Specific Contract No 1

FRAMEWORK CONTRACT

EASME/EMFF/2016/008

Improving scientific advice for the conservation and management of oceanic sharks and rays

Final Report

Written by R. Coelho (IPMA), P. Apostolaki (MRAG), P. Bach (IRD), T. Brunel (IMARES), T. Davies (MRAG), G. Díez (AZTI), J. Ellis (CEFAS), L. Escalle (IRD), J. Lopez (AZTI), G. Merino (AZTI), R. Mitchell (MRAG), D. Macias (IEO), H. Murua (AZTI), H. Overzee (IMARES), J.J. Poos (IMARES), H. Richardson (MRAG), D. Rosa (IPMA), S. Sánchez (AZTI), C. Santos (IPMA), B. Séret (IRD), J. O. Urbina (IEO), N. Walker (CEFAS)

January – 2019

EUROPEAN COMMISSION

Executive Agency for Small and Medium-sized Enterprises (EASME)
Unit A.3- European Maritime and Fisheries Fund (EMFF)

E-mail: EASME-EMFF@ec.europa.eu

European Commission
B-1049 Brussels

Specific Contract No 1

FRAMEWORK CONTRACT
EASME/EMFF/2016/008

Improving scientific advice for the conservation and management of oceanic sharks and rays

Final Report

Executive Agency for Small and Medium-sized Enterprises (EASME)
European Maritime and Fisheries Fund (EMFF)
2019 EN

LEGAL NOTICE

Luxembourg: Publications Office of the European Union, 2019

ISBN: 978-92-9202-455-0
doi: 10.2826/229340

1. CONTENTS

2. EXECUTIVE SUMMARIES

2.1. *Executive Summary*

The purpose of this specific study is to provide the Directorate-General for Maritime Affairs and Fisheries (DG MARE) with:

- Updated information regarding the association or occurrence of pelagic sharks and rays in different fisheries;
- Updated information regarding data collection and methodological approaches for the assessment of conservation status of sharks;
- A critical review of existing Conservation and Management Measures (CMMs) for sharks and of the current conservation status of the species concerned; and
- Proposals to improve and/or provide alternative options for conservation and management of sharks taking into account any recent methodological advances and new data or information.

The species of interest are the main pelagic sharks caught by pelagic fisheries, including under Sustainable Fisheries Partnership Agreements (longline and purse seine fisheries). The study also considers some pelagic elasmobranchs included in Article 13 (species prohibitions) of the Council Regulation 2016/72 fixing for 2016 the fishing opportunities for certain fish stocks. The main regions focused are the oceanic regions covered by tuna-RFMOs where those species of elasmobranch are represented in the catches, specifically the Atlantic (ICCAT region), the Indian Ocean (IOTC region) and the Pacific (WCPFC and IATTC regions).

The following tasks were addressed under the project:

- Task 1. Update EUPOA sharks study;
- Task 2. Provide a critical overview of recent developments;
- Task 3. Categorise stocks of sharks and rays;
- Task 4. Evaluate methodological approaches;
- Task 5. Compile and analyse existing Conservation and Management Measures;
- Task 6. Analyse best practices and potential alternative measures;
- Task 7. Develop a conceptual framework for management plans;
- Task 8. Organise a workshop;
- Task 9. Implement case studies;
- Task 10. Identify gaps in knowledge.

Task 1. Update of the EUPOA sharks study

Current scientific knowledge on the state of pelagic elasmobranch species by tuna-RFMO was collated and the EUPOA sharks study was updated including data on their state of knowledge and updated the data compilation of the EUPOA sharks study, in terms of historical catch and effort, discards levels; length frequency data, biological information and fishery indicators.

In recent years, there have been improvements in terms of data collection and reporting of shark data. However, current data availability varies substantially depending on the species (major *versus* occasional species) and the specific type of data. Specifically, and while current catch data collection and reporting has improved in recent years, the availability of historical data is still scarce and limits the use of catch time series for assessment purposes.

Species identification is still an issue in some cases, especially when species complexes are reported, as for example in the hammerhead or thresher sharks. Discard data is very poor, often inexistent, and this is an issue where urgent improvements are needed.

Size frequency data has also improved in recent years, especially for the major shark species, and biological information is in general also good for the major shark species. However, there are still data gaps in terms of size frequencies and biological data, especially for the more occasionally elasmobranch species. Critical cases are the manta and devil rays, where biological information is extremely poor.

Indicators have been recently produced for the major shark species for all oceans, mostly for use in the latest stock assessments. Ecological Risk Assessments (ERAs) have also been produced for all oceans. However, for the more occasional species, besides blue and shortfin mako sharks, there is almost no information available that could be used to provide information on the status of those stocks.

Task 2. Critical overview of recent developments

This task undertook a critical review of what has changed and whether improvements were observed regarding data availability, application of assessment methodologies and, adoption and implementation of Conservation and Management Measures (CMMs) for sharks and rays covered in the study.

Shark data availability prior to 2009 varied amongst tuna-RFMO, but since the adoption of the EU Plan of Action for Sharks in 2009 improvements in data collection and availability have been made in all tuna-RFMOs. This includes mandatory logbook reporting of the main species and biological data from observers.

However, and despite the improvement in data reporting requirements, the actual data availability remains poor in all tuna-RFMOs. Historical catches were mostly aggregated in the past, which hampers stock assessments. Additionally, issues like the general lack of discards data, and lack of information on the processing method that can confound what is being reported, further decreases the quality and reliability of data. On this last point, it is noted that the Regulation (EU) No 605/2013 on the removal of fins of sharks on board vessels does not apply to non EU fleets, resulting in those added difficulties for estimating total catches. This lack of complete data sets means that conventional stock assessment methods have not been possible to apply to pelagic sharks, except for the main species. For the other species only data-limited methods or indicator analysis are usually applied.

All tuna-RFMOs have adopted CMMS for sharks management and conservation that theoretically reach all the EUPOA conservation requirements. However, most are difficult to monitor and control, and more research is in general needed to evaluate their impact.

Task 3. Categorisation of stocks of sharks and rays

This task identified and categorised pelagic elasmobranch stocks based on data availability and assessment possibilities, indicating what currently hinders scientific advisory bodies to provide quantitative assessments, and then described additional data needs to improve the assessment of those stocks. For the categorisation, we used the ICES categories where stocks fall within one of six categories, with categories 1-2 referring to "data-rich" stocks and categories 3–6 referring to "data-limited" stocks.

Pelagic elasmobranchs fall mainly under the data-limited categories, particularly categories 3-4, except for the main species (blue shark and shortfin mako) that could in some cases be considered as under categories 1-2. Manta and devil rays are all considered Category 6, as almost no information is available that could inform stock assessments for those species.

Currently, only ERAs can be fully implemented for most pelagic shark species, and have in fact been already carried out for all Oceans. Other methods, either indicators or stock assessment (data-limited or traditional), can be implemented in some cases but with additional estimations and/or substitutions from other Oceans.It is expected that, as more (or higher quality) data becomes available, the trend will be to move from indicator approaches to data-limited assessments and eventually data-rich assessments. We also note that the use of more complex models does not necessarily mean that the assessments are improved, but simply that the methods can use more sources of data. As such, even in cases where complex assessments can be carried out, the quality of the data inputs still remains the most important issue to have in consideration for future improvements.

Task 4. Evaluation of methodological approaches

This task described and evaluated methodological approaches that are used for the assessment of status of data-limited stocks. Specifically, we describe assessment methodologies used for stocks of elasmobranchs, explored alternative methodological approaches that could be considered, outlining strengths and weaknesses, and outlined the improvements needed to transition towards more complex models and/or strengthen the current assessments.

Except for the main species, most of shark species covered by the tuna-RFMOs are not assessed using conventional stock assessment techniques, mostly due to data limitations. Some alternative methodologies that have been employed include ERAs, stock status indicators, maximum impact sustainable threshold, and IUCN Red List criteria.

There is a wealth of other approaches that could also be employed. Those include data-limited assessments as catch-only methods, intermediate assessments as surplus production models, mark-recapture analysis, and more complex and data intensive methods as age or length-structured models. In addition to models simulating the dynamics of the stocks, there is also the option to use Bayesian statistical approaches that can use prior (external) information or testing the robustness of scientific advice through Management Strategy Evaluation (MSE), starting specifically with data-limited MSE approaches.

The main current data limitations relate to catch (i.e., total population removals) and Catch-Per-Unit-Effort (CPUE) data as well as the understanding of biological processes such as natural mortality. Several shark species currently in ICES category 4 or 5 are expected to move one category up if the quality of catch and/or CPUE data improves and some information about biological processes (e.g., productivity) becomes available.

Species in ICES category 3 require a more multifaceted approach to move higher in the ICES scale. This involves improvements in historical catch and effort, better quality of data on biological processes and a broader spectrum of biological parameters (natural mortality, growth, etc.).

As it is not clear whether significant improvement in data can be made in the short term, it might be of more value, as a first step, to support efforts to improve the data that would achieve more robust implementation of the models already used for the assessment of each species.

<u>Task 5. Compilation and analyses of existing CMMs</u>

This task compiled and compared existing Conservation and Management Measures (CMMs) adopted by the various tuna-RFMOs and other relevant international *fora*.

From 2004 to 2016, tuna-RFMOs have set up a considerable number of resolutions on CMMs for sharks and rays specifically eight for IATTC, 12 for ICCAT, eight for IOTC and nine for WCPFC. These resolutions concerns principally input and/or output controls, fishing gear modification, fishing practices and incentives to limit finning and discards.

The prohibition of retention is in place in all oceans for several shark species. There are also regulations for the full utilization of carcasses, usually using a 5% fin/body ratio, and the prohibition/control on international trade regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). There is also a ban of wire leader or shark lines in place in the Pacific Ocean (WCPFC, IATTC).

The control and compliance with those resolutions by the CPCs is complex. There would be the need for compliance officers or other mechanisms to cover fully the fishing activities, using human and/or electronic means. However, it is noted that scientific and compliance duties should be kept as separated tasks.

Wire leader bans have been demonstrated as beneficial for many shark species. However, such measure may have economical impacts on the catches. As such, the benefit for the conservation of shark and ray stocks and for the possible impact on the economy of some pelagic longline fisheries still needs to be investigated. Leader materials should also be considered with regards to the hook type used (J-style *versus* circle hooks), as those interactions are still unknown.

The shark fins to carcass ratios in place in the tuna-RFMOs are highly dependent on factors such as species/genus and cutting/processing practices. The ratio adopted has been generalized to 5%, but the real ratios can range from 1.3% to 10.9%, depending on the species, fish processing method (whole carcass *versus* dressed carcass) and fins processing methods (type of cut and wet versus dried fins). As such, we recommend that the natural (or some artificial) attachment of fins to the body of sharks until the landing points should be adopted CMMS for all tuna-RFMOs, which would more effectively control the ban of finning and would not be constrained by this variability in the ratios. With the fins attached policy there are also added benefits in terms of species identification.

It is also recommended that more CMMs should be based on spatial/temporal closures of fishing for areas with high density of both mature females and juveniles for the most susceptible species. However, it is noted that the proposal of such areas requires much biological and distribution data that is generally not yet available at the tuna-RFMOs. As such, more resources need to be devoted to improve the study on the spatial and seasonal distribution of pelagic sharks.

Finally, we recommend developing a research program to better assess the impact of the combination hook types (circle *versus* J) and leader material (wire *versus* monofilament) on 1) shark retention rates, and 2) at-vessel and post-release mortalities in pelagic longline fisheries. Such study should take into consideration both the impact on the shark bycatch component, as well as on the bony fish species (e.g., swordfish).

Task 6. Analyse best practices and potential alternative measures

This task outlined and analysed best practices and other alternative measures that could be adopted in the short and long term by tuna-RFMOs to reduce catches and/or post-release mortality of unwanted catches of sharks and rays, highlighting their strengths and weakness.

For most of the mitigation measures studied and suggested, many still need more research before being implemented at a commercial level. Some results directly from research have already been adopted by the industry, mainly to set up best practices aiming to enhance the survival of fish discarded (mainly for purse seine fisheries). But in general, more studies are needed and there will be the need to set up incentives to facilitate the adoption of mandatory mitigation measures by the industry.

There are several studies investigating the at-vessel mortality of elasmobranchs for both pelagic longline and purse seine fisheries, but those types of data and studies for gillnet fisheries are crucially lacking.

Post-release mortality data have been collected for some species showing variations depending of biological attributes (species, size, sex and mode of gill ventilation) and factors associated with capture (gear type, soak time, catch mass and composition, handling practices). But in general, there is the need to develop research programs to improve the data collection of post-release mortality, particularly for species banned for retention.

We recommend futher research to better assess the impact on technical mitigation measures for sharks in tuna fisheries, including more studies focused on biodegradable FADs for purse seine, hook type (shape and size) and leader material for longlines, and mesh size and material for gillnet fisheries.

We also recommend the increase of the level of the observer coverage (both human observers and/or electronic monitoring) for all tuna fisheries. However, we also note that within the tuna-RFMOs most CPCs (Contracting Party or Cooperating non-Contracting Party, Entity or Fishing Entity) do not achieve the minimum percentages currently adopted, and in some cases do not have observer programs. As such, a 1st step would be to make sure all main fleets achieve the minimum coverage ratios and submit the data, and then increase the coverage as needed, possibly by complementing with electronic monitoring.

Task 7. Development of a conceptual framework for management plans

This task developed and proposed a conceptual framework for elaborating and implementing management plans for sharks (in line with Article 10 of the Common Fisheries Policy (CFP)), including the development of a list of minimum requirements that such plans should include and guidelines for evaluating such plans. Globally, frameworks for the conservation and management of sharks are mostly underpinned by the FAO's International Plan of Action for Sharks (IPOA-Sharks).

The plans should be developed by individual EU Member States (MSs), but harmonised amongst MSs that cover the same stocks, and should not be limited to fisheries that target sharks but also those that retain or discard shark bycatch. The conceptual objective should refer to biological, economic and social sustainability, and the management plans must fit within the legal framework of any relevant RFMOs and be consistent with Article 10 of the CFP and the objectives of the EUPOA.

Recommendations are made on proposed minimum requirements for management plans including details on the species and ecosystem, overview of the fishery, management objectives, conservation reference points, catch and discard limits, bycatch mitigation, indicators, time frame and, monitoring and evaluation in order to provide feedback and adapt the plans.

Task 9. Case studies

The following case studies were developed during this Project: 1) silky shark - ICCAT, 2) silky shark - IOTC, 3) blue shark - IOTC and 4) shortfin mako - IOTC. The case studies were intended to provide advancements to the scientific working groups of the tuna-RFMOs, and were agreed and chosen because they represent different and various situations.

Case study 1 (silky shark - ICCAT) was chosen because the silky shark is currently a no-retention species in several tuna-RFMOs, including ICCAT. ERAs have been conducted in the Atlantic, but no stock assessments are available or planned by ICCAT. As data for a full stock assessment is not available or likely to be available in the near future, we investigated alternative measures, specifically using EU observer data to map habitat preferences from a set of biotic and abiotic oceanographic factors, providing therefore information on spatio-temporal dynamics of the species and hotspots. The results could be considered for the development of alternative management plans.

