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Deliverable D6.4

Report on the developments needed to produce relevant management tools

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Executive Summary

This document reports on the developments needed to produce management tools that are relevant for each of the case studies in the FarFish project. The tools have been selected in coordination with the production of Management Plan zero for each case study (D4.1 - MP0 for each case study). It has shared with Work Package 4 the consultation process with partners of FarFish, including the case study leaders, and with external relevant bodies such as ICCAT or IOTC. The selected tools have been incorporated into the Management Plan Zero and have also been coordinated with Work Package 2 to feed through Deliverables 2.3 (Report on biological and ecological data in FFDB pilot version 1) and 2.6 (Report on biological and ecological data in FFDB pilot version 2), and the data these tools will demand. The tools are planned to use the data available from the FarFish database (D6.2 – FFDB pilot version 1, D6.5 – FFDB pilot version 2, D6.9 - FFDB) and to provide results that will be stored in the same database. They incorporate measures to explore better compliance through satellite advances in sensing and communication, models for semi-automatic stock assessment when needed or assessment of the role of the physical environment in creating stock fluctuations. They have all been identified during the consultancy process as necessary and non-redundant with the tools presently available in the different case studies.

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Table of Contents

Abbreviations

AIS	Automatic Identification System
CECAF	Fishery Committee for the Eastern Central Atlantic
DLM	Data Limited Methods
FFDB	FarFish DataBase
HCR	Harvest Control Rule
ICCAT	The International Commission for the Conservation of Atlantic Tunas
IOTC	The Indian Ocean Tuna Commission
MPR	Management Plan Recommendation
RFMO	Regional Fisheries Management Organisations
RFMS	Responsive Fisheries Management System
VIIRS	Visible Infrared Imaging Radiometer Suite
WP	Work Package

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1 Introduction

Development of decision support tools that can assist with fisheries management decisions are a major focus in the FarFish project, which is why a specific work package (WP) has been allocated for that task. The overall objective of WP6 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 FarFish case studies. To create this added value it is necessary to avoid redundancies with already available resources through a diagnosis of the technical gaps, as well as the models available. This effort largely corresponds to the ongoing work in WP2 i.e. Task 2.4 that is assessing current stock assessment methods in each case study. This report has benefitted from that ongoing effort through an effective dialogue and coordination between WP2 and WP6. This coordination has also been beneficial to WP2 since it helps to focus efforts allocated to deliverables 2.3 and 2.6 about biological and ecological data and its incorporation in the FarFish database - FFDB (deliverables 6.2, 6.5 and 6.9). The FFDB will include the type and format of data necessary for the implementation of tools developed in FarFish.

This dialogue and coordination has also benefitted from the ongoing work at WP4. Thus, to guarantee relevance, these tools have been selected in coordination with the production of the version zero of the Management Plan (D4.1) and, therefore, sharing with WP4 the consultation process to partners of FarFish, including the case study leaders, as well as to external relevant bodies such as ICCAT or IOTC. This co-creation process, already exercised during the FP7 project MareFrame prevents mismatches between relevant actors and scientists when assessing what tools are needed in a particular fishery. It has been used here to make the tools as relevant as possible to actors within what is scientifically feasible. This coordination has also benefited WP4 since the Management Plan Zero (D4.1) already incorporates tools to be explored in WP6.

Given the disparity of FarFish case studies, it is clear that the tools generated in WP6 will first and foremost need to be useful to the actors involved in the spiral procedure for implementing a Responsive Fisheries Management System (RFMS). The tools must therefore 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 remain once the project has ended.

This report describes the tools to be developed under the constraints considered above. The FarFish project is though organised in accordance with the spiral development model, which means that the project will go through several iterations on its way that will allow project partners to amend their "direction" in accordance with the knowledge gathered. This iterative component of the spiral procedure means that the tools discussed in this report may not be definitive and the composition

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may be modified if the actors involved demand further alternatives or when the tools developed turn out to be not applicable e.g. due to lack of data or relevance.

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2 Process of identifying the tools

The process of identifying those tools that provide added value, relevance and usefulness to the different actors involved in the spiral procedure for implementing RFMS includes diverse actors that are within FarFish consortium, as well as other stakeholders that are not partners in the project. Based on similar co-creation experiences from past projects like MareFrame, it is evident that this interaction must be undertaken at the very early stages of the project. This early identification allows time for the development and further refinement of the tools, since the initial idea of what might be the necessary tools might substantially change through the interaction with the different actors. The flexibility to accommodate what the actors demand must persist during the spiral procedure, since the actors may identify new tools or recommend amelioration to those already developed. Flexibility might also be necessary to propose alternatives when the initial idea cannot be implemented because of imponderables such as the absence of enough data to implement a certain model. In any case, the tools identified in the following sections are the intersection, through the dialogue described in this section, between what is technically feasible and the needs identified by actors.

