vessels are compliant
6: Mauritania	OT5.3: Increased onboard observer coverage on all high-capacity pelagic vessels in place OT5.4: Data on all catches, discards and bycatches provided	FarFish-DLMtool and Oceanographic support for small pelagics dynamics using Copernicus Marine Service	Even there is still a lack of good quality data for small pelagics, several efforts have been performed with UCA to gather small pelagics data in areas close to Mauritania. Using the data available several Data limited stock assessment methods have been implemented. There is also a promising ongoing work connecting chub mackerel population dynamics with environmental variables in the Moroccan coast.
7: Seychelles	OT6.3 MPAs and no-take zones identified in the SMSP are respected OT6.6 Vessel Monitoring System (VMS) or Automatic		Lack of access to VMS data and no transmission of AIS data

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	Identification System (AIS) signals are transmitted.		
8: Seychelles	OT6.2 Catches of non-target species registered in e-logbooks	FarFish DLM-tool	Linked to indicator I_4_CS6, to conduct the key activity to explore data-limited methods (DLM) applied to data available for non-target species. Promising results were obtained with a data limited stock assessment method applied to Common dolphinfish in the area.
Mauritania, Senegal, Cape Verde and Seychelles	MR2 aims to improve the quality of the current stock assessment	FarFish-DLMtool FarFish DLM course	Even not a specific OT, training on data limited methods for stock assessment provided to scientist of the CS countries would indirectly help to achieve this in the long term.

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