Case study 2 (silky shark - IOTC) was chosen because IOTC is currently the only tuna-RFMO where there are no CMMs for silky shark. The IOTC has not yet carried out any stock assessment for this species, and while the Working Party on Ecosystems and Bycatch (WPEB) has a first assessment planned for 2019, there is great uncertainty on what will be actually achieved as data availability by CPCs is thought to be very scarce. Therefore, the rationale for this case study was to serve as a preparation for the IOTC 2019 assessment, exploring what can be done now and what needs to be improved until 2019. We focused on data-limited methods and explored the feasibility to standardize CPUE series for the EU longline fisheries in the region. Currently, for this species and ocean, only data-limited methods with high level of estimations and substitutions can be carried out, but a preliminary stock status was calculated and provided.

Case study 3 (blue shark - IOTC) was chosen as blue shark is the species that can be considered as the most data-rich, within the pelagic sharks. Blue shark is the main pelagic shark captured and landed worldwide in pelagic fisheries, and quantitative stock assessments have been conducted for all oceans, in some cases using data-intensive integrated assessment models. As such, this species was further studied mainly to explore what else would still be needed to further improve the assessments and move forward in terms of advice. Specifically, this case study tested some exploratory management procedures (MPs) to show options/trade-offs and determine which MPs would be more robust and would perform better under the current assessment uncertainties. This case study also focused on exploratory analysis with length based indicators, as alternative methods to the traditional stock assessments. Finally, a draft operational management plan was prepared for this species and region.

Case study 4 (shortfin mako - IOTC) was chosen because this species is very important in EU catches, especially for longline fisheries, being the 2nd most captured and landed shark after the blue shark. Further, the shortfin mako is one of the most vulnerable pelagic shark species, mainly due it's very low productivity and high interactions with the fisheries. Shortfin mako has been assessed in ICCAT in 2017, with very pessimistic stock status and projections. No stock assessments have been yet carried out in IOTC, but the WPEB has planned a first assessment for 2020, and there are already some indicators available, particularly in terms of standardized CPUE series and size data. Therefore, this case study was developed to provide to the IOTC/WPEB a preliminary stock status, in preparation for the 2020 assessment. The methods focused were mainly data-limited approaches, but we also tested more traditional stock assessment methods, specifically production models.

The case studies are provided in a separate volume of this report.

Task 10. Identifying gaps in knowledge

The objective of this task 10 was to identify and prioritise gaps in knowledge and research that could contribute to progress in the implementation of the EUPOA sharks and the MoU Sharks. Research needs to fill gaps that hinder the elaboration of sound scientific advice for the species concerned were identified. This task provided a final revision of all the work carried out for the project, highlighting the current gaps in knowledge and identifying future needs.

Whilst there have been improved assessments of the main oceanic shark species, several key data gaps exist. Although the key data gaps vary between species, stocks and management areas, the following broad areas of work require further data collection (monitoring) and/or research and are considered of high priority: 1) quantitative data on at-vessel and post-release mortality by species and métier, and bycatch mitigation measures; 2) more robust estimates of catch (landings and estimates of dead and live discards), including reconstruction of historical catch scenarios; 3) catch composition data (species, sex and length composition); 4) spatial data (geo-referenced data on species distributions/occurrence and by life history stage); 5) more robust biological parameters (age and growth parameters, natural mortality estimates, reproductive parameters) where current studies are lacking or inadequate; 6) more reliable indices of stock abundance; 7) testing the applicability of recently developed data-limited assessment methods; 8) overall assessment of the status of bycatch sharks and rays that are not currently assessed; 9) development of appropriate management frameworks; and 10) improved evaluation of the stock units, landings, catches and status of oceanic sharks.

Some of these data gaps require dedicated scientific investigations, including either field and/or laboratory studies, some relate to (often ongoing) monitoring programmes, and others relate to studies requiring data compilation and analysis.

2.2. *Resumen Ejecutivo*

El objetivo de este estudio específico es proporcionar a la dirección general de asuntos marítimos y de pesca (DG Mare):

- Información actualizada sobre la asociación u ocurrencia de tiburones y rayas pelágicas en diferentes pesquerías;
- Información actualizada sobre la recopilación de datos y enfoques metodológicos para la evaluación del estado de conservación de los tiburones;
- Una revisión crítica de las medidas de conservación y ordenación existentes (MMC) para los tiburones y del estado actual de conservación de las especies de que se trate;
- Propuestas para mejorar y/o proporcionar alternativas de conservación y géstion de tiburones teniendo en cuenta cualquier avance metodológico reciente y nuevos datos o información.

Las especies en las que nos hemos enfocado son los principales tiburones pelágicos capturados por las pesquerías pelágicas, incluidos en los acuerdos de asociación pesquera sostenible (palangre y pesca cerquera). El estudio también considera algunos elasmobranquios pelágicos incluidos en el artículo 13 (prohibiciones de especies) del Consejo de Regulacion 2016/72 fijando para 2016 las posibilidades de pesca de ciertas poblaciones de peces. Las principales regiones en las que nos centramos son las regiones oceánicas cubiertas por las Organizaciones Regionales de Ordenación Pesquera (OROP) atuneras, donde las especies de elasmobranquios están representadas en las capturas, específicamente en el Atlántico (región de ICCAT), el Océano Índico (región de IOTC) y el Pacífico (regiones de WCPFC y IATTC).

En el marco del proyecto se desarrollaron las siguientes tareas:

- Tarea 1. Actualizar el estudio de tiburones EUPOA;
- Tarea 2. Proporcionar una visión crítica de los acontecimientos recientes;
- Tarea 3. Categorizar las poblaciones de tiburones y rayas;
- Tarea 4. Evaluar enfoques metodológicos;
- Tarea 5. Compilar y analizar las medidas de conservación y gestión existentes;
- Tarea 6. Analizar las mejores prácticas y las posibles medidas alternativas;
- Tarea 7. Desarrollar un marco conceptual para los planes de géstion;
- Tarea 8. Organizar un taller;
- Tarea 9. Implementar casos prácticos;
- Tarea 10. Identificar brechas en el conocimiento.

Actualización del estudio EUPOA tiburones

Esta tarea recompiló el estado de conocimiento de elasmobranquios pelágicos por las OROPs incluyendo su estado de conocimiento y actualizó la compilación de datos del estudio de tiburones EUPOA, en términos de captura y esfuerzo histórico, niveles de descartes; datos de frecuencia de tallas, información biológica e indicadores pesqueros.

En los últimos años se han producido mejoras en términos de recopilación de datos y presentación de informes sobre los datos de los tiburones. Sin embargo, la disponibilidad actual de datos varía sustancialmente dependiendo de la especie (especies principales versus ocasionales) y del tipo específico de datos. En concreto, y si bien la recolección de datos y los informes de capturas actuales tendieron a mejorar en los últimos años, la disponibilidad de datos históricos sigue siendo escasa y limita el uso de series temporales de captura enevaluaciones.

La identificación de especies sigue siendo un problema en algunos casos, especialmente cuando se tratan complejos de especies, como por ejemplo en los de tiburones martillo o trilladoras. Los datos de descarte son muy pobres, a menudo inexistentes en la mayoría de los casos, y este es un problema para el que se necesitan mejoras urgentes.

Los datos de frecuencia de talla también tendieron a mejorar en los últimos años, especialmente para las principales especies de tiburones, y la información biológica es en general también buena para las principales especies de tiburones. Sin embargo, todavía hay falta de datos en términos de frecuencias de tallas y datos biológicos, especialmente para las especies ocasionales de elasmobranquios. Un caso crítico son las rayas manta y diablos donde la información biológica es extremadamente pobre.

Recientemente se han producido indicadores para las principales especies de tiburones para todos los océanos, principalmente para su uso en las últimas evaluaciones de poblaciones. También se han realizado evaluaciones de riesgos ecológicos para todos los océanos. Sin embargo, para las especies más ocasionales, además de los tiburones tintorera y marrajo común, prácticamente no hay información disponible que podría utilizarse para proporcionar información sobre el estado de esas poblaciones.

Revisión crítica del desarrollo actual

Esta tarea comprendió una revisión crítica de lo que ha cambiado recientemente y las mejoras en cuanto a la disponibilidad de datos, la aplicación de metodologías de evaluación y la adopción y aplicación de medidas de conservación y gestión (MMC) para los tiburones y rayas que compusieron el estudio.

La disponibilidad de los datos del tiburón antes de 2009 varió entre las OROPs atuneras pero desde la adopción del plan de acción de la Unión Europea (UE) para los tiburones en 2009 se han realizado mejoras en la recolección y disponibilidad de datos en todas ellas. Esto incluye el registro de diario obligatorio de las principales especies y datos biológicos de los observadores.

Sin embargo, y a pesar de la mejora en los requisitos de presentación de informes de datos, la disponibilidad real de datos sigue siendo deficiente en todas las OROPs. Las capturas históricas se agruparon en su mayor parte en el pasado, lo que dificulta las evaluaciones de las poblaciones. Además, cuestiones como la falta general de datos de descartes, y la falta de información sobre el método de procesamiento del pescado (que no permite identificar si la captura reportada ha sido en peso vivo o procesado, el cual habría que ajustar), disminuyen aún más la calidad y la fiabilidad de los datos. En este último punto, se observa que la política de la UE sobre la extracción a bordo de las aletas de tiburón no se aplica a las flotas no comunitarias, lo que resulta en dificultades adicionales para estimar las capturas totales. Esta falta general de datos completos significa que la aplicación de métodos convencionales de evaluación de stock no ha sido posible para tiburones pelágicos, excepto para las principales especies. Para las otras especies sólo se aplican métodos de datos limitados.

Todas las OROP han adoptado MMC para la gestión y conservación de tiburones que teóricamente alcanzan todos los requesitos de conservación de EUPOA. Sin embargo, la mayoría son difíciles de monitorizar y controlar y se necesita más investigación en general para evaluar su impacto.

Categorización de stocks de tiburones y rayas

Durante esta tarea se identificaron y categorizaron las poblaciones de elasmobranquios pelágicos basándose en la disponibilidad de datos y posibilidades de evaluación para mostrar lo que actualmente impide a los organismos consultivos proporcionar evaluaciones cuantitativas. A continuación, durante esta tarea se describieron los datos adicionales necesarios para mejorar la evaluación de esas poblaciones. Para la categorización, usamos las categorías del Consejo Internacional para la Exploración del Mar (CIEM) donde las acciones se encuentran dentro de una de las seis categorías, con las categorías 1-2 que se refieren a "rico en datos " y categorías 3–6 refiriéndose a "datos limitados".

Los elasmobranquios pelágicos se sitúan principalmente bajo las categorías de datos limitados, en particular las categorías 3-4, excepto las principales especies (tiburón azul y marrajo común) que en algunos casos podrían considerarse como categorías 1-2. Las rayas manta y diablo son considerados de categoría 6, ya que casi no hay información disponible que pudiera informar a las evaluaciones de esas especies.

En la actualidad, sólo las ERAs pueden aplicarse plenamente para la mayoría de las especies de tiburones pelágicos, y de hecho ya se han llevado a cabo para todos los océanos. Otros métodos, ya sean indicadores o evaluaciones de stock (datos limitados o tradicionales), pueden aplicarse en algunos casos, pero con estimaciones y/o sustituciones adicionales de otros océanos;

Se espera que, a medida que se disponga de más datos (o datos de mayor calidad) para pasar de los enfoques de indicadores, a las evaluaciones con datos limitados por datos y eventualmente a las evaluaciones ricas en datos. También observamos que el uso de modelos más complejos no significa necesariamente que las evaluaciones sean mejoradas, sino simplemente que los métodos pueden utilizar más fuentes de datos. Como tal, incluso en los casos en que se pueden realizar evaluaciones complejas, la calidad de los datos sigue siendo la cuestión más importante a tener en cuenta para futuras mejoras.

Evaluación de metodologías utilizadas

Esta tarea describió y evaluó los enfoques metodológicos utilizados para evaluar el estado de los stocks de datos limitados. Específicamente, describimos metodologías de evaluación utilizadas para las poblaciones de elasmobranquios, exploramos enfoques metodológicos alternativos que podrían ser considerados, esbozando puntos fuertes y débiles, y esbozando las mejoras necesarias para la transición a modelos más complejos y/o fortalecer las evaluaciones actuales.

Con excepción de las principales especies, la mayoría de las especies de tiburones cubiertas por las OROPs no son evaluadas utilizando técnicas convencionales de evaluación de stock, principalmente debido a limitaciones de datos. Algunas metodologías alternativas que se han utilizado incluyen ERAs, indicadores de estado de stock, umbral de impacto máximo sostenible y criterios de la lista roja de la Unión Internacional para la Conservación de la Naturaleza (UICN).

Hay una gran cantidad de enfoques adicionales que también podrían emplearse. Estos incluyen evaluaciones de datos limitados baseados en capturas, evaluaciones intermedias como modelos de producción excedente, análisis de marcaje y recaptura, y métodos más complejos e intensivos en datos como modelos estructurados por edad o talla. Además de los modelos para simular la dinámica de los stocks pobres en datos, también existe la opción de emplear enfoques estadísticos bayesianos o probar la robustez del asesoramiento científico mediante evaluación de estrategias de gestión (MSE).

Las principales limitaciones de datos se refieren a los datos de captura y captura por unidad de esfuerzo (CPUE), así como a la comprensión limitada de los procesos biológicos como la mortalidad natural. Se espera que varias especies de tiburones que se encuentran actualmente en la categoría 4 o 5 del CIEM mejoren su categoría si la calidad de los datos de captura y/o CPUE mejora y se dispone de cierta información sobre los procesos biológicos (por ejemplo, la productividad).

Las especies de la categoría 3 del CIEM requieren un enfoque más polifacético para mejorar. Esto implica mejoras en la captura histórica y el esfuerzo, y una mejor calidad de los datos sobre los procesos biológicos y para un espectro más amplio de los parámetros biológicos (mortalidad natural, crecimiento, etc)

Como no está claro si se pueden hacer mejoras significativas en los datos a corto plazo, podría ser de mayor utilidad, como primer paso, apoyar los esfuerzos para mejorar los datos que logren una implementación más robusta de los modelos ya utilizados para la evaluación de cada especie.

Compilación y análisis de MMC

Esta tarea compiló y comparó las MMC existentes adoptadas por las distintas OROPs y otros foros internacionales.

Desde 2004 a 2016, las OROPs atuneras han establecido un número considerable de resoluciones sobre medidas de conservación y ordenación (MMC) para tiburones y rayas, específicamente 8 para la IATTC, 12 para ICCAT, 8 para IOTC y 9 para WCPFC. Estas resoluciones se refieren principalmente a los controles de entrada y/o salida, la modificación de artes de pesca, las prácticas pesqueras y los incentivos para limitar la extracción de las aletas y los descartes.