2.1 Interaction with actors within FarFish consortium

The interaction with actors that are already involved in FarFish took advantage of the physical meetings already undertaken by the consortium, namely the Kick-off meeting at the start of the project and the Work package- & case study leader meeting that was held when the project had been running for six months:

2.1.1 Kick-off meeting in Vigo

This meeting was held in June 2017 and it was an initial contact with all partners in the consortium, including members of the private sector like ANFACO-CECOPESCA and OPROMAR as, well as public bodies like the Seychelles Fishing Authority and CRODT. In addition to the information gathered about their expectations with regard FarFish through personal contacts as well as from their formal presentations, the agenda of the kick off included *ad hoc* sessions where the work package leaders and the case study leaders could directly interact. Since WP2 and WP6 have important technical linkages, to optimize operability, it was decided that these two WPs will meet together with the case studies. This was a very good opportunity to have a first and direct feedback from the case study leaders and their technical expectations for the tools. Several conclusions could be extracted from these interactions:

- There are cases where new stock assessment models for the key species are not needed since the actors already rely in the existing tools. This is for instance the case of tuna fishery in the Atlantic and Indian oceans.
- There was a need to differentiate hake stocks in NW Africa.
- There is a need to gather information from the SE Atlantic case study.

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- There is a need to diagnose the impact of non-EU countries in SW Atlantic and probably also in other case studies where EU fisheries may represent a small component of the effort. The lack of information for some fleets (e.g. China, Taiwan, Korea or Russia) hinders any rigorous understanding of the effect of the fishery on the stocks and ecosystems.

2.1.2 Case study and work package leaders meeting in Faro

This meeting was held in November 2017. Although the meeting was primarily intended for the Investigative Team formed by WPs 2, 3 and 4, as an *ad hoc* procedure to interact with case study leaders, since it was hosted at the location of the institution leading WP2 (University of Algarve) and close to the location of the institution leading WP6 (ICMAN-CSIC at Cádiz), the opportunity was used by WP2 and WP6 to meet with the leaders of the different case studies. The meeting resulted in a concomitant input reinforcing the four points identified above during the kick-off meeting. In addition, the leader of the Mauritanian case study identified their interest in further research on mid-trophic level fisheries.

2.2 Interaction with actors that are not partners of FarFish consortium

The interaction with actors outside of FarFish consortium benefitted from the process initiated in WP4 to define the version zero of the management plan (D4.1 - MP0). This joint work between WP4 and WP6 helps to prevent stakeholder fatigue and provides coherence to the whole exercise with objectives defined in MP0 that are associated to tools that are feasible and relevant to the case studies. During this process, interactions through emails with case study leaders was also constant, as well as with the leader of WP2, since some of the tools that were identified in the process demanded gathering and/or processing of additional data.

2.2.1 ICCAT and IOTC

Of the necessary interactions with actors outside of the consortium, it was of particular relevance to communicate with ICCAT and IOTC. These RFMOS are members of the FarFish reference group and the members of FarFish consortium had pointed out potential overlapping of FarFish with the work already being conducted; specifically in regards to the Cape Verde and Seychelles case studies. Formal communications were held through email with a joint message sent by Javier Ruiz (leader of WP6) and Nina Mikkelsen (WP4) to ICCAT and IOTC with a request for identifying what tools FarFish could generate that could add value to the present work conducted in the RFMO. Feedbacks from both bodies was very kind, efficient and positive towards FarFish strategy and contained a very useful input of what these two regional bodies consider as relevant added value. The feedback from Mr. Chris O'Brien (Executive Secretary) after consultation with the IOTC Secretariat identified the following components in his communications:

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- Any work that will contribute to improved compliance is welcomed.
- The team thought that the issues below, as they relate to Seychelles might be worth examining:
    - The assessment of the sustainability of non-target species included in the recent discard ban (17/04) that are not currently assessed (e.g. dolphinfish, wahoo, barracuda, rainbow runners).
    - Analysis of the economic and social impacts of the discard ban (17/04).

The feedback from Mr. Paul de Bruyn (By-Catch Coordinator, at Department of Research and Statistics, ICCAT) identified the following components:

- Collection of data is fundamental to the management of the stock in the area, both by-catch and target. My only comment about this point is that HCRs for by-catch of a pelagic species in particular would need to be done on a regional level, not solely for a national fishery, particularly if the HCRs are to be model based (HCRs based on an operating model linked to an assessment) and not empirical (e.g. If catches exceed xx tonnes reduce effort by xx). Pelagic species are affected by a diverse range of fleets over a wide area, and so localized HCRs are somewhat limited in their effectiveness. It would be more productive for the data collected to be shared with RFMO working groups (including the participation of the scientists who collected them), where they can then be integrated into a more universal/regional study.
- Monitoring Control, and Surveillance matters are of course fundamental to sound fisheries management. This is a very important point and any method to increase compliance is welcomed.

As can be seen from these inputs, in both cases, and in concomitance with the feedback received by the relevant CS leaders, increased compliance and bycatch are considered as element of interest.

2.2.2 CECAF

The Fishery Committee for the Eastern Central Atlantic (CECAF) was approached formally through emails by the FarFish coordinator and in a more informal way by WP6 since one of the technical members (Eva García) usually attending the meetings is in Cádiz, location of the institution leading WP6. This was a face to face meeting held in November 2017 after Ms. García very kindly accepted a request to have the meeting. The input received was also efficient and helpful and seems to indicate that the stock assessment models presently used for assessment (BIODIM) already extract the maximum information from the stock given the existing data, and that this has been confirmed by an external evaluation of the procedures implemented. It also seems that any tool helping to speed up and enrich the present efforts could be a relevant added value.