La prohibición de la retención está en marcha en todos los océanos para varias especies. Hay también regulaciones para la utilización completa de canaleslos cadáveres, usando una relación aleta/cuerpo del 5%, y la prohibición/el control sobre el comercio internacional regulado por la Convención sobre el Comercio Internacional de Especies Amenazadas de Fauna y Flora Silvestres (CITES). También existe una prohibición de las líneas de tiburón en el Océano Pacífico (WCPFC, CIAT).

El control y el cumplimiento de esas resoluciones por las las partes contratantes (CPCs) es complejo. Sería necesario los funcionarios encargados del cumplimiento de las normas u otros mecanismos alternativos cubrieran plenamente las actividades pesqueras, utilizando medios humanos y/o electrónicos. Sin embargo, se observa que los deberes científicos y de cumplimiento deben mantenerse como tareas separadas.

Las prohibiciones de los líderes de alambre (o reinales de acero) se han demostrado como beneficiosas para muchas especies de tiburones. Sin embargo, tal medida puede tener impactos económicos en las capturas. Como tal, todavía es necesario investigar el beneficio para la conservación de las poblaciones de tiburones y rayas y para el posible impacto en la economía de algunas pesquerías de palangre pelágico. Los materiales del líder también deben ser considerados con respecto al tipo del gancho usado, pues esas interacciones siguen siendo desconocidas.

La relación entre el peso de la aleta de tiburón y el peso total aletas de tiburón que está actualmente en vigor en las OROPs atuneras son altamente dependientes de factores tales como especies/género y prácticas de corte/procesamiento. La relación adoptada se ha generalizado al 5%, pero las ratios reales pueden variar de

1,3% a 10,9%, dependiendo de la especie, el método de procesamiento de pescado (entero versus eviscerado, etc) y métodos de procesamiento de aletas (tipo de corte y aletas húmedas versus secas). Como tal, recomendamos que la obligación de descarga de tiburones con las aletas sujetas al cuerpo (naturalmente o semi-cortadas) sea adoptada como MMC para todas las OROPs, que permitirían un control más eficaz de la prohibición del corte de las aletas y un uso más eficaz de las ratios al conocerse la especie descargada. Con la política de aletas acopladas también hay beneficions añadicios en términos de identificación de especies.

También se recomiendan medidas basadas en cierres espaciales/temporales de la pesca para las áreas con alta densidad de hembras maduras y de juveniles para las especies más susceptibles. Sin embargo, se observa que la propuesta de estas áreas requiere muchos datos biológicos y de distribución que generalmente no están disponibles para todos los océanos.

Finalmente, recomendamos desarrollar un programa de investigación para evaluar el impacto de los tipos de anzuelos combinados (circle versus J) y el material de la línea madre "leader" (alambre versus monofilamento) en 1) las tasas de retención de tiburón, y 2) mortalidades en ele buque y posteriores a la liberación en pesquerías de palangre pelágico. Dicho estudio debería tomar en consideración el impacto en la componente tanto de capturas accesorias de tiburón, como en las de las especies objetivo (e.g., pez espada).

Analizar buenas prácticas y medidas alternativas.

Esta tarea describió y analizó las mejores prácticas y otras medidas alternativas que podrían ser adoptadas a corto y largo plazo por OROPs del atún para reducir las capturas y/o la mortalidad posterior a la liberación de las capturas no deseadas de tiburones y rayas, destacando sus fortalezas y debilidades.

Para la mayoría de las medidas de mitigación estudiadas y sugeridas se requiere más investigación antes de ser implementadas a nivel comercial. Algunos resultados de la investigación ya han sido adoptados por la industria, principalmente para establecer buenas prácticas con el objetivo de mejorar la supervivencia de los peces desechados (principalmente para las pesquerías de cerco). Pero en general, se necesitan más estudios y habrá necesidad de establecer incentivos para facilitar la adopción de medidas de mitigación obligatorias por la industria.

Hay varios estudios que investigan la mortalidad de elasmobranquios en los buques de palangre pelágico y de pesca de cerco, pero esos tipos de datos y estudios para la pesca enmalle son deficientes.

Se han recolectado datos de mortalidad posteriores a la liberación para algunas especies, estos muestran variaciones en función de los atributos biológicos (especies, tamaño, sexo y modo de ventilación branquial) y factores asociados con la captura (tipo de engranaje, tiempo de remojo, masa de captura y composición, manejo de prácticas). Pero en general, existe la necesidad de desarrollar programas de investigación para mejorar la recolección de datos de la mortalidad posterior a la liberación, especialmente para las especies prohibidas para la retención.

Recomendamos el desarrollo de investigaciones para evaluar mejor el impacto de las medidas técnicas de mitigación para los tiburones en la pesca del atún, incluyendo más estudios centrados en los dispositivos agregadores de peces (FADs) biodegradables para el cerco, el tipo de anzuelo (forma y tamaño) y el material para los palangreros, y el tamaño de malla y material para la pesca enmalle.

También recomendamos el aumento del nivel de la cobertura de los observadores (tanto observadores humanos como de seguimiento electrónico) para todas las pesquerías atuneras. Sin embargo, también observamos que dentro de las OROPs la mayoría de las CPCs no alcanzan los porcentajes mínimos actualmente adoptados, y en algunos casos no tienen programas de observadores. Como tal, un 1er paso sería asegurar que todas las flotas principales logren las ratios de cobertura mínimas y presenten los datos, y luego aumentar la cobertura según sea necesario, posiblemente complementando con la monitorización electrónica.

Desarrollo de marco conceptual para planes de gestión

Esta tarea elaboró y propuso un marco conceptual para la elaboración y ejecución de planes de gestión para los tiburones (de conformidad con el artículo 10 de la Política Pesquera Común - PPC), incluido el desarrollo de una lista de requisitos mínimos que deberían incluir dichos planes y directrices para su evaluación. A nivel mundial, los marcos para la conservación y ordenación de los tiburones se sustentan principalmente en el plan de acción internacional de la FAO para los tiburones (PAI-tiburones).

Los planes deben ser desarrollados por los estados miembros de la UE pero armonizados entre estados que cubren las mismas acciones, y no deben limitarse a las pesquerías que apuntan a los tiburones, sino también a las que retienen o descartan la captura incidental de tiburón. El objetivo conceptual debería referirse a la sostenibilidad biológica, económica y social, y los planes de gestión deben encajar dentro del marco jurídico de cualquier OROP y ser coherentes con el artículo 10 de la PPC y los objetivos de la EUPOA.

Se formulan recomendaciones sobre los requisitos mínimos propuestos para los planes de gestión, incluidos los detalles sobre la especie y el ecosistema, visión general de la pesquería, objetivos de gestión, puntos de referencia de conservación, límites de captura y descarte, mitigación de la captura incidental, indicadores, marco de temporal y, seguimiento y evaluación con el fin de proporcionar retroalimentación y adaptar los planes.

Casos de estudio

Durante este proyecto se desarrollaron los siguientes estudios de caso: 1) tiburón sedoso -ICCAT, 2) tiburón sedoso-IOTC, 3) tiburón azul-IOTC y 4) marrajo común IOTC. Los casos de estudio se destinaron principalmente a proporcionar los progresos a los grupos de trabajo científicos de las OROPs, y se acordaron y eligieron porque representan situaciones diferentes y diversas.

Se eligió el caso de estudio 1 (tiburón sedoso - ICCAT) porque el tiburón sedoso es actualmente una especie de no retención en varias OROPs atuneras. Las ERAs se han llevado a cabo en el Atlántico, pero ICCAT no dispone de evaluaciones de stock. Como los datos para una evaluación de stock completa no están disponibles o probablemente estén disponibles en un futuro próximo, investigamos medidas alternativas, específicamente utilizando datos de observadores de la UE para describir las preferencias de hábitat de un conjunto de factores oceanográficos bióticos y abióticos, proporcionando por lo tanto la información sobre la dinámica espacio-temporal de la especie y puntos de agregación. Los resultados pueden ser considerados para el desarrollo de planes de gestión alternativos.

El caso de estudio 2 (tiburón sedoso - IOTC) fue elegido porque actualmente esta OROP es la única donde no hay MMC para el tiburón sedoso. La IOTC todavía no ha llevado a cabo ninguna evaluación de stock para esta especie, y mientras que el WPEB tiene una primera evaluación prevista para 2019, hay una gran incertidumbre sobre lo que realmente se logrará ya que la disponibilidad de datos por CPCs se cree que es muy escasa. Por lo tanto, la justificación para este caso de estudio era servir como preparación para la evaluación de 2019, explorando qué se puede hacer ahora y qué necesita ser mejorado hasta 2019. Nos centramos en los métodos de datos limitados y exploramos la viabilidad de estandarizar las series de

CPUE para las pesquerías palangreras de la UE en la región. Actualmente, para esta especie en la IOTC sólo se pueden llevar a cabo métodos para datos limitados con alto nivel de estimaciones y sustituciones. Pese a ello se calculó y proporcionó un estado de stock preliminar.

El caso de estudio 3 (tiburón azul - IOTC) fue elegido porque dentro de los tiburones pelágicos, esta es una de las especies que pueden ser consideradas como relativamente ricas en datos. El tiburón azul es el principal tiburón pelágico capturado y descargado en todo el mundo en pesquerías pelágicas, y se han realizado evaluaciones cuantitativas de su abundancia en todos los océanos, en algunos casos utilizando modelos de evaluación que requieren series de datos completas. Como tal, esta especie se estudió principalmente para explorar qué más se necesitaría para mejorar las evaluaciones y avanzar en términos de asesoramiento. Específicamente, este caso de estudio probó algunos procedimientos de manejo exploratorios (MPs) para mostrar opciones/soluciones intermedias y determinar qué MPs serían más robustas y funcionarían mejor bajo las incertidumbres actuales de la evaluación. Este caso de estudio también se centró en el análisis exploratorio con indicadores basados en la talla, como métodos alternativos a las evaluaciones de stock tradicionales. Finalmente, para esta especie y región se elaboró un proyecto de plan de géstion operacional.

El caso de estudio 4 (marrajo común - IOTC) fue elegido porque esta especie es muy importante en las capturas de la UE, especialmente para la pesca con palangre, siendo el segundo tiburón más capturado y descargado después del tiburón azul. Además, el marrajo común es una de las especies de tiburones pelágicos más vulnerables, debido principalmente a su muy baja productividad y a las altas interacciones con las pesquerías. El marrajo mako ha sido evaluado en ICCAT en 2017, con estatus y proyecciones de stock muy pesimistas. No se han realizado evaluaciones de stock en IOTC, pero el WPEB ha planeado una primera evaluación para 2020, y ya existen algunos indicadores disponibles, particularmente en términos de series de CPUE estandarizadas y datos de tallas. Por lo tanto, este caso de estudio fue desarrollado para proporcionar a IOTC/WPEB una evaluación preliminar, en la preparación para la evaluación de 2020. Los métodos se centraron principalmente en los enfoques de datos limitados, pero también se probaran métodos de evaluación de stock más tradicionales, específicamente los modelos de producción.

Los casos de estudio se presentan en un volumen separado a este informe.

Identificación de brechas de conocimiento

El objetivo de esta tarea fue identificar y priorizar las brechas en el conocimiento y la investigación que podrían contribuir al progreso en la implementación de los tiburones EUPOA y los tiburones MoU. Además, se identifican las necesidades de investigación para colmar las lagunas que dificultan la elaboración de un asesoramiento científico sólido para las especies afectadas. Esta tarea proporcionó una revisión final de todo el trabajo realizado en el proyecto, destacando las brechas actuales en el conocimiento y la identificación de las necesidades futuras.

Aunque se han mejorado las evaluaciones de las principales especies de tiburones oceánicos, existen varias faltas de datos clave. Aunque las faltas de datos clave varían entre las especies, las poblaciones y las áreas de gestión, las siguientes áreas de trabajo requieren más recopilación de datos (monitoreo) y/o investigación y se consideran de alta prioridad: 1) datos cuantitativos sobre el buque y mortalidad posterior a la liberación por especies y métier, y medidas de mitigación de la captura incidental; 2) estimaciones más robustas de capturas (desembarques y estimaciones de descartes muertos y vivos), incluyendo la reconstrucción de escenarios de captura histórica, 3) datos de composición de capturas (especies, sexo y composición de longitud), 4) datos espaciales (datos geo-referenciados sobre especies distribuciones/ocurrencia y por etapa de la historia de la vida), 5) parámetros biológicos más robustos (parámetros de edad y crecimiento, estimaciones de mortalidad natural, parámetros reproductivos) en los que los estudios actuales carecen o son inadecuados, 6) índices de abundancia más fiables, 7) prueba de la aplicabilidad de los métodos de evaluación de datos limitados recientemente desarrollados, 8) evaluación del estado general de los tiburones y rayas capturados de manera incidental que actualmente no se evalúan, 9) desarrollo de marcos de gestión apropiados y 10) mejora de la evaluación de las unidades de población, descargas, capturas y estatus de tiburones oceánicos.

Algunas de estas brechas de datos requieren investigaciones científicas específicas, incluyendo estudios de campo y/o de laboratorio, algunas se refieren a programas de monitoreo (a menudo en curso), y otros se refieren a estudios que requieren recopilación y análisis de datos.

2.3. *Résumé Executif*

L'objectif de cette étude spécifique est de fournir à la direction générale des affaires maritimes et de la pêche (DG MARE):

- Des informations mises à jour concernant l'association ou la présence de requins pélagiques et de raies dans différentes pêcheries;

- Des informations mises à jour concernant la collecte de données et les approches méthodologiques pour l'évaluation de l'état de conservation des requins;
- Un examen critique des mesures de conservation et de gestion (MCG) existantes pour les requins et de l'état de conservation actuel des espèces concernées; et
- Propositions d'améliorer et / ou de fournir des options alternatives pour la conservation et la gestion des requins, en tenant compte des avancées méthodologiques récentes et des nouvelles données ou informations.

Les espèces ciblées sont les principaux requins pélagiques capturés par les pêcheries pélagiques, y compris sous accords de partenariat de pêche durable (pêcheries à la palangre et à la senne). L'étude considère également certains élasmobranches pélagiques inclus dans l'article 13 (interdictions d'espèces) du règlement 2016/72 du Conseil fixant pour 2016 les possibilités de pêche pour certains stocks de poissons. Les principales régions ciblées sont les régions océaniques couvertes par les ORGP thonières où les espèces d'élasmobranches sont représentées dans les captures, notamment l'Atlantique (région CICTA), l'océan Indien (région de la CTOI) et le Pacifique (régions WCPFC et IATTC).

Les tâches suivantes ont été développées dans le cadre du projet:

- Tâche 1. Mettre à jour l'étude des requins de l'EUPOA;
- Tâche 2. Fournir un aperçu critique des développements récents;
- Tâche 3. Catégoriser les stocks de requins et de raies;
- Tâche 4. Évaluer les approches méthodologiques;
- Tâche 5. Compiler et analyser les mesures de conservation et de gestion existantes;
- Tâche 6. Analyser les meilleures pratiques et les mesures alternatives possibles;
- Tâche 7. Élaborer un cadre conceptuel pour les plans de gestion;
- Tâche 8. Organiser un atelier;
- Tâche 9. Mettre en œuvre des études de cas;
- Tâche 10. Identifier les lacunes dans les connaissances.

Mise à jour de l'étude EUPOA sur les requins

Cette tâche a compilé l'état des connaissances sur les espèces d'élasmobranches pélagiques par les ORGP thonières, avec mise à jour la compilation des données d'étude des requins d'EUPOA, en termes de prises et d'effort historiques, niveaux de rejets; données de fréquence de taille, informations biologiques et indicateurs de la pêcherie.

Ces dernières années, il y a eu des améliorations en termes de collecte et de transmission de données sur les requins. Cependant, la disponibilité actuelle des données varie considérablement selon les espèces (espèces majeures ou espèces occasionnelles) et le type spécifique de données. Plus précisément, et bien que la collecte de données sur les prises et les rapports actuels aient tendance à s'améliorer ces dernières années, la disponibilité des données historiques est encore faible et limite l'utilisation des séries chronologiques de capture dans des évaluations.

L'identification des espèces reste un problème dans certains cas, en particulier lorsque des complexes d'espèces sont signalés, comme par exemple dans les complexes d'espèces de requins-marteaux ou de requins-renards. Les données sur les rejets sont rares et incomplètes, souvent inexistantes dans la plupart des cas, et il s'agit d'un problème nécessitant des améliorations urgentes.

Les données sur la fréquence des tailles ont également eu tendance à s'améliorer ces dernières années, en particulier pour les principales espèces de requins, et les informations biologiques sont généralement bonnes pour les principales espèces de requins. Cependant, il existe encore des lacunes dans les données en termes de fréquences de taille et de données biologiques, en particulier pour les espèces d'élasmobranches prises plus occasionnellement. Un cas critique sont les raies manta et mobulas, pour lesquelles où l'information biologique est extrêmement manquante.

Des indicateurs ont récemment été produits pour les principales espèces de requins de tous les océans, principalement pour les dernières évaluations de stocks. Des évaluations des risques écologiques ont également été réalisées pour tous les océans. Cependant, pour les espèces plus occasionnelles, la plupart des autres à l'exception du requin peau bleue et du requin mako, il n'existe pratiquement aucune information disponible pouvant fournir des informations sur l'état de ces stocks.

<u>Aperçu critique des développements récents</u>

Cette tâche a entrepris un examen critique de ce qui a changé et des améliorations observées concernant la disponibilité des données, l'application des méthodologies d'évaluation et l'adoption et la mise en œuvre des mesures de conservation et de gestion (CMMs) des requins et des raies couvertes par l'étude.

La disponibilité des données sur les requins avant 2009 variait entre les ORGP thonières, mais depuis l'adoption du Plan d'action de l'UE pour les requins en 2009, des améliorations dans la collecte et la disponibilité des données ont été faites dans toutes les ORGP thonières. Cela comprend la déclaration obligatoire des livres de bord des principales espèces et des données biologiques des observateurs.

Cependant, et malgré l'amélioration des exigences de déclaration des données, la disponibilité réelle des données reste médiocre dans toutes les ORGP thonières. Les captures historiques étaient pour la plupart agrégées par le passé, ce qui entrave les évaluations des stocks. De plus, des problèmes tels que le manque général de données sur les rejets et le manque d'informations sur la méthode de traitement (qui peut confondre ce qui est rapporté en tonne équivalent-carcasse), diminue davantage la qualité et la fiabilité des données. Sur ce dernier point, il convient de noter que la politique de l'Union européenne relative aux palangres ne s'applique pas aux flottes hors UE, ce qui entraîne des difficultés supplémentaires pour estimer les captures totales. Ce manque général de bases de données complètes signifie que les méthodes conventionnelles d'évaluation des stocks n'ont en général pas pu être appliquées aux requins pélagiques, sauf pour les espèces principales. Pour les autres espèces, seules des méthodes pour données limitées sont appliquées.

Toutes les ORGP thonières ont adopté les CMMs pour la gestion et la conservation des requins qui, théoriquement, satisfont à toutes les exigences de conservation d'EUPOA. Cependant, la plupart sont difficiles à surveiller et à contrôler, et il est généralement nécessaire d'effectuer plus de recherches pour évaluer leur impact.

Catégorisation des stocks de requins et de raies

Cette tâche a identifié et catégorisé les stocks d'élasmobranches pélagiques en fonction de la disponibilité des données et des possibilités d'évaluation, indiquant ce qui empêche actuellement les organes consultatifs scientifiques de fournir des évaluations quantitatives, puis décrit les données supplémentaires nécessaires pour améliorer l'évaluation de ces stocks. Pour la catégorisation, nous avons utilisé les catégories CIEM où les stocks se classent dans l'une des six catégories, les catégories 1 et 2 se référant aux stocks «riches en données» et les catégories 3 à 6 se référant aux stocks «limités en données».

Les élasmobranches pélagiques se classent principalement dans les catégories aux données limitées, en particulier les catégories 3-4, sauf pour les espèces principales (requin peau bleue et requin mako) qui pourraient dans certains cas être considérées comme appartenant aux catégories 1-2. Les raies manta et mobulas sont toutes considérées comme Catégorie 6, car presque aucune information n'est disponible pour l'évaluation des stocks de ces espèces.

À l'heure actuelle, seules les ERA peuvent être entièrement mises en œuvre pour la plupart des espèces de requins pélagiques, et ont déjà été réalisées pour tous les océans. D'autres méthodes, soit des indicateurs soit une évaluation des stocks (aux données limitées ou traditionnelle), peuvent être mises en œuvre dans certains cas, mais avec des estimations supplémentaires et/ou des substitutions d'après d'autres océans;

Au fur et à mesure que davantage de données seront disponibles (ou que les données seront de meilleure qualité), on s'attend à passer d'approches d'indicateurs à des évaluations limitées en données et, éventuellement, à des évaluations riches en données. Nous notons également que l'utilisation de modèles plus complexes ne signifie pas nécessairement que les évaluations sont améliorées, mais simplement que les méthodes peuvent utiliser davantage de sources de données. Ainsi, même dans les cas où des évaluations complexes peuvent être réalisées, la qualité des données utilisées reste la question la plus importante à prendre en compte pour les améliorations futures.

Évaluation des approches méthodologiques

Cette tâche décrit et évalue les approches méthodologiques utilisées pour l'évaluation de l'état des stocks aux données limitées. Plus précisément, nous décrivons les méthodologies d'évaluation utilisées pour les stocks d'élasmobranches, explorons d'autres approches méthodologiques qui pourraient être considérées, soulignant leurs forces et les faiblesses, ainsi que les améliorations nécessaires pour passer à des modèles plus complexes et / ou renforcer les évaluations actuelles.

À l'exception des espèces principales, la plupart des espèces de requins couvertes par les ORGP thonières ne sont pas évaluées à l'aide de techniques conventionnelles d'évaluation des stocks, principalement en raison des limites des données. Parmi les autres méthodes employées, citons les ERA, les indicateurs d'état des stocks, le seuil d'impact maximal durable et les critères de la Liste rouge de l'UICN

Il existe une multitude d'autres approches qui pourraient également être utilisées. Celles-ci comprennent des évaluations à données limitées comme les méthodes basées uniquement sur la capture, des évaluations intermédiaires comme modèles de production excédentaire, l'analyse de marquage et recapture, et des méthodes plus complexes et intensives en données comme les modèles structurés en fonction de l'âge ou de la longueur. En plus des modèles pour simuler la dynamique des stocks pauvres en données, il est également possible d'utiliser des approches statistiques bayésiennes ou de tester la robustesse des avis scientifiques par l'évaluation de la stratégie de gestion;

Les principales limitations des données concernent les données de capture et de CPUE ainsi qu'une compréhension limitée des processus biologiques tels que la mortalité naturelle. On s'attend à ce que plusieurs espèces de requins qui sont actuellement dans la catégorie CIEM 4 ou 5 se déplacent vers une catégorie supérieure si la qualité des données de prises et / ou de PUE s'améliore et si certaines informations sont disponibles sur les processus biologiques (productivité). Les espèces de la catégorie 3 du CIEM ont besoin d'une approche plus complexe pour passer à l'échelle supérieure du CIEM. Cela implique des améliorations dans les données de prises et d'efforts historiques, et une meilleure qualité des données sur les processus biologiques et pour un spectre plus large de paramètres biologiques (mortalité naturelle, croissance, etc.)

Comme il n'est pas clair si une amélioration significative des données peut être réalisée à court terme, il serait peut-être plus utile, dans un premier temps, de soutenir les efforts visant à améliorer les données qui permettraient une mise en œuvre plus robuste des modèles déjà utilisés pour l'évaluation de chaque espèce.

Compilation et analyses des CMM existantes

Cette tâche a compilé et comparé les CMM existantes adoptées par les diverses ORGP thonières et d'autres forums internationaux pertinents.

De 2004 à 2016, les ORGP thonières ont adopté un nombre considérable de résolutions sur les mesures de conservation et de gestion (CMM) pour les requins et les raies, en particulier 8 pour l'IATTC, 12 pour l'ICCAT, 8 pour la CTOI et 9 pour la WCPFC. Ces résolutions concernent principalement les contrôles des entrées et/ou des sorties, la modification des engins de pêche, les pratiques de pêche et les incitations à limiter le finning et les rejets.

L'interdiction de rétention est en place dans tous les océans pour plusieurs espèces. Il existe également des règlements pour l'utilisation complète des carcasses, en utilisant un ratio d'aileron / corps de 5%, et l'interdiction / le contrôle du commerce international réglementé par la CITES. Il y a également une interdiction de bas de lignes en acier ou de lignes à requins en place dans l'océan Pacifique (WCPFC, IATTC).

Le contrôle et le respect de ces résolutions par les CPC sont complexes. Il faudrait que les responsables de la conformité ou d'autres mécanismes couvrent pleinement les activités de pêche, en utilisant des moyens humains et / ou électroniques. Cependant, il est noté que les tâches scientifiques et celles de conformité doivent être traitées en tant que tâches séparées.

Il a été démontré que les interdictions des bas de lignes en acier étaient bénéfiques pour de nombreuses espèces de requins. Cependant, une telle mesure peut avoir des impacts économiques sur les captures. À ce titre, les avantages pour la conservation des stocks de requins et de raies et pour l'impact possible sur l'économie de certaines pêcheries palangrières pélagiques doivent encore être étudiés. Les matériaux des bas de ligne doivent également être pris en compte en ce qui concerne le type d'hameçon utilisé, car ces interactions sont encore inconnues.

Les ratios ailerons / carcasses des requins en place dans les ORGP thonières dépendent fortement de facteurs tels que l'espèce / le genre et les pratiques de coupe / transformation. Le ratio adopté a été généralisé à 5%, mais les ratios réels peuvent varier de 1,3% à 10,9%, selon l'espèce, la méthode de transformation du poisson (carcasse entière ou tonne équivalent-carcasse) et les méthodes de traitement des ailerons (type de coupe et nageoires fraîches ou sèches). Nnous recommandons ainsi de maintenir les nageoires fixées au corps des requins (naturellement ou artificiellement) jusqu'à ce que les points de débarquement soient adoptés par les CMM pour toutes les ORGP thonières, qui contrôlerait efficacement l'interdiction du finning et ne serait pas limitée par cette variabilité dans les ratios.

Il est également recommandé que davantage de CMM se basent sur des fermetures spatio-temporelles de la pêche dans les zones à forte densité de femelles matures et de juvéniles pour les espèces les plus sensibles. Cependant, il est noté que la proposition de telles zones nécessite beaucoup de données biologiques et de distribution qui ne sont généralement pas encore disponibles dans les ORGP thonières.

Enfin, nous recommandons de développer un programme de recherche pour mieux évaluer l'impact des combinaisons de types d'hameçons (cercle versus J) et des matériaux de bas de ligne (acier ou monofilament) sur 1) les taux de rétention des requins, et 2) les mortalités sur le navire et après relâche dans les pêcheries palangrières pélagiques.

Analyser les meilleures pratiques et les mesures alternatives potentielles

Cette tâche a défini et analysé les meilleures pratiques et autres mesures alternatives qui pourraient être adoptées à court et à long terme par les ORGP thonières pour réduire les captures et / ou la mortalité après relâche des requins et des raies, mettant en évidence leurs forces et faiblesses.

Pour la plupart des mesures d'atténuation étudiées et suggérées, beaucoup ont encore besoin de plus de recherches avant d'être mises en œuvre au niveau commercial. Certains résultats directement issus de la recherche ont déjà été adoptés par l'industrie, principalement pour mettre en place des bonnes pratiques visant à améliorer la survie des poissons mis au rebut (principalement pour les senneurs). Mais en général, davantage d'études sont nécessaires et il sera nécessaire de mettre en place des incitations pour faciliter l'adoption par l'industrie de mesures d'atténuation obligatoires.

Plusieurs études étudient la mortalité des élasmobranches à bord des navires pour les pêcheries à la palangre pélagique et à la senne, mais ces types de données et d'études sur les pêcheries au filet maillant font cruellement défaut. Des données sur la mortalité après relâche ont été recueillies pour certaines espèces montrant des variations selon les attributs biologiques (espèce, taille, sexe et mode de ventilation branchiale) et les facteurs associés à la capture (type d'engin, temps d'immersion, masse et composition des captures, pratiques de manipulation). Mais en général, il est nécessaire de développer des programmes de recherche pour améliorer la collecte de données sur la mortalité après la remise à l'eau, en particulier pour les espèces dont la rétention est interdite.

Nous recommandons le développement de recherches pour mieux évaluer l'impact sur les mesures techniques d'atténuation pour les requins dans les pêcheries de thonidés, y compris plus d'études sur les DCP biodégradables pour les senneurs, le type d'hameçon (forme et taille) et le matériel de bas de ligne pour les palangres, et la taille des mailles pour la pêche au filet maillant.

Nous recommandons également l'augmentation du taux de couverture par des observateurs (observateurs humains et / ou surveillance électronique) pour toutes les pêcheries de thonidés. Cependant, nous notons également qu'au sein des ORGP thonières, la plupart des CPC n'atteignent pas les pourcentages minimums actuellement adoptés et, dans certains cas, ne disposent pas de programmes d'observateurs. Une première étape consisterait donc à s'assurer que toutes les flottes principales atteignent les ratios de couverture minimum, soumettre les données, puis augmenter la couverture si nécessaire, éventuellement en complétant par un suivi électronique.

Développement d'un cadre conceptuel pour les plans de gestion

Cette tâche a développé et proposé un cadre conceptuel pour l'élaboration et la mise en œuvre des plans de gestion des requins (conformément à l'article 10 de la PCP), notamment l'élaboration d'une liste d'exigences minimales et de lignes directrices pour l'évaluation de ces plans. À l'échelle mondiale, les cadres de conservation et de gestion des requins sont principalement soutenus par le Plan d'action international de la FAO pour les requins (IPOA-Sharks).