An additional source of regional information was obtained by consultation of the last report from the Joint Scientific Committee on the Fisheries Agreement between the Islamic Republic of Mauritania and the European Union. In coherence with the inputs received by the Mauritanian case study leader, the report identified mid trophic levels as stocks in need of more research efforts and, in particular, the impact of oceanographic fluctuations on the size of the population. Reports from the FAO/CECAF Working Group on the Assessment of Demersal Resources- Subgroup North were also examined.

2.2.3 Global Fishing Watch

Given the feedback obtained by members inside and outside of the consortium, and in particular given the request for compliance, it was considered convenient to approach the international program Global Fishing Watch. This is a program conducted by several institutions, including private partners like Google or NGOs like Oceana. The program is collecting high spatial and temporal resolution data of fishing efforts worldwide through the use of AIS records obtained from communication satellites. In March 2018, Global Fishing Watch acknowledged FarFish as a scientific collaborator and gave FarFish access to their fishing effort data.

2.2.4 NOAA

In the same line of developing tools to support compliance, and although it did not involve any formal or informal communication, WP4 has explored NOAA online archives to ensure access so sensitive satellite information able to detect individual vessels from the space by mean of advanced image processing techniques. This information will also be available to FarFish

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3 Tools per case study

As described in the previous sections, identification of the tools involved interaction with multiple actors within and outside the consortium. It also implied a tight coordination between WP2 and WP4. WP2 will be assessing the stock assessment models available in each case study. It is also in charge of biological and ecological data for the FFDB and data that will be feeding some of the tools implemented in WP4. On the other hand, the development of the different management plan recommendations (MPRs) in WP4 demands a coherent frame between the objectives and the necessary tools to achieve these objectives.

Table 1 shows a synthesis incorporating all these elements in each CS. It identifies the MP0 objective where this type of tools is demanded and the necessary inputs from WP2, data in a particular format, in order to implement the tool. The table also distributes the workload among the partners involved and identifies a set of risks.

FarFish is working under a co-creation frame where the tools to be produced are the result of the dialogue described above among actors involved in the spiral procedure for implementing Responsive Fisheries Management System. This implies that some of the requests received in the consultation process were not foreseen at the time of writing the proposal; otherwise it would not be a credible co-creation. However, it also implies higher risks and flexibilities during the implementation phase since some of the tools demanded might have difficulties to be achieved.

An example is the request to differentiate stocks of hake in NW Africa which demands collection and analysis of data from black hake catches at sea. This demand is the result of the consultation process and, therefore, emerged during the implementation phase of FarFish. Partners in WP6 are presently looking for this expertise as inputs from outside the consortium, but it is not fully sure that collection and analysis of data from black hake catches at sea. Another feature of Table I is that it allows to classify the diversity of tool demands that have been received during the consultation period into five basic sets, namely:

1) Model implementation to evaluate 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

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Table 1. Schematic view of the potential tools to be developed of WP2 and WP4, including partners and risks involved

Demands from MP0	Demands to WP2	Potential tools	Partners	Risks
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, STL	Not enough sensitivity and/or resolution
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
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools.		Satellite remote sensing & AIS	CSIC, STL	Not enough sensitivity and/or resolution
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 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
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools.		Satellite remote sensing & AIS	CSIC, STL	Not enough sensitivity and/or resolution

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Demands from MP0	Demands to WP2	Potential tools	Partners	Risks
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 Further formal contacts with CECAF may identify further tools.
Mauritania				
Advanced knowledge on how the signal of oceanographic processes affects the shrimps 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 mid-trophic stock dynamics in an oceanographic context	CSIC CCMAR	No neat assessment is achieved
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
Contribute to better compliance in the area by supporting enforcement by utilizing latest available satellite systems and tools		Satellite remote sensing & AIS	CSIC, STL	Not enough sensitivity and/or resolution

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4 Tool families

As described in the previous section, the tools demanded during the consultation can be classified in the five sets described below.

4.1 Data Limited Methods

Despite the important economic and social importance of fisheries worldwide, only 80% of world catches come from species for whether current catch levels are sustainable (Costello et al., 2012). This highlights the need for tools that are able to be applied even under conditions where little data (frequently only catch and more rarely effort) and technical expertise is available. A reference for sustainability is available through these tools to managers even in conditions of poor data and expertise. Owing to this overall situation, on the basis of methods described in Carruthers et al. (2014), a collaboration between the University of British Columbia's Fisheries Centre and the Natural Resources Defence Council (NRDC) developed a data limited toolkit formalized as the DLMtool R package. This is an add-on which fully complies with the four conditions identified as necessary in the introductory section of this deliverable for the tools to be implemented in FarFish: it does not demand high technical skills, it is open access at free platforms and it will remain after the project.

The tool contains a set of methods commonly used and it will be implemented in coordination with the data gathered in WP2 for the cases identified in Table 1. Table 2 synthesizes the methods to be implemented, more detail can be found in Newman et al. (2014), and below is a brief description of some of the most used methods:

- *Beddington and Kirkwood Life-History Analysis (BK):* The method provides a TAC value given by the product of an approximation of F_{MSY} and an estimated current biomass (B). Abundance can be approximated by using a catch curve analysis (Beverton and Holt, 1957) or mean-length analysis (Gedamke and Hoenig, 2006) while F_{MSY} is calculated as described in Beddington and Kirkwood (2005), as follows:
$$F_{MSY} = \frac{0.6k}{0.67 - L}$$
where k is the estimated growth rate and L is the estimated length at first capture, measured relative to Linf .

- *Surplus Production MSY (SPMSY):*

  This is a catch-based method described in Martell and Froese (2013). This method requires a time series of catches, the growth rate, the maximum age, the time required to achieve a length equal to L_{50}/Linf and a range of stock sizes at the first and final year of the catch data time series. An initial population range between 0.5 and 0.9 would imply that the stock is between half and 90% of carrying capacity at the beginning of the time series. The first step in this method is to estimate the rate of population increase, r, sampling from a uniform distribution the limits of which are set on the basis of growth rate, maximum age and the time required to achieve length equal to L_{50}/Linf. After that the carrying capacity value, K, is sampled from a uniform distribution $unif(\frac{\bar{C}_y}{r}, 10\frac{\bar{C}_y}{r})$, where $\bar{C}_y$ is the mean value of the catches time series and r the rate calculated in the previous step. With those values the initial population status, B_1, is defined as follows:

  $$B_1 = \lambda_0 K$$

  Where λ_0 is a value sampled randomly from the interval with bounds defined by the initial population range and K, as it was defined before.

  The annual biomass in next years is calculated using a Schaefer production model, where the observed catch is subtracted from the biomass at the start of the year, as follows:

  $$B_{y+1} = [B_y + r + B_y (1 - B_y/K) - C_{y+1}]/K$$

  This procedure is repeated several times and then a Bernoulli distribution is used for discriminating against which values of r and K provide biomass time series, $\mathbf{B}_Y$, with values below the carrying capacity and above 0, and with values for initial and final population between the initial and final stock range. For each of these combinations a TAC value can be calculated with the following equation:

  $$TAC = K * B_Y * r/2$$

  where B_Y is the value corresponding to the last year in time series $\mathbf{B}_Y$.

- *Demographic FMSY (*Fdem)

  The Fdem method is a management procedure that provides a TAC given by the product of estimated F_{MSY} and current biomass (*B*). The F_{MSY} is approximated by r/2 with r as the rate of population increase. This rate is estimated using the following equation presented in McAllister et al. (2001) (suggested by the first time by Lotka in 1907):

  $$\sum_{a=0}^{A} e^{-ra} l_a m_a = 1,$$

  where, l_a represents the female survival rate from age 0 to age *a*, m_a is the fecundity at age and A, the maximum age. Survival can be obtained from female natural mortality (M_a), as: $S_a = e^{-M_a}$, and m_a can be expressed as a function of weight at age (w_a), proportion of individuals mature at age a (g_a) and the fecundity of those mature at age a (f_a). Weight at age can be approximated with the weight at length relationship, the proportion g_a using the inverse form of the Von Bertalanffy growth function (specified Linf ,k, t_0 and L_{50}) and the fecundity f_a is calculated with a form of Beverton-Holt stock-recruitment curve using the following equation:

$$f_a = \frac{1}{SBPR(1-h)/(4h)}$$

where *h* is the estimated steepness parameter and *SBPR* is the spawner biomass per recruitment calculated as a function of l_a, w_a and g_a .

The current biomass (*B*) can be approximated by using a catch curve analysis (Beverton and Holt, 1957) or mean-length analysis (Gedamke and Hoenig, 2006).

Table 2: Summary of selected data limited methods in the data limited toolkit with description and source of information (more complete descriptions can be found in Newman et al., 2014.

Method	Variation	Source
Depletion-Based Stock Reduction Analysis	DBSRA	Dick and MacCall (2011)
Depletion-Corrected Average Catch	DCAC	MacCall, (2009)
Beddington and Kirkwood - Life-History Analysis	BK	Beddington and Kirkwood (2005)
FMSY To M Ratio (F_{RATIO})	F_{RATIO}	Walters and Martell (2002)
Surplus Production MSY	SPMSY	Martell and Froese (2013)
Yield Per Recruit Analysis	YPR	Beverton and Holt, (1957)
Surplus Production Stock - Reduction Analysis	SPSRA	McAllister et al. (2001)
Demographic F_{MSY}	F_{DEM}	McAllister et al. (2001)

The scientific literature on data-limited methods is increasing exponentially owing to their large need of applying rigorous methods for sustainable fisheries, even in conditions where data and expertise are not optimal. Thus, in addition to the methods identified in the DLM toolkit, we will explore the compliance of other tools with the four conditions identified earlier, for being useful to FarFish goals. Among these tools, we will explore others like those described in Rosenberg et al. (2014), like the Catch-only-model with sampling-importance resampling (COMSIR, Vasconcellos, M. and Cochrane, K., 2005) and the State-space catch-only model (SSCOM, Thorson et al., 2013) or the more recent Refined ORCS (Only reliable catch stocks) approach (Free et al. 2017).

4.2 Big-Data analysis from satellite in support of compliance.

4.2.1 Automatic Identification System (AIS)

Automatic identification system (AIS) broadcast at regular intervals, via a VHF transmitter, information on vessel identity, position, velocity or navigational status. AIS was designed as a navigational aid, so that the transmitted information is received by AIS transceivers fitted on other ships or on land-based systems. When it was developed in the 1990s and owing to its VHF transmission with a coverage within the visual range, it was not anticipated to be detectable from space. However, companies and government programs have later deployed AIS receivers on satellites. Thus, companies like ORBCOMM operate a global satellite network equipped with AIS receivers, as well as the necessary

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elements to report this information to land. This capacity to receive AIS messages from space is presently growing in a very fast manner, since it allows worldwide vessel control in quasi real-time and the logistic management of fleets by cargo companies. Since AIS is required on vessels exceeding 300 Gross tonnes, it also brings new opportunities to survey fishing activities at a scale that was totally unforeseen only a few years ago. This opportunity has already been demonstrated by the Global Fishing Watch project. With the support of partners like Google or Oceana, this program aims at increased transparency, and therefore compliance, of fishing activities worldwide. The recent publication (Kroodsma et al. 2018) resulting from this project very neatly evidences the power of this information in surveying fishing activities at a planetary level.