Les plans devraient être élaborés par les États membres individuels de l'UE mais harmonisés entre les États membres qui couvrent les mêmes stocks, et ne devraient pas être limités aux pêcheries ciblant les requins, mais aussi à celles qui conservent ou rejettent les prises accessoires de requins. L'objectif conceptuel devrait se référer à la durabilité biologique, économique et sociale, et les plans de gestion doivent s'inscrire dans le cadre juridique de toute ORGP pertinente et être compatibles avec l'article 10 de la PCP et les objectifs du FAO.

Des recommandations sont formulées sur les exigences minimales proposées pour les plans de gestion, notamment sur l'espèce et l'écosystème, les objectifs de gestion, les points de référence de conservation, les limites de prise et de rejet, l'atténuation des prises accessoires, les indicateurs, le cadre temporel, le suivi et l'évaluation, dans le but de fournir des commentaires en retour et d'adapter les plans.

Études de cas

Les études de cas suivantes ont été développées pendant ce Projet: 1) requin soyeux - ICCAT, 2) requin soyeux - CTOI, 3) requin bleu - CTOI et 4) requin-mako - CTOI. Les études de cas étaient principalement destinées à fournir des avancées aux groupes de travail scientifiques des ORGP thonières, et ont été acceptées et choisies parce qu'elles représentent des situations différentes et variées.

L'étude de cas 1 (requin soyeux - ICCAT) a été choisie parce que le requin soyeux est actuellement une espèce sans rétention dans plusieurs ORGP thonières, y compris à l'ICCAT. Des EER ont été menées dans l'Atlantique, mais aucune évaluation des stocks n'est disponible ou prévue par l'ICCAT. Les données pour une évaluation complète du stock n'étant pas disponibles ou susceptibles d'être disponibles prochainement, nous avons étudié des mesures alternatives, en utilisant spécifiquement les données d'observateurs de l'UE pour cartographier les préférences d'habitat à partir d'un ensemble de facteurs océaniques biotiques et abiotiques, fournissant ainsi de l'information sur la dynamique temporelle des espèces et des points chauds. Les résultats pourraient être pris en compte pour l'élaboration de plans de gestion alternatifs.

L'étude de cas 2 (requin soyeux - CTOI) a été choisie car actuellement la CTOI est la seule ORGP thonière où il n'y a pas de CMM pour le requin soyeux. La CTOI n'a encore effectué aucune évaluation des stocks pour cette espèce, et bien que le GTEPA ait une première évaluation prévue pour 2019, il y a une grande incertitude sur ce qui sera réellement réalisé car la disponibilité des données par les CPC est très rare. Par conséquent, la raison d'être de cette étude de cas était de préparer l'évaluation de la CTOI 2019 en explorant ce qui peut être fait maintenant et ce qui doit être amélioré jusqu'en 2019. Nous nous sommes concentrés sur des méthodes limitées en données et avons exploré la faisabilité pour les pêcheries palangrières de l'UE dans la région. Actuellement, pour cette espèce et cet océan, seules des méthodes limitées en données avec un niveau élevé d'estimations et de substitutions peuvent être réalisées, mais un état de stock préliminaire a été calculé et fourni.

L'étude de cas 3 (requin peau bleue - CTOI) a été choisie car le requin peau bleue est, chez les requins pélagiques, l'espèce qui peut être considérée comme la plus riche en données. Le requin peau bleue est le principal requin pélagique capturé et débarqué dans le monde entier dans les pêcheries pélagiques, et des évaluations quantitatives des stocks ont été menées sur tous les océans, dans certains cas en utilisant des modèles d'évaluation à forte intensité de données. En tant que telle, cette espèce a été plus amplement étudiée principalement pour explorer ce qui serait encore nécessaire pour améliorer encore les évaluations et aller de l'avant en termes de conseils. Plus précisément, cette étude de cas a testé certaines procédures de gestion exploratoires (MP) pour montrer les options / compromis et déterminer quels MP seraient plus robustes et fonctionneraient mieux dans le cadre des incertitudes actuelles de l'évaluation. Cette étude de cas a également porté sur l'analyse exploratoire avec des indicateurs basés sur la longueur, comme méthodes alternatives aux évaluations traditionnelles des stocks. Enfin, pour cette espèce et cette région, un projet de plan de gestion opérationnelle a été préparé.

L'étude de cas 4 (requin mako - CTOI) a été choisie car cette espèce est très importante dans les captures de l'UE, en particulier pour les pêcheries à la palangre, étant le deuxième requin capturé et débarqué après le requin peau bleue. En outre, le requin mako est l'une des espèces de requins pélagiques les plus vulnérables, principalement en raison de sa très faible productivité et de ses interactions élevées avec les pêcheries. Le requin-taupe bleu a été évalué à l'ICCAT en 2017, avec un état des stocks et des projections très pessimistes. Aucune évaluation des stocks n'a encore été réalisée à la CTOI, mais le GTEPA a prévu une première évaluation pour 2020, et certains indicateurs sont déjà disponibles, notamment en termes de séries de PUE normalisées et de données de tailles. Par conséquent, cette étude de cas a été élaborée pour fournir à la CTOI / GTEPA un état des stocks préliminaire, en préparation de l'évaluation de 2020. Les méthodes ciblées étaient principalement des approches à données limitées, mais nous avons également testé des méthodes d'évaluation des stocks plus traditionnelles, en particulier des modèles de production.

Ces études de cas sont fournies dans un volume séparé de ce rapport.

<u>Identifier les lacunes dans les connaissances</u>

L'objectif de cette tâche 10 était d'identifier et de hiérarchiser les lacunes en matière de connaissances et de recherche susceptibles de contribuer à l'avancement de la mise en œuvre des requins de l'EUPOA et du MoU. En outre, identifier les besoins de recherche pour combler les lacunes qui entravent l'élaboration de conseils scientifiques judicieux pour les espèces concernées. Cette tâche a permis une révision finale de tous les travaux menés dans le cadre du projet, mettant en évidence les lacunes actuelles dans les connaissances et identifiant les besoins futurs.

Bien qu'il y ait eu des évaluations améliorées des principales espèces de requins océaniques, plusieurs données clés manquent. Bien que les principales lacunes dans les données varient selon les espèces, les stocks et les zones de gestion, les grands domaines de travail suivants nécessitent d'autres collectes de données (surveillance) et / ou recherche et sont considérés comme hautement prioritaires: 1) données quantitatives sur la mortalité à bord et après la relache, par espèce et métier, et les mesures d'atténuation des prises accessoires; 2) des estimations plus robustes des captures (débarquements et estimations des rejets morts et vivants), y compris la reconstitution de scénarios historiques de captures, 3) des données sur la composition des captures (espèces, composition par sexe et taille), 4) des données spatiales (données géoréférencées sur la distribution et l'occurrence des espèce, par stade de croissance). 5) des paramètres biologiques plus robustes (paramètres d'âge et de croissance, estimations de la mortalité naturelle, paramètres de reproduction) lorsque les études actuelles sont insuffisantes ou inadéquates, 6) des indices plus fiables de l'abondance du stock, 7) des tests de l'applicabilité de méthodes d'évaluation pour données limitées, récemment élaborées, 8) Statut global des requins et des raies qui ne sont pas actuellement évalués, 9) élaboration de cadres de gestion appropriés et 10) évaluation améliorée des unités de stock, des débarquements, des captures et de l'état des requins océaniques.

Certaines de ces lacunes nécessitent des études scientifiques spécifiques, y compris des études de terrain et / ou de laboratoire, certaines concernent des programmes de surveillance (souvent en cours) et d'autres concernent des études nécessitant de la compilation et de l'analyse de données.

3. GENERAL INTRODUCTION

3.1. *General introduction to the specific contract*

EASME has commissioned the AZTI led consortium (AZTI, AGROCAMPUS, CEFAS, IEO, IPMA, IMARES, IRD, MRAG) for the Framework Contract EASME/EMFF/2016/008 for the "*Provision of scientific advice for fisheries beyond EU waters*"[1]. The present document refers to the Final Report of the Specific Contract (SC) Nº 1 under this framework.

The purpose of this specific study is to provide the Directorate-General for Maritime Affairs and Fisheries (DG MARE) with:

- updated information regarding the association or occurrence of pelagic sharks and rays in different fisheries;
- updated information regarding data collection and methodological approaches for the assessment of conservation status of sharks;
- a critical review of existing Conservation and Management Measures (CMMs) for sharks and of the current conservation status of the species concerned; and
- proposals to improve and/or provide alternative options for conservation and management of sharks taking into account any recent methodological advances, new data or information.

In general terms, the geographical scope of this study is the Atlantic Ocean, Mediterranean Sea, North Sea, Baltic Sea, the Indian and the Pacific Oceans. The study covers in particular, the main pelagic sharks caught by pelagic fisheries including under Sustainable Fisheries Partnership Agreements (longline and purse seine fishery, as well as other major fisheries depending on the areas). The study is primarily focused on the pelagic longline and purse seine fisheries and on blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), longfin mako (*Isurus paucus*), porbeagle (*Lamna nasus*), silky shark (*Carcharhinus falciformis*), oceanic whitetip shark (*Carcharhinus longimanus*), hammerheads (*Sphyrna* spp.) and thresher sharks (*Alopias* spp.). It also considers pelagic elasmobranch species included in Article 13 of the Council Regulation 2016/72[2] fixing for 2016 the fishing

[1] See Appendix I for list of acronyms used in the report.

[2] Council Regulation (EU) 2016/72 of 22 January 2016 fixing for 2016 the fishing opportunities for certain fish stocks and groups of fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, and amending Regulation (EU) 2015/104.

opportunities for certain fish stocks. The starting point for the development of this study will be the first EUPOA sharks study (Murua et al., 2013a).

To this end the following tasks were proposed and developed:

- **Task 1. Update EUPOA sharks study:** Develop an inventory and summary table of pelagic elasmobranch (sharks and rays) species by tuna-RFMO including their state of knowledge and update the data compilation of the EUPOA sharks study (historical catch and effort; estimation of discards levels; length frequencies from observers; biological information and fishery indicators), including also a description of new data now available.

- **Task 2. Provide a critical overview of recent developments:** Provide a critical overview of what has changed in recent years regarding data availability and the application of methodological approaches for the assessment of conservation status of sharks and rays after the adoption of the International Plans of Action for sharks and the EUPOA sharks. This includes an overview of data and information availability to perform specific quantitative, semi-quantitative or qualitative stock assessments for the main pelagic shark and ray stocks falling under the scope of the study. Provide also a critical overview of what has changed regarding management measures and recommendations for management within the EU and at international level.

- **Task 3. Categorise stocks of sharks and rays:** Identify and categorise shark and ray stocks based on data and assessment availability. Indicate what hinders scientific advisory bodies to provide quantitative assessments and describe measures necessary (e.g. identify more precisely data collection needs/sources/gaps) that could improve the assessment of these stocks.

- **Task 4. Evaluate methodological approaches:** Describe and evaluate methodological approaches that are used for the assessment of the conservation status of data poor/limited stocks by relevant scientific bodies. Identify and list the methodological approaches used for shark stocks by relevant scientific bodies and other organisations (e.g., IUCN, TRAFFIC). Explore different methodological approaches that could be considered specifically for data poor and assessment limited stocks of sharks and rays, and outline the strengths and weaknesses of adopting different types of methodological approaches to data poor stocks.

- **Task 5. Compile and analyse existing Conservation and Management Measures**: Compile and compare existing Conservation and Management Measures (CMMs), in particular retention bans, adopted by relevant international fora (e.g., a possible source is the Food and Agriculture Organization of the United Nations) for fisheries that target sharks or have sharks and rays as by-catch or associated species. Analyse their effectiveness in terms of achieving the conservation objectives that have underpin their adoption. CMMs should be compiled and the advantages and disadvantages regarding their scope, geographic scale of application, implementation and effectiveness in achieving conservation and any other objectives, shall be assessed. Where appropriate, proposed solutions addressing the identified shortcomings shall be discussed. Among others, the appropriateness and impact (including socio-economic when possible) of a ban in the use of wire leaders/tracers on the EU Longline fleet shall be assessed on a fishery basis and updated information on the use of fins to carcass ratio, including recent advice from relevant scientific bodies shall be compiled.

- **Task 6. Analyse best practices and potential alternative measures**: Outline and analyse best practices and other alternative measures that could be adopted in the short and long term by tuna-RFMOs to reduce catches and/or post-release mortality of unwanted catches of sharks and rays. For fisheries that do not target these species, highlight their strengths and limitations/weaknesses.

- **Task 7. Develop a conceptual framework for management plans**: Develop and propose a conceptual framework for elaborating and implementing management plans for sharks (in line with Article 10 of the CFP), including the development of a list of minimum requirements that such plans should include and guidelines for evaluating such plans. The work initiated by the EU in Western Central Pacific Fisheries Commission shall be used as a starting point.

- **Task 8. Organise a workshop:** Organise a workshop between DG MARE, EASME and scientists of the consortium to analyse outcomes of tasks 1-7 and to discuss approaches and methodologies to address task 9.

- **<u>Task 9</u>. Implement case studies**: Implement case studies for a group of selected species or stocks (between 4 and 6 stocks) with the following goals:
  - Critically assess what obstacles prevent obtaining appropriate scientific (quantitative assessments) advice for the selected species or stocks;
  - Explore tools for the selected species or stocks that are likely to help overcoming these obstacles in the short term and analyse their performance;
  - For the selected species or stocks for which the current state of knowledge does not allow for short term solutions, explore alternative methods to be implemented at a longer term;
  - Propose potential management plans or elements to be included in management plans, for the selected case studies.

- **<u>Task 10</u>. Identify gaps in knowledge**: Identify and prioritise gaps in knowledge and research that could contribute to progress in the implementation of the EUPOA sharks and the MoU Sharks. Also, identify research needs to fill gaps that hinder the elaboration of sound scientific advice for the species concerned.

3.2. *Species and regional scope of the study*

The species scope of this study are the main pelagic shark species caught by pelagic fisheries, including under Sustainable Fisheries Partnership Agreements (longline and purse seine fishery), as well as other major fisheries depending on the oceanographic region. In particular, the study is focused on the pelagic longline and purse seine fisheries and on blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), longfin mako (*Isurus paucus*), porbeagle (*Lamna nasus*), silky shark (*Carcharhinus falciformis*), oceanic whitetip shark (*Carcharhinus longimanus*), hammerheads (*Sphyrna* spp.) and thresher sharks (*Alopias* spp.).

The study also considers some of the pelagic elasmobranch species included in Article 13 (species prohibitions) of the Council Regulation 2016/72 fixing for 2016 the fishing opportunities for certain fish stocks, when possible and data is available for those species, including, white shark (*Carcharodon carcharias*), basking shark (*Cetorhinus maximus*), manta rays (*Manta* spp., 2 species) and devil rays (*Mobula* spp., 9 species)[3]. Some of these species are either more coastal and/or endemic to particular regions and so those species that have more interactions with pelagic fisheries in oceanic ecosystems are addressed in greater detail.