Since FarFish has case studies that are in remote places, e. g. SE Atlantic, and with difficulties to conduct *in situ* surveillance by the corresponding authorities, this could be a useful tool to assess fishing activities, not only at the planetary level but also at the level of interest to FarFish case studies. It could also help in support of the case studies that, although not so remotely located, involve a large area which present difficulties for continuous *in situ* surveillance. To this aim, WP6 contacted Global Fishing Watch with a request to use their information in the context of the FarFish project. On February 26 of 2018 an important pool of data with more than 2.89 Gbit was released to FarFish. This includes archives with fishing effort and vessel presence binned into grid cells 0.01 degrees on a side and measured in units of hours. Fishing activity is identified via a neural network classifier and vessel registry databases. The neural net classifies fishing vessels into six categories:

- Drifting longlines
- Purse seines, both pelagic and demersal
- Trawlers
- A category that includes set longlines, set gillnets, and pots and traps
- Squid jiggers, mostly large industrial pelagic operating vessels
- A combination of vessels of unknown fishing gear and other, less common gears such as trawlers or pole and line

Data are provided under the following table structure:

- Date.
- Latitude of the southern edge of the grid cell, in 100ths of a degree.
- Longitude of the eastern edge of the grid cell, in 100ths of a degree.
- Flag state of the fishing effort.
- Gear type.
- Hours that vessels of this gear type and flag were present in this grid cell on this day.
- Hours that vessels of this gear type and flag were fishing in this grid cell on this day.
- Number of mmsi of this flag state and gear type that visited this grid cell on this day.

The database received incorporates these data for the whole ocean between years 2012 and 2016. It therefore represents a huge source of information at high spatial and temporal resolution, and with a wide spatial and temporal coverage.

Since this information was received very recently, WP6 is now exploring its potential in support of compliance for the FarFish case studies. The envisaged tool will incorporate the following components:

- Detailed focus on the region of interest to CS
- Implemented on open-access schemes
- Equal footing operability
- Facilitate comparison of AIS versus declared effort data

Despite the potentials contained in this Big-Data set, there are still limitations in the information received to get the full power that could be extracted to AIS data for the generation of tools in support of compliance; namely:

- Although with high spatial and temporal resolution, the received data are aggregated. The agreements between ORBCOMM and Global Fish Watch do not allow the later to provide to third parties the individual vessel messages transmitted by AIS. Therefore, individual vessels cannot be identified in the database.
- Data are not provided in a real-time fashion and it takes several months before the effort data is released by Global Fish Watch. This prevents the use of these data to undertake immediate actions in favour of compliance to the responsible institutions.
- Fishing vessels are becoming increasingly aware of the fact that they can be detected through AIS even when in remote places where in situ vigilance is difficult. Although switching off the AIS transmitter for vessels above 300GT is a manifest violation of the Regulation 19 of Chapter 19 of the International Convention for the Safety of Life at Sea (SOLAS), there seems to be increasing evidence that some vessels are switching their AIS off when involved in certain fishing activities. This seems to be more the case for the fishing vessels from less compliant flags.

The first two limitations affect only the Global Fishing Database owing to its contract with ORBCOMM. However, if the price for this information (AIS messages gathered by satellites) is paid, access in real-time and for individual vessels can be obtained either from ORBCOMM or from other companies or reseller such as Marine Traffic (www.marinetraffic.com). WP6 will explore the possibility to create tools for the use of this information in case the actors involved show interest in paying for it. The last limitation is an imponderable since a switched off transmitter means no access to effort data. There are, however, further possibilities to use advances in satellite technology to gather information under these circumstances. These are explored in the following paragraph.

4.2.2 *Visible Infrared Imaging Radiometer Suite (VIIRS)*

It has been known for several decades that satellites can see lights of fishing vessel operating during the night. However, it is not until the launching of VIIRS that recording this information became available at resolutions high enough to be useful in assessing fishing efforts. Thus, the VIIRS day/night band (DNB) collects low light imaging data with a pixel footprint 742 x 742 m and 14 bit resolution. Although, obviously, this spatial resolution is not enough to identify individual vessels (by name or number) it can detect the light they emit at night. The analysis of this information has proven useful to asses fishing activities, in particular for intensely lit vessels. Although the present capacity, in terms of spatial resolution and intensity of light detected, is still too low to detect all fishing activities at vessel level, this is a technology in expansion and the present generation of VIIRS detectors has evidenced much more capacity than the precedent OLS to detect fishing activities (Elvidge et al. 2015). Consequently, it will become a tool of increasing power to detect both legal and illegal activities at sea.

However, as with AIS data, as sensors in satellites increase their time and space resolution as well as their sensitivity, the information provided becomes Big-Data whose full potential can only be obtained by intelligent algorithms for analysis. Thus, the basic data unit of VIIRS data is an aggregate spanning an area 3,000 km wide and 2,600 km high. The data volume for a DNB aggregate is 540 MB. It is necessary to develop an automatic system for reporting locations of boats from VIIRS data. This algorithm will follow the lessons learnt in implementing similar detection techniques (see Figure 1 as an example). WP6 has already investigated NOAA availability of information, which is provided online. SNPP VIIRS DNB image data can be downloaded from NOAA Comprehensive Large Array Data Stewardship System (CLASS), http://www.class.ngdc.noaa.gov/ and are available generally within three hours of an overflight of the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite (Figure 2). The VIIRS DNB layer is created using a sensing technique designed to capture low-light emissions under varying illumination conditions and is displayed as a gray-scale image that can be subsequently processed to extract the necessary information.

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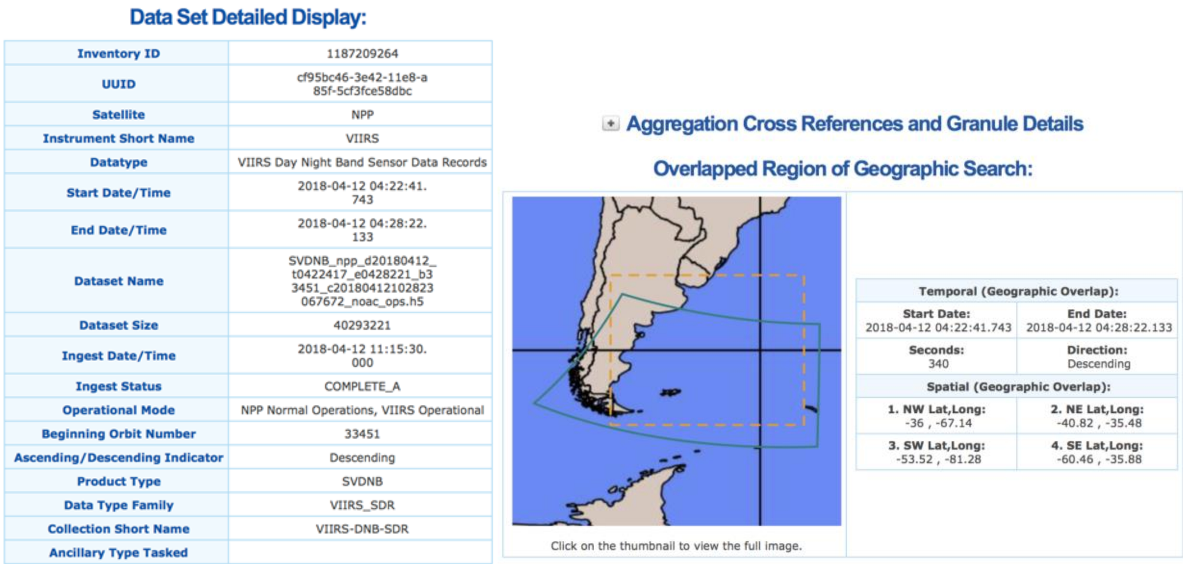
Figure 1. Example of algorithm to detect fishing activity VIIRS data (Elvidge et al. 2015).



Data Set Detailed Display:

Inventory ID	1187209264
UUID	cf95bc46-3e42-11e8-a 85f-5cf3fce58dbc
Satellite	NPP
Instrument Short Name	VIIRS
Datatype	VIIRS Day Night Band Sensor Data Records
Start Date/Time	2018-04-12 04:22:41. 743
End Date/Time	2018-04-12 04:28:22. 133
Dataset Name	SVDNB_npp_d20180412_ t0422417_e0428221_b3 3451_c20180412102823 067672_noac_ops.h5
Dataset Size	40293221
Ingest Date/Time	2018-04-12 11:15:30. 000
Ingest Status	COMPLETE_A
Operational Mode	NPP Normal Operations, VIIRS Operational
Beginning Orbit Number	33451
Ascending/Descending Indicator	Descending
Product Type	SVDNB
Data Type Family	VIIRS_SDR
Collection Short Name	VIIRS-DNB-SDR
Ancillary Type Tasked	

Aggregation Cross References and Granule Details

Overlapped Region of Geographic Search:

Temporal (Geographic Overlap):	
Start Date: 2018-04-12 04:22:41.743	End Date: 2018-04-12 04:28:22.133
Seconds: 340	Direction: Descending
Spatial (Geographic Overlap):	
1. NW Lat,Long: -36 , -67.14	2. NE Lat,Long: -40.82 , -35.48
3. SW Lat,Long: -53.52 , -81.28	4. SE Lat,Long: -60.46 , -35.88

Click on the thumbnail to view the full image.

Figure 2. Example of data set availability for the region of interest where SW Atlantic is located

Despite the significant limitations these techniques still have in terms of resolution and sensitivity, the implementation of the algorithm, and in conjunction with the analysis of AIS information, is expected to produce a contrast between AIS and VIIRS information. This contrast has the potential to diagnose the existence of dark fishing activities, i. e. activities that occur with the AIS transmitter switched off.