The regional scope, of the study covers the Atlantic Ocean, Mediterranean Sea, North Sea, Baltic Sea, the Indian and the Pacific Oceans. However, the Consortium notes the need to focus the main efforts of the project and resources into the oceanic regions where the case study elasmobranch species are represented in the catches. It is noted that most nations with fisheries in the North Sea and Mediterranean Sea report their pelagic tuna and tuna-like catches (including pelagic sharks) to ICCAT, and that the Baltic Sea is a low salinity water body outside the stock ranges of the case study species (any incidences of those species in the Baltic Sea would be mainly vagrants and not representative of the stocks). Therefore, the particular areas of focus of the project are the Atlantic (including adjacent North and Mediterranean seas, as possible and when data are available at ICCAT or ICES and GFCM), the Indian Ocean (considering data from IOTC), and the Pacific (considering the WCPFC and IATTC).

The region-specific list of shark and ray species that, on the basis of their presumed status and the potential need to underpin conservation measures based on sound scientific advice, are being considered for the tasks of the study and from which a selection will be considered as candidates for case studies is:

Atlantic and adjacent seas (ICCAT)

- blue shark (*Prionace glauca*)
- shortfin mako (*Isurus oxyrinchus*)
- longfin mako (*Isurus paucus*)
- porbeagle (*Lamna nasus*), in conjunction with ICES
- silky shark (*Carcharhinus falciformis*)
- oceanic whitetip shark (*Carcharhinus longimanus*)
- hammerheads (*Sphyrna* spp., data often grouped as SPN in ICCAT).
- thresher sharks (*Alopias* spp., especially A *superciliosus* as the main thresher species of interest in ICCAT).

Indian Ocean (IOTC)

[3] See Appendix II with revised taxonomic checklists and notes.

- blue shark (*Prionace glauca*)
- shortfin mako (*Isurus oxyrinchus*)
- silky shark (*Carcharhinus falciformis*)
- oceanic whitetip shark (*Carcharhinus longimanus*)
- hammerheads (*Sphyrna* spp., especially *S lewini* as the main hammerhead species of interest in IOTC, but with data often grouped as SPN in IOTC)
- thresher sharks (*Alopias* spp., especially A *superciliosus* and *A pelagicus* as the main threshers species of interest in IOTC, but with data often grouped as THR in IOTC).
- porbeagle (*Lamna nasus*)

Western and Central Pacific (WCPFC)

- blue shark (*Prionace glauca*)
- mako sharks (*Isurus* spp., data usually grouped as MAK in WCPFC)
- silky shark (*Carcharhinus falciformis*)
- oceanic whitetip shark (*Carcharhinus longimanus*)
- thresher sharks (*Alopias* spp., data usually grouped as THR in WCPFC).
- hammerheads (*Sphyrna* spp., data usually grouped as SPN in WCPFC)
- porbeagle (*Lamna nasus*)

Eastern Pacific (IATTC)

- blue shark (*Prionace glauca*)
- mako sharks (*Isurus* spp., data usually grouped as MAK in IATTC)
- silky shark (*Carcharhinus falciformis*)
- oceanic whitetip shark (*Carcharhinus longimanus*)
- thresher sharks (*Alopias* spp., data usually grouped as THR in IATTC).
- hammerheads (*Sphyrna* spp., data usually grouped as SPN in IATTC)
- porbeagle (*Lamna nasus*)

3.3. *Objective and structure of the report*

This document presents the Final Report of the project. Each task is one chapter of the report and starts with a summary of the key findings and recommendations, followed by the objectives, methods, results and discussion. This report provides mainly the details for tasks 1 to 7, and task 10. Task 8 (workshop) is provided as a summary, and task 9 (case studies) are provided in a separate volume. In each task reported, the main results and discussion are presented in the main report body, while all detailed and additional information are provided in the Appendices.

4. TASK 1 - UPDATE EUPOA SHARKS STUDY

4.1. *Key findings and recommendations*

- In recent years there have been improvements in terms of data collection and reporting of shark data. However, current data availability varies substantially depending on the species (major *versus* occasional species) and the specific type of data;
- While catch data collection and reporting has improved in recent years, the availability of historical data is still scarce, limiting the use of catch time series. For this reason, producing alternative catch data reconstructions (time series) for stock assessment purposes is still necessary and should be regarded as a priority;
- Species identification is still an issue in some cases, especially when species complexes are reported (i.e., genus instead of species-specific levels), such as for hammerheads or thresher complexes cases;
- Discard data is very poor (inexistent in most cases). The very limited number of CPCs that collect and report this data remains extremely low, which is problematic and needs urgent improvement;
- Length frequency data has also improved in recent years, especially for the major species. But as for the other types of data, the limited number of CPCs that collect and report this data remains relatively low, which is again problematic;
- Biological information is, in general, good for the major shark species. There are still some biological data gaps, especially for the more occasionally species. Biological information for manta and devil rays is extremely poor;
- Recently, indicators have been produced for the major shark species for all oceans, mostly for use in the latest stock assessments. Ecological Risk Assessments (ERA) have also been produced for all oceans. However, for rare species (other than blue and shortfin mako sharks) there is very limited information available that could be used to provide information on the status of those stocks.

4.2. *Objectives*

This task compiled the state of knowledge of pelagic elasmobranchs (sharks and rays) species by tuna-RFMO including their state of knowledge and update the data compilation of the EUPOA sharks study (historical catch and effort; estimation of discards levels; length frequencies from observers; biological information and fishery indicators), including also a description of new data now available.

To accomplish this, task 1 was divided in the following sub-tasks:

- Historical catches;
- Discard levels;
- Length-frequencies;
- Biological information;
- Indicators.

4.3. *Methodology*

Overall, this task revised and summarized new data submitted and compiled by region/ocean. Most of the information was obtained from the tuna-RFMOs (ICCAT, IOTC, IATTC, WCPFC) fishery statistics databases, reports and scientific documents presented during the different Working Parties, Scientific Committee and Commission meetings. In some cases the tuna-RFMO data administrators have been contacted to provide some additional fishery statistics or clarifications in the existing databases. Moreover, a large number of reports and scientific documents presented to the tuna-RFMO meetings were analyzed to identify the availability of shark catch and by-catch data for various fleets and countries in each region.

Sub-task 1.1 - Historical catch data

The original goal of this sub-task was to update the shark catch estimation presented in Murua et al. (2013a). However, during this project the Consortium was also able to improve the EUPOA-Sharks method and create time series of catches instead of the overall means as was presented in Murua et al. (2013a).

For this task, the Consortium conducted a revision on the available catch and effort data for the oceanic sharks and rays defined in the scope of the study in the various tuna-RFMOs and from other relevant sources, in the Atlantic, Indian and Pacific Oceans, and Mediterranean Sea.

For updating the EUPOA results the data was processed in a 3-step approach including 3 main general tables:

- Data gaps table: a table showing which countries report data to the tuna-RFMO on shark catches (i.e., a table presenting if the data is available or not by country);

– tuna-RFMO official catch data for major fleets and countries catching sharks based on current data available in the tuna-RFMO: this table includes the catches of sharks and/or the target species, which may be indicative of global shark catch;

– Estimation of "possible" catch shark by major fleets and countries targeting sharks, based on the ratio of shark catch/by-catch over target species. The ratios were estimated through observers, literature or personal communication as per Murua et al. (2013a).

The first two tables are revision tables based on currently available information. The estimations of potential catches that is presented in the 3rd table, datasets available in tuna-RFMOs were analyzed in order to identify fleets susceptible to generate important catch of sharks. As reported by Murua et al. (2013a) the basic assumption is that the target species quantities declared by flag/fleet to tuna-RFMOs are correct, and that it is reliable to use these estimates to compute the potential shark catches knowing each fleet specific *métier* (target species and their gear characteristics) and the corresponding catch ratio (shark by-catch/target species). The volume of sharks caught by each fleet can then be estimated.

Based on the original nominal databases of tuna-RFMOs, which includes tuna and shark catch information by year, species, area, gear, country, flag and fleet, the "potential" shark catches by major fleets involved in fisheries capturing sharks were then estimated. Data used are reported as nominal catches by species for the period 2000-2015, noting that the EUPOA study focused on the years 2000-2010, and for this project we updated with information from the more recent years (2011-2015).

The final tables are the result of the following steps:

1 - Ratio references tables by *métier*: preparation of reference tables of ratio shark by-catch/catch over target species catch by metier.

1.1 - A list of *métiers* (combination of gear and target species group) is identified and for each of these *métier* the following is defined:

1.1.1 - A ratio of shark (all species together) catch to target species group (in weight);

1.1.2- Shark species composition in proportion (sum = 1): For this specific sub-task of the project we will focus on the 18 major pelagic sharks species or groups of species, to maintain the continuity of the methodology used during the EUPOA study (see Murua et al., 2013a).

The ratio's reference table is a summary including a list of *métiers* and the ratio of shark catch (all species together) to target species group (in weight) as well as the shark species composition (in proportion) of the studied shark species. The ratio's reference tables are used as presented in the EUPOA study (Murua et al., 2013a). This ratio reference table by *métier* incorporates the gear/target species information for each gear indicating the group of species targeted by the fishery. The ratio is the quantity (tonnes) of sharks (all species) caught for one ton of target species. For example, it has been assumed in the EUPOA that bait boats (BB) generates zero (0) tons of sharks per ton of major tunas, whereas gillnet combined (GN) generates 2 tons of sharks per ton of target species (mostly tunas). This information is based on literature available, expert knowledge and unpublished observer data.

2 - Preparation of data.

2.1 - Data task I (total nominal catches by flag and year) from each tuna-RFMO was compiled by fishery, i.e., a combination of flag, fleet and gear for the period 2000-2015 (16 years),

2.2 - Mean nominal catches were calculated for target species groups (studied shark species, major tuna including billfishes but excluding swordfish, other sharks, other species, small tunas, swordfish). Two types of means were then calculated:

2.2.1 - Simple mean using all 16 years including zeros (0s). This means that if a country makes no declaration one year, this will be used as a 0 catch to calculate the mean. With this scenario it is assumed that each 0 or blank (no declaration) in the data corresponds to a year without catch (real zero). This method provides the update of the "Low Estimate" scenario, as was done in the EUPOA study;

2.2.2 - For positive years only, in this case assuming that most zero declarations do not correspond to zero catches, but to missing data (e.g., lack of data submission). In this scenario, the mean is estimated by considering only years with positive shark catches. This method provides the update of the "High estimate" scenario, as was done in the EUPOA study;

2.2.3. The number of positive years is compiled and compared to analyse the effect of these two different assumptions in the final results.

2.2. For each fishery, a specific *métier* is identified (combination of a gear and a target species group) according to expert knowledge and species group profiles declared.

3 Estimation of "potential" shark catches by *métier*.

3.1 - Based on the ratio by *métier* (step 1) and target species average nominal catch declared (step 2), the potential catch of the studied sharks by species are then estimated:

3.1.1 - Shark sp catch = Target spp * $\text{Ratio}_{\text{shark species/target species}}$

3.2. The results are summarized and ranked by:

3.2.1 - Shark species mostly impacted;

3.2.2 - *Métiers* with most impact on shark catches (overall);

3.2.3 - *Métiers* with most impact in shark catches (species-specific).

This analysis was carried out for each ocean on a tuna-RFMO basis. For the specific case of the Mediterranean Sea, noting that the pelagic tuna fisheries data are reported to ICCAT while the rest of the fisheries is reported to GFCM, the major fisheries (country/fleet/gear) targeting tunas and sharks in the Mediterranean Sea were identified using information available on the ICCAT database.

Additionally to this update of the EUPOA results, time series have also been created for some species complexes, species or stocks. The usefulness and relevance of this new extension of the method is that those time series can be used as alternative scenarios in the tuna-RFMOs stock assessments.

Sub-task 1.2 - Discard levels

This sub-task revised and summarised the information on discards of the main oceanic pelagic sharks, including at-vessel mortality and post release survival rates. Information on discards were obtained from the catch and effort (Task II) or nominal catch (Task I) information, when available, and can then be augmented by additional information provided in statistical data reports and scientific documents presented to the tuna-RFMOs.

Sub-task 1.3 - Length frequencies

This sub-task revised and summarised the length frequency data available, based on observer, port sampling, self-sampling programmes, and other relevant sources. Additionally, the consortium also explored additional data that has been compiled by specific Shark Working Groups of the various tuna-RFMOs and other relevant sources for specific stock assessments of some pelagic shark species, especially the major sharks as blue shark and shortfin mako shark (e.g., Coelho et al., 2015a, 2017a, 2018).

Sub-task 1.4 - Biological information

Biological information was collated and summarized for the main shark species caught in large pelagic fisheries of the Atlantic, Indian and Pacific Ocean and Mediterranean Sea. This compilation was carried out preferably to the stock level within each species, in cases where such separation of biological information at the stock level is available. The available literature, as well as manuals and documents, were consulted to obtain the key biological parameters and relationships that are and/or can be used for stock assessment purposes, including age and growth, reproduction, mortality, tagging, and length/weight relationships and other relevant conversion factors.

This task updated the biological information gathered in Murua et al. (2013). Data was compiled from the scientific and grey literature, including papers and technical documents presented to the scientific bodies of tuna-RFMOs. The databases from the tuna-RFMOS were also searched.

Sub-task 1.5 - Fishery indicators

Detailed information on the currently available fishery indicators that have been produced by the Sharks Working Groups of the various tuna-RFMOs and other relevant sources were compiled and described. Those included, among others, indicators on nominal catch trends, CPUE trends (nominal or standardized), average weights and/or sizes of catches, and spatial distribution.

The data for this specific component was gathered from reports on the stock assessments (e.g., standardized CPUE series used as input on stock assessments), and compiled from other scientific and grey literature, including papers and technical documents presented to the scientific bodies of tuna-RFMOs. The databases from the tuna-RFMOS were also searched for the existence of indicators.

4.4. *Results and Discussion*

<u>*Sub-task 1.1 - Historical catch data*</u>

ICCAT

The collection and reporting of catches of sharks caught in association with species managed by ICCAT has been in general very incomplete over time, and as such the ICCAT database for sharks and other bycatch is thought to be very incomplete. The catches of sharks, when reported, in most cases represent only the catches of species and specimens retained onboard and there is very limited information on discards (see subtask 1.2). Additionally, for the EU vessels there is now a fin-attached policy in place for sharks that allows a better monitoring of the total retained catches, this policy does not apply to other (non EU) fleets and, as such, the information on how the fins and carcasses are processed separately is usually not reported. Thus, there are currently substantial difficulties to estimate the total catches of sharks in the Atlantic Ocean. The reporting for the major ICCAT shark species (BSH, SMA and POR) is considered to be better than for other species; however, still there are inconsistencies in the reporting of the fishery statistics even for those main shark species.