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4.3 Oceanographic support to stock dynamics

Small species with short life span are very sensitive to environmental fluctuations. In many cases their landings are based on recruitment, which increases their sensitivity to the forcing of the physical environment since the permanence of the stocks relies on the survival of early stages rather than on adults with higher resilience against the forcing. This tight dependence of the physical environment results in vulnerabilities that may emerge from synergies between fishery exploitation and adverse environmental conditions. Mid-trophic species in NW Africa are likely to suffer these types of synergies. Thus, they are short-lived species whose life cycle is embedded in a very dynamic environment such as the region in NW Africa, where the subtropical Canary Current (one of the four major upwelling systems in the world) and the tropical Mauritanian-Cape Verde currents meet to form the North Equatorial Current. Complex 3-D circulation processes, including surface southward and deep poleward currents, control the biological productivity and the physical environment of this region. This includes the demersal zone where shrimp and octopus live. Large scale fluctuations such as the Azores subtropical high or the monsoons force the oceanography of the region and their signals are ultimately transferred into landing changes, in particular for short-lived species. Understanding this process is essential to create a frame where the fishery can be better managed and where biological and economic vulnerabilities can be minimized. Therefore, WP6 will create the knowledge where these short-lived species in Mauritania can be understood in the oceanographic frame of the region and where biological and economic vulnerabilities can be assessed. The procedure will follow that already implemented for small species in the past (Ruiz et al. 2017) during the FP7 project MareFrame, with similar expected outputs as tools for the involved actors.

4.4 Tools to differentiate hake stocks in NW Africa

There are two species of black hake distributed in Moroccan, Mauritanian and Senegalese waters; the Senegalese hake *Merluccius senegalensis* and the Benguela hake *Merluccius polli* (also called tropical African hake). The two species belong to different Euro-African lineages of hakes confirmed by mitochondrial sequences and nuclear 5S rDNA (Campo et al. 2007), but their morphological similarity and co-occurrence in catches has hindered correct and reliable sorting into species on-board. Therefore, *M.polli* and *M.senegalensis* are managed together as one single species *Merluccius* (FAO 2016). In addition to the directed fishery, the black hake species constitute a significant part of the bycatch of cephalopod boats, shrimpers and trawlers (FAO 2016).

Stock structure for each species throughout the region is not well known because there are no available studies on identities (Fall et al., 2016), and assessment are therefore artificially carried out by each country (Fernández-Peralta et al. 2017). According to inspections by IEO scientific observers in 2002 and 2012, the *M. Polli* makes up more than 90 percent of the catches in Mauritanian waters (FAO 2016). Although stock differentiation of black hake is a poorly researched issue, recent studies

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on the biology of *M. senegalenis* and *M. polli* have provided new evidence on the life strategies of both hake species, which combined with identified migration patterns supports separate assessment of the species (Fernández-Peralta et al. 2017), which will enhance the long term sustainability of the black hake fishery in the region.

The two species can be separated by morphological and meristic characteristic by trained personnel. Morphologically, the position of the mouth differs between the two, as does some colorization. The two species can also be separated by the number of gill rakes. Owing to this potential for separation, the following actions are proposed as complementary tools to existing knowledge with the aim of differentiating the stocks:

1) In coordination with WP2, developing a template for self-sampling by the fleet in accordance with RMFS approach, and the fleet will be asked to collect data for catch composition (stock differentiation).
2) In coordination with WP7, relevant actors will be trained to perform this stock identification through different training programmes developed within the project.
3) In coordination with WP2, to encourage scientific studies for stock identification of black hakes in NW African waters to reduce or close these major knowledge gaps, combining several methods, potentially revealing if there are separate sub-populations with different life history characteristics which might separate the assessment in separate coastal stocks. For example, the coastal cod managed separately in Norwegian waters, where the Northeast arctic cod dominate by abundance and distribution. These stocks belong to the same species, have seasonal overlap in distribution, but are reproductive isolated and have different life history characteristics.

4.5 Visualization tools

Visualization tools are described in detail at D6.3, the work conducted here is aimed at guarantying the visualization link of the different tools described here. In particular, it is expected to project outputs on visualization maps as outcomes of the focus of AIS big-data as well, as the output of the DLM.

5 Discussions

This report describes the decision support tools that have initially been identified for development in the FarFish project. This is though only a preliminary list of tools, as the FarFish project is organised in accordance with the spiral development model, which means that the project will go through several iterations on its way that will allow project partners to amend their “direction” in accordance with the knowledge gathered. This iterative component of the spiral procedure means that the tools discussed in this report may not be definitive and the composition may be modified if the actors involved demand further alternatives or when the tools developed turn out to be not applicable e.g. due to lack of data or relevance.

The tools identified within this report will now be developed in co-creation with the intended users; both within the FarFish consortium and with stakeholders outside the project. The results from that work will then result in reassessment of the tools and their applicability, relevance, added value and usefulness.

References

Beddington, J. R., & Kirkwood, G. P. (2005). The estimation of potential yield and stock status using life-history parameters. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1453), 163–170. https://doi.org/10.1098/rstb.2004.1582

Beverton, R. J. H, & Holt, S. J. (1957). *On the dynamics of exploited fish populations*. London : Her Majesty's Stationery Office. Retrieved from https://trove.nla.gov.au/version/29836762

Campo D, Machado-Schiaffino G, Perez J, Garcia-Vazquez E. (2007). Phylogeny of the genus Merluccius based on mitochondrial and nuclear genes. *Gene 406*,171-179.