The ICCAT databases that are available are:

- <u>Task I nominal catch data</u> (landings and discards by species, stock, gear, fleets and year): This database represents the most basic information that is used in most stock assessments, and is supposed to represent the total removals from the population. The availability of this timely data is essential for the SCRS (Standing Committee Research and Statistics) work, especially when stock assessments are being carried out.
- <u>Task II catch and effort and size sampling</u>: Those data are more detailed in terms geographic area information, but often reflect only partial coverage (or sampling) compared to Task I statistics. Task II information is the main source of data used by the Secretariat to estimate important datasets to be used in the assessment of the species, as for example the catch-at-size or the catch-at-age. The data catalogues shown in sub-task 1.5 (Appendix III - Tables III.4 to III.10) summarize if Task II data is available for each given year/flag/gear. Data for the blue shark tends to be more complete than for other species, and also for the North Atlantic stock. The most data-limited

species is the porbeagle. Also, the case of the Mediterranean is particularly problematic with almost no data reported or available. Several reiterations have been made by both the SC-ECO (Sub-Committee on Statistics) and the ICCAT Secretariat on the need for CPCs to report this detailed Task II catch-effort statistics, including on targeted and bycatch species, with the corresponding effort and units, time (month) and area strata as detailed as possible (LL: 5°x5° squares; other gears: 1°x1° squares).

In general, the global statistics on shark catches have been improving, but are still considered insufficient to permit the SCRS to provide robust quantitative advice on stock status with sufficient precision to guide fishery management toward optimal harvest levels.

Another major issue with shark species is that, historically, many species have been reported in aggregated form (no species-specific information) by a considerable number of fleets. Those "unclassified" sharks can include general codes as CVX: Carcharhiniformes; CXX: Coastal Sharks nei; DGX: Squalidae; PXX: Pelagic Sharks nei; SHX: Squaliformes; SKH: Selachimorpha; SYX: Scyliorhinidae, and can represent about 20% on average of the total shark catches. The Sharks Species working group has been trying to split these catches by species, but there is a need of continued inputs from CPCs and the progress has been very limited.

The 3 shark species that ICCAT lists as main sharks are:

- *Prionace glauca*, blue shark
- *Isurus oxyrinchus*, shortfin mako,
- *Lamna nasus*, porbeagle

However, many other species are of interest to the group, and CPCs also occasionally report data on other species. In 2015, the SCRS requested that a list of "sharks" (elasmobranchs, referring to sharks and rays) species that are considered oceanic, pelagic and highly migratory, and that should therefore fall under the ICCAT Convention, be prepared and provided by the Sharks Working Group. The Sharks Working Group prepared such list in its 2016 inter-sessional meeting (Anon, 2016a), highlighting the fact that those would be the species that meet the criteria agreed for inclusion in the list (oceanic, pelagic and highly migratory), but that many of them are not caught exclusively by ICCAT fisheries and most are not necessarily targeted and/or commercial species.

This revised list of species that fall under those categories (oceanic, pelagic and highly migratory), as prepared by the working group in 2016, is presented bellow (* = Species uncommonly caught by ICCAT fisheries):

- Order Orectolobiformes
  - Family Rhincodontidae
    - *Rhincodon typus*, whale shark *
- Order Lamniformes
  - Family Pseudocarchariidae
    - *Pseudocarcharias kamoharai*, crocodile shark
  - Family Lamnidae
    - *Carcharodon carcharias*, white shark *
    - *Isurus oxyrinchus*, shortfin mako
    - *Isurus paucus*, longfin mako
    - *Lamna nasus*, porbeagle
  - Family Megachasmidae
    - *Megachasma pelagios*, megamouth shark *
  - Family Cetorhinidae
    - *Cetorhinus maximus*, basking shark *
  - Family Alopiidae
    - *Alopias vulpinus*, common thresher
    - *Alopias superciliosus*, bigeye thresher
- Order Carcharhiniformes
  - Family Pseudotriakidae
    - *Pseudotriakis microdon*, false catshark *
  - Family Carcharhinidae
    - *Carcharhinus falciformis*, silky shark
    - *Carcharhinus galapagensis*, Galapagos shark*
    - *Carcharhinus longimanus*, oceanic whitetip shark
    - *Galeocerdo cuvier*, tiger shark
    - *Prionace glauca*, blue shark
  - Family Sphyrnidae
    - *Sphyrna lewini*, scalloped hammerhead
    - *Sphyrna mokarran*, great hammerhead
    - *Sphyrna zygaena*, smooth hammerhead
- *Order Squaliformes*
  - Family Dalatiidae
    - *Euprotomicroides zantedeschia*, taillight shark *
    - *Euprotomicrus bispinatus*, pygmy shark *
    - *Isistius brasiliensis*, cookiecutter shark *
    - *Isistius plutodus*, largetooth cookiecutter shark *
    - *Mollisquama cf. parini*, pocket shark *
    - *Squaliolus laticaudus*, spined pygmy shark *
- *Order Myliobatiformes*

- Family Dasyatidae
    - *Pteroplatytrygon violacea*, pelagic stingray
- Family Mobulidae
    - *Manta alfredi*, inshore manta ray *
    - *Manta birostris*, pelagic manta ray *
    - *Mobula hypostoma*, devil ray *

Due to the current limitations in data submission and availability, several recommendations have been put in place in ICCAT to address this issue and try to improve data collection and reporting on shark catches, as well as improved research and advice. A full list of the CMMs currently in place in ICCAT is presented in Appendix VIII, including those that explicitly have requests for data and science, as well as reporting obligations.

Even though many recommendations have been prepared and are currently active and in place, the data limitations are still significant. Due to these limitations, the Sharks Working Group needs to carry out regular substitutions on shark catches to be used in the stock assessments, particularly for BSH (last assessed in 2015 – Anon., 2015b) and SMA (last assessed in 2017 – Anon., 2017).

Catch reconstruction for ICCAT - Atlantic

Given the continued lack of sufficient quantitative information for stock assessment purposes, there is a high interest in using alternative methods for reconstructing alternative catch histories, especially for the main shark species. The original outputs of the EUPOA Project were presented to the ICCAT SCRS in the 2013 Species Groups meetings (Murua et al., 2013b), showing the overall estimated shark species catches for the period 2000-2010. However, at that time it was not possible to estimate the potential shark catches by year, and therefore the results could not be used in the stock assessments.

Now, based on the same method but adding the stratification by year, it was possible to further develop the results into time series that the 2017 SMA assessment, considered as a sensitivity scenario (Anon., 2017). Based on information provided in Task I, the major fisheries (country/fleet/gear) targeting tunas, swordfish and sharks in the Atlantic Ocean were identified.

According to the aggregated total catch available in the ICCAT database, in the Atlantic during the last 16 years (2000-2015), the largest shark catches (all species) have been declared by Spain, followed by Portugal, Japan, Namibia and Brazil. The flags/CPCs that account for 99% of the catches are listed in Table 4.4.1.

Figure 4.4.1 shows the total sharks reported landing (major sharks and other species) for the period of 2000-2015.

Table 4.4.1. Sharks (all species) total (cumulative) reported catches by fleet from 2000 to 2015. Only fleets until cumulative catches of 99% are shown (source: ICCAT Task 1 database).

Flag	Total catch (t)	%	Cum %
EU.Spain	558,449	59.6	59.6
EU.Portugal	140,924	15.0	74.7
Japan	64,020	6.8	81.5
Namibia	42,753	4.6	86.1
Brazil	34,769	3.7	89.8
Chinese Taipei	28,669	3.1	92.9
Canada	10,263	1.1	94.0
U.S.A.	8,783	0.9	94.9
Belize	6,944	0.7	95.6
Uruguay	6,200	0.7	96.3
EU.France	5,795	0.6	96.9
South Africa	5,289	0.6	97.5
China PR	5,240	0.6	98.0
Panama	4,478	0.5	98.5
Maroc	3,938	0.4	98.9
Korea Rep.	2,055	0.2	99.2

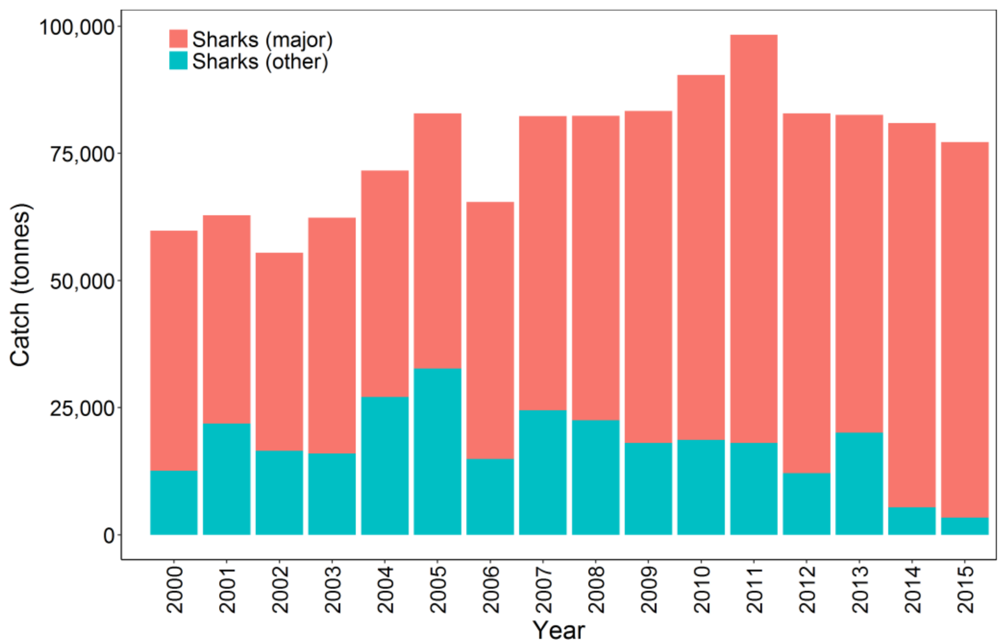


Figure 4.4.1. Reported landings of sharks (t) between 2000 and 2015 in the Atlantic (ICCAT) for major sharks (BSH, SMA and POR) and other shark species.

The estimated "potential" shark catches were 150,000 t considering the "High estimation" scenario (see methods, for Low estimation scenario results see Appendix IIIIV). This contrasts to the currently reported shark catches of around 80,000 t presently declared in ICCAT for the Atlantic Ocean (Figure 4.4.2). Among the different *métiers* identified, longlines targeting sharks (LL-shark) is the most impacting with the majority of the total estimated studied shark species catches (Figure 4.4.3). This is followed by general longline and other/unknown gears.

In terms of shark species, blue sharks have the most estimated catches, followed by shortfin mako. Those two species are mainly impacted by longline fisheries (LL-Sharks and LL). Other species with some relevance are hammerheads and then general Carcharhinidae sharks and other sharks that are mainly impacted by gillnets (Figure 4.4.4).

In terms of fleets and *métiers*, in the Atlantic Ocean the impact on pelagic sharks is highly concentrated in just a few fisheries (Figure 4.4.5). The EU longline fleets, particularly Spain followed by Portugal, are responsible for the majority of the catches, and the main captured species are blue shark and shortfin mako. Other important fleets and *métiers* that contribute to the overall shark catches are longlines from Brazil, Taiwan, Japan, Namibia and Senegal (Figure 4.4.5).

One important note from these results is that these fleets/*métiers* were identified on the basis of tuna and tuna like reported catches to ICCAT. Such data is based on the national reports from the national fisheries agencies, and can have significant limitations due to data collection, reporting efficiency and problems related with species identification. As such, the presented estimates are affected by possible under or non reporting and non-reporting of the main targeted tuna and tuna like species by each country.

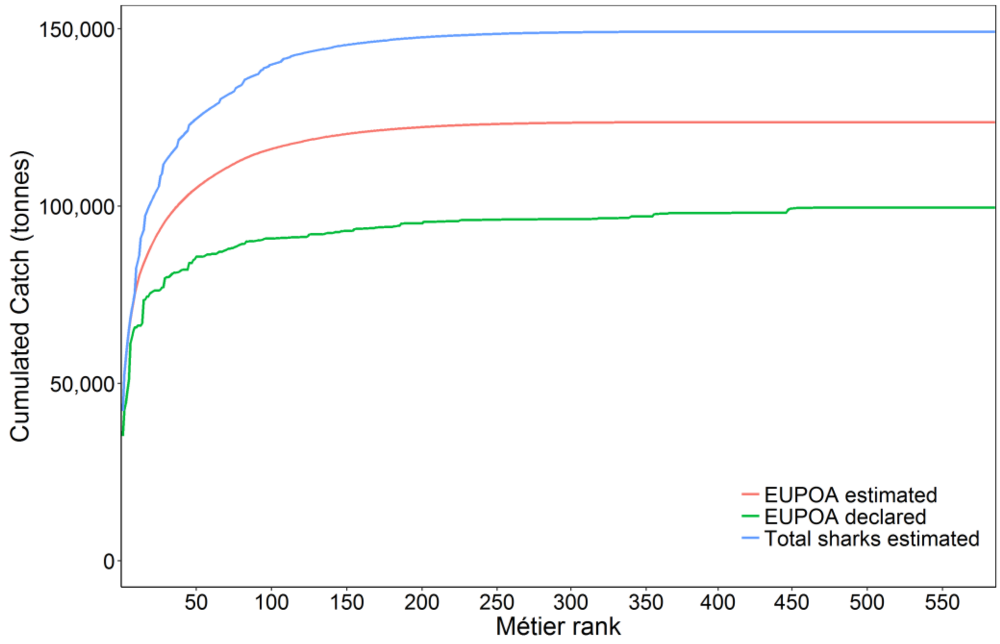


Figure 4.4.2. Cumulative declared catches (tonnes) and "High" estimation scenario reconstructed catches (tonnes) ranked by *métier* (from *métier* with higher estimated EUPOA catches to *métier* with lower estimated EUPOA catches). "EUPOA" refers to the 18 species originally considered in the EUPOA project and "Total sharks" refers to all shark species combined.