Carruthers, T. R., Punt, A. E., Walters, C. J., MacCall, A., McAllister, M. K., Dick, E. J., & Cope, J. (2014). Evaluating methods for setting catch limits in data-limited fisheries. *Fisheries Research*, *153*, 48–68. https://doi.org/10.1016/j.fishres.2013.12.014

Costello, C., Ovando, D., Hilborn, R., Gaines, S. D, Deschenes, O., & Lester, S. E. (2012). Status and Solutions for the World's Unassessed Fisheries. Science, 338(6106), 517-520. doi: 10.1126/science.1223389

Dick, E. J., & MacCall, A. D. (2011). Depletion-Based Stock Reduction Analysis: A catch-based method for determining sustainable yields for data-poor fish stocks. *Fisheries Research*, *110*(2), 331–341. https://doi.org/10.1016/j.fishres.2011.05.007

Elvidge, C. D., Zhizhin, M., Baugh, K., & Hsu, F.-C. (2015). Automatic Boat Identification System for VIIRS Low Light Imaging Data. *Remote Sensing*, *7*(3), 3020–3036. https://doi.org/10.3390/rs70303020

Fao (2016). Report of the FAO/CECAF Working Group on the Assessment of Demersal Resources – Subgroup North. Fuengirola, Spain, 18–27 November 2013. Rapport du Groupe de travail FAO/COPACE sur l'évaluation des ressources démersales – Sous-groupe Nord. Fuengirola, Espagne, 18-27 novembre 2013. In: CECAF/ECAF Series/COPACE/PACE Séries, Rome, Italy/Italie.

Fernández-Peralta, L., L.F. Quintanilla, and J. Rey (2017). Overlapping Distribution of Two Sympatric Species: The Case of Black Hakes, Merluccius polli Cadenat 1960 and Merluccius senegalensis Cadenat 1960, Off Mauritania, in Deep-Sea Ecosystems Off Mauritania. Springer. p. 241-275.

Free, C.M., Jensen, O.P., Wiedenmann, J. & Deroba, J.J. (2017) Refined ORCS approach: A catch-based method for estimating stock status and catch limits for data-poor fish stocks. Fisheries Research 193:60-70. http://dx.doi.org/10.1016/j.fishres.2017.03.017

Gedamke, T., & Hoenig, J. M. (2006). Estimating Mortality from Mean Length Data in Nonequilibrium Situations, with Application to the Assessment of Goosefish. *Transactions of the American Fisheries Society*, *135*(2), 476–487. https://doi.org/10.1577/T05-153.1

Kroodsma D.A., Mayorga J., Hochberg T., Miller N.A., Boerder K., Ferretti F., Wilson A., Bergman B., White T.D., Block B.A., Woods P., Sullivan B., Costello C., Worm B. Tracking the global footprint of fisheries. Science. 2018, 359(6378):904-908. doi: 10.1126/science.aao5646.

MacCall, A. D. (2018). Depletion-corrected average catch: a simple formula for estimating sustainable yields in data-poor situations, 5.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 727891.
www.farfish.eu

Martell, S., & Froese, R. (2013). A simple method for estimating MSY from catch and resilience. *Fish and Fisheries*, *14*(4), 504–514. https://doi.org/10.1111/j.1467-2979.2012.00485.x

McAllister, M. K., Pikitch, E. K., & Babcock, E. A. (2001). Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. *Canadian Journal of Fisheries and Aquatic Sciences*, *58*(9), 1871–1890. https://doi.org/10.1139/cjfas-58-9-1871

Newman, D., Carruthers, T., MacCall, A., Porch, C., & Suatoni, L. (n.d.). Improving the Science and Management of Data-Limited Fisheries: An Evaluation of Current Methods and Recommended Approaches, 38.

Rosenberg, A.A., Fogarty, M.J., Cooper, A.B., Dickey-Collas, M., Fulton, E.A., Gutiérrez, N.L., Hyde, K.J.W., Kleisner, K.M., Kristiansen, T., Longo, C., Minte-Vera, C., Minto, C., Mosqueira, I., Chato Osio, G., Ovando, D., Selig, E.R., Thorson, J.T. & Ye, Y. (2014). Developing new approaches to global stock status assessment and fishery production potential of the seas. FAO Fisheries and Aquaculture Circular No. 1086. Rome, FAO. 175 pp.

Ruiz, J., Rincón, M.M., Castilla, D., Ramos, F., del Hoyo, J.J.G. 2017. Biological and economic vulnerabilities of fixed TACs in small pelagics: An analysis of the European anchovy (Engraulis encrasicolus) in the Gulf of Cádiz. Marine Policy, 78: 171–180.

Thorson, J.T., Minto, C., Minte-Vera, C.V., Kleisner, K. , & Longo, C. (2013). A new role for effort dynamics in the theory of harvested populations and data-poor stock assessment. Can. J. Fish. Aquat. Sci., 70, 1829-1844.

Vasconcellos, M. & Cochrane, K. (2005). Overview of world status of data-limited fisheries: inferences from landings statistics. Pages 1-20 in G.H. Kruse, V.F. Gallucci, et al. editors. Fisheries assessment and management in data-limited situations; proceedings ; Lowell Wakefield Symposium, 21, Anchorage, AK (USA), 22-25 Oct 2003 . Alaska Sea Grant College Program, Fairbanks, AK.

Walters, C., & Martell, S. J. D. (2002). Stock Assessment Needs for Sustainable Fisheries Management. BULLETIN OF MARINE SCIENCE, 70(2), 10.

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