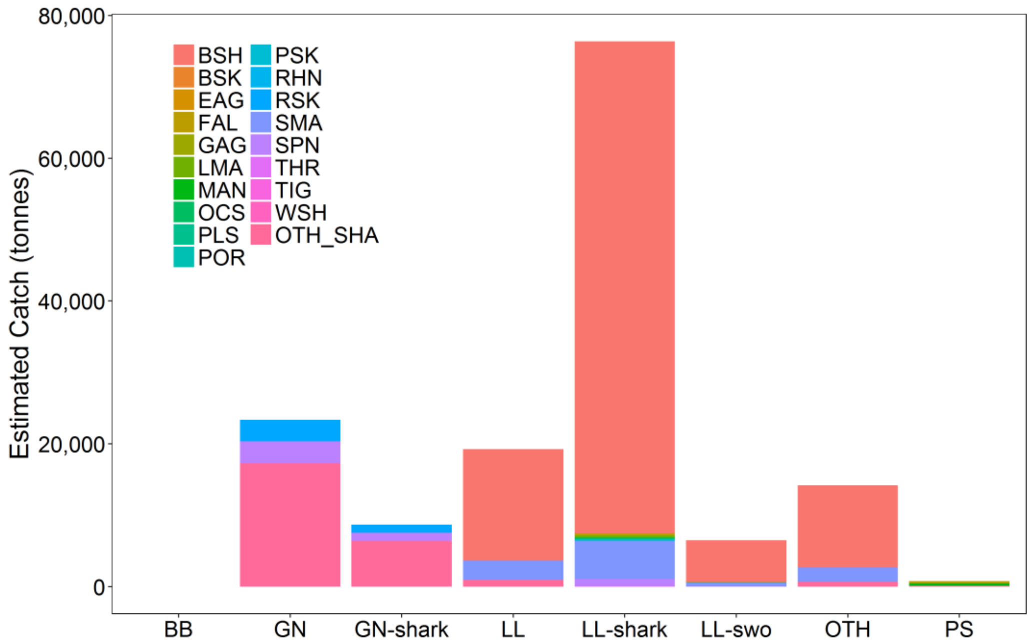


Figure 4.4.3. Estimated catch (tonnes) by *métier* and by species in the Atlantic Ocean (ICCAT), for the "High" scenario estimation. See Appendix I for acronyms list.

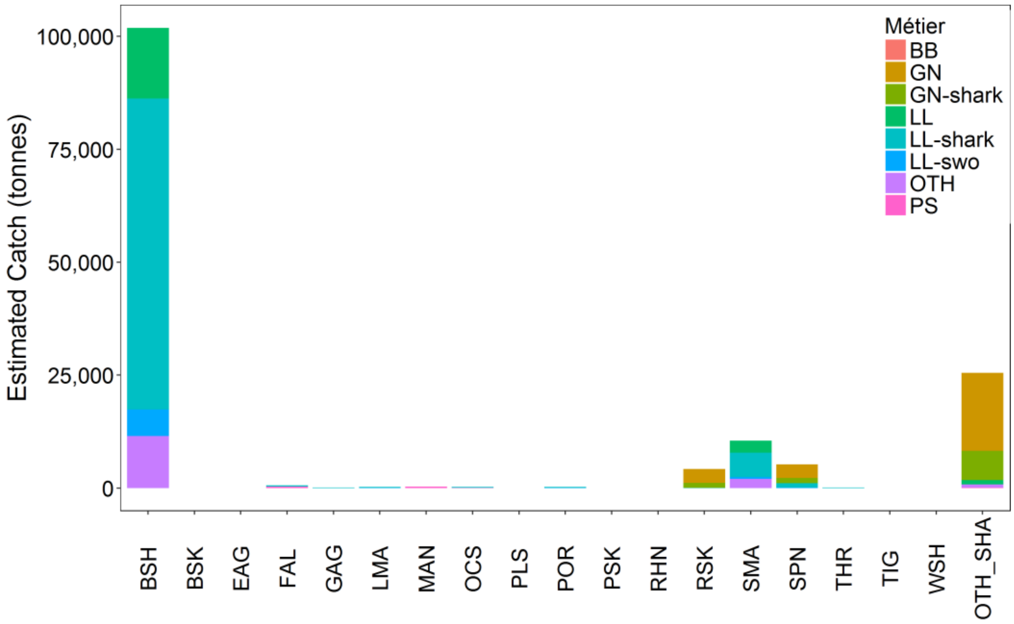


Figure 4.4.4. Estimated catch (tonnes) of the EUPOA shark species and other sharks by *métier* in the Atlantic Ocean (ICCAT), for the "High" estimation scenario. See Appendix I for acronyms list.

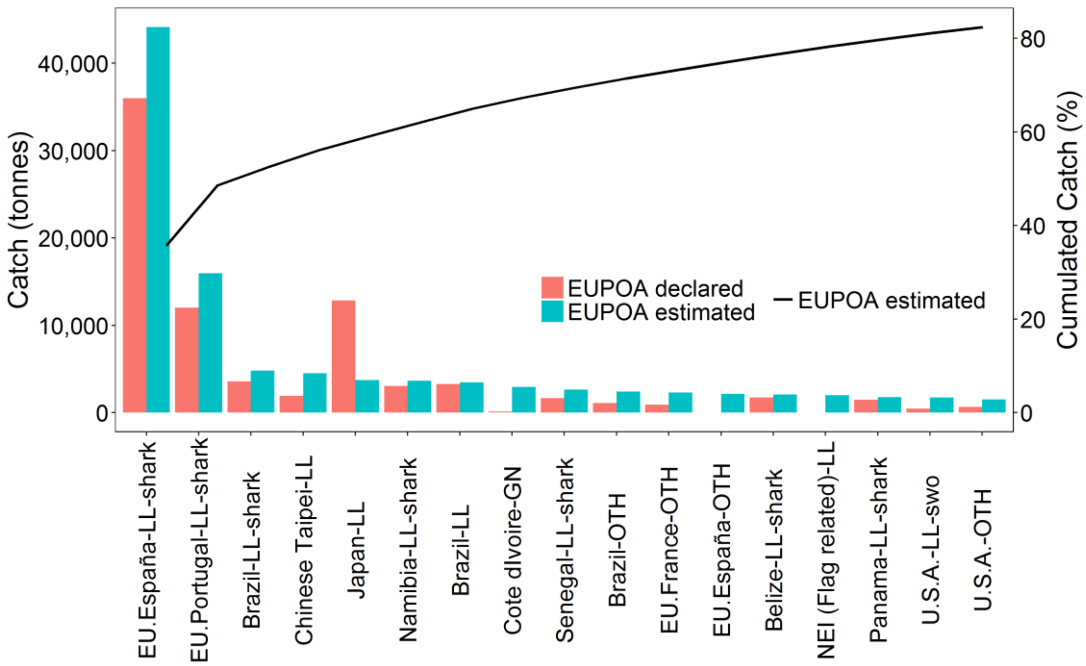


Figure 4.4.5. Declared and estimated catch (tonnes) and cumulative percentage of estimated catch of EUPOA shark species for the main fisheries (flag and *métier*) responsible for catching pelagic sharks species in the Atlantic Ocean (EUPOA shark species), under the "High" estimation scenario. See Appendix I for acronyms list.

In terms of time series, and as an extension to the EUPOA project method, it was now possible to make estimates of the time series of catches. The estimates start in 1971, as that is the starting year of many stock assessment models for sharks, before the expansion of oceanic fisheries in the 1970's. The time series for the EUPOA shark species and for all sharks is shown in Figure 4.4.6.

With the extension of the method, it is now also possible to reconstruct alternative catches for specific species delimited by stock, which can be directly included in the stock assessments. Figure 3.1.3.7 shows the alternative reconstructed catches for shortfin mako for both the North and South Atlantic stocks. This particular series is of special interest, as the shortfin mako was assessed by the ICCAT sharks working group (in June 2017), and this reconstructed series was used as a sensitivity scenario to the nominal catches reported to ICCAT (Anon, 2017). For this specific case of the shortfin mako, the main differences in the declared *vs.* estimated catches are particularly in the earlier years of the time series, which is consistent with the fact that underreporting and lack of species specific information was more problematic in the past (Figure 4.4.7).

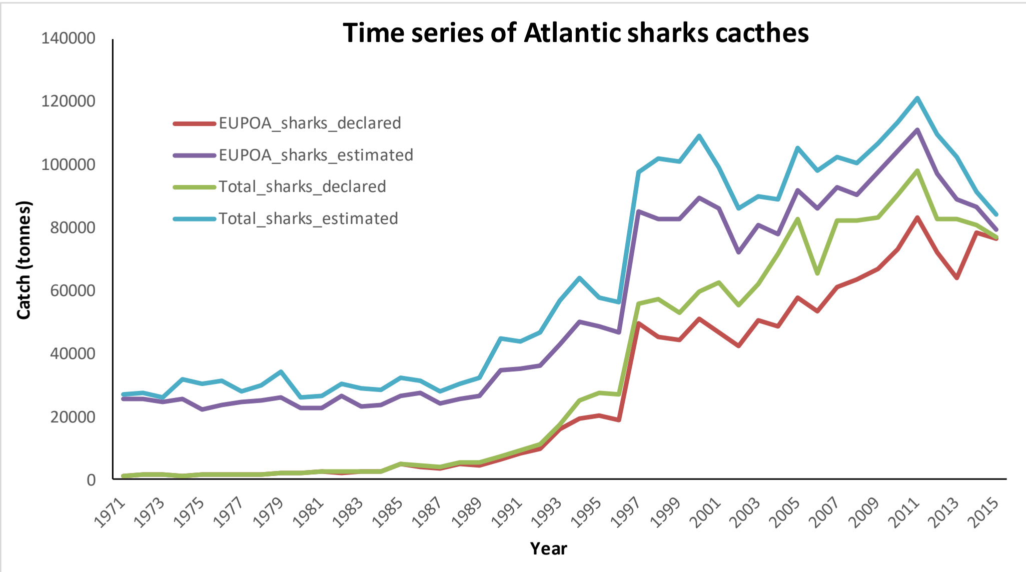


Figure 4.4.6. Time series of sharks nominal catches declared and available at the ICCAT database and those estimated in this study, between 1971 and 2015, for the Atlantic Ocean. Lines are shown both for the total shark species and for the EUPOA species.

Figure 4.4.7. Time series of declared vs. estimated shortfin mako shark (SMA) catches, between 1971 and 2015, for the North and South Atlantic stocks.

Catch reconstruction for ICCAT - Mediterranean

Nations with pelagic fisheries in the Mediterranean Sea should report their pelagic tuna and tuna-like catches (including pelagic sharks) to ICCAT; therefore the catch reconstruction is based on ICCAT Task I for the Mediterranean region, showing the overall estimated shark species catches for the period 2000-2015.

According to the aggregated total catch available in the ICCAT database, in the Mediterranean during the last 16 years (2000-2015), the largest shark catches (all species) have been declared mainly by Turkey, followed by Italy, Morocco, Spain, Malta and Bulgaria. The list of flags that account for 99% of the catches are shown in Table 4.4.2. Figure 4.4.8 shows the total sharks reported landing (major sharks and other species) for the period of 2000-2015.

Table 4.4.2. Sharks (all species) total (cumulative) reported catches by fleet from 2000 to 2015. Only fleets until cumulative catches of 99% are shown (source: ICCAT Task 1 database).

Flag	Total catch (t)	%	Cum %
Turkey	3387.00	42.1	42.1
EU.Italy	1876.45	23.3	65.5
Maroc	867.70	10.8	76.3
EU.Spain	522.66	6.5	82.8
EU.Malta	437.08	5.4	88.2
EU.Bulgaria	353.79	4.4	92.6
EU.France	324.00	4.0	96.7
EU.Portugal	171.91	2.1	98.8

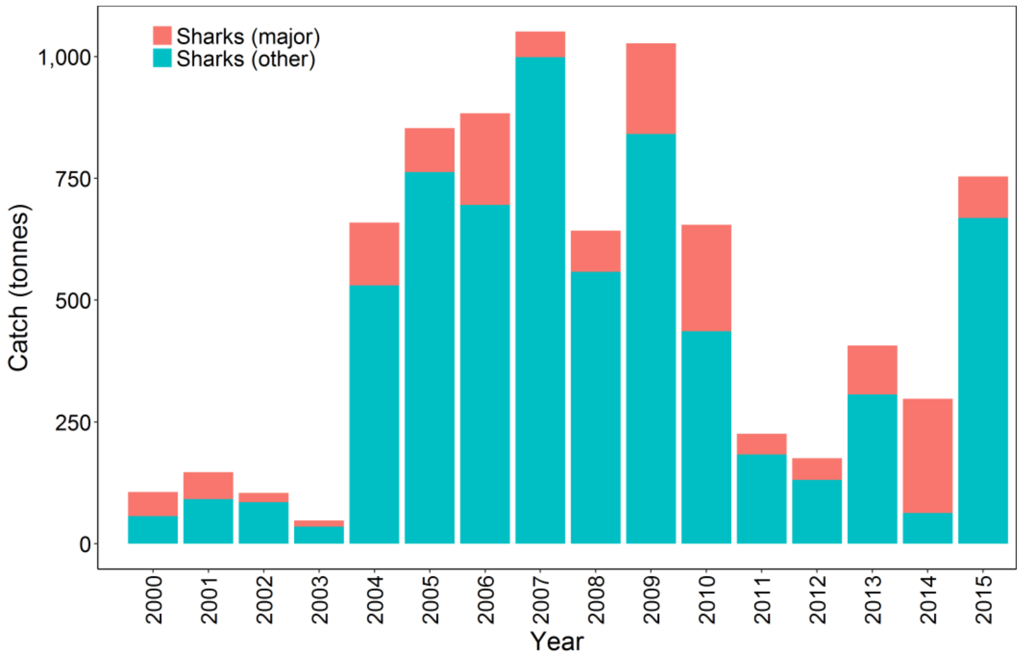


Figure 4.4.8. Reported landings of shark catches (t) between 2000 and 2015 in the Mediterranean (ICCAT) for major sharks (BSH, SMA and POR) and other shark species.

There are numerous and serious issues and problems with this official data, and therefore using this data for stock assessment purposes is not possible. For example, the high catches reported by Turkey (Table 4.4.2) refer to school shark (GAG, *Galeorhinus galeus*) which is a demersal species and not a pelagic shark. Another even more critical example are the relatively high reported catches of other shark species in 2015 (Figure 4.4.8) part of which refers to data submitted by EU Bulgaria from the Black Sea on spined pygmy shark (QUL, *Squaliolus laticaudus*) a very small deep sea shark that is highly unlikely to interact with ICCAT (pelagic) fisheries and that is not reported to occur in the Mediterranean or the black sea. As such, any attempt to reconstruct historical catches from the Mediterranean is fundamental if stock assessments are to be carried out in the future.

The estimated "potential" shark catches are 9,600 t considering the High estimation scenarios (see methods, for Low estimation scenario results see Appendix III). This contrasts to the currently reported shark catches of around 400 to 800 t presently declared in ICCAT for the Mediterranean Sea (Figure 4.4.9).

Among the identified different *métiers*, longlines targeting swordfish (LL-swo-albo) is the most impacting with the majority of the total estimated studied shark species catches (Figure 4.4.10). This is followed by gillnets targeting swordfish (GN-swo-tul, GN-swo-it) and other types of longlines targeting swordfish and sharks (LL-swo-sp, LL-sharks).

In terms of shark species, blue sharks have the highest number of estimated catches, followed by thresher sharks and shortfin mako. These three species are mainly impacted by longline fisheries (LL-swo-albo and LL-sharks) and gillnets targeting swordfish (GN-swo-tul). Other species with some relevance are the tope sharks followed by the pelagic stingray that are mainly impacted by longlines targeting sharks (LL-sharks) (Figure 4.4.11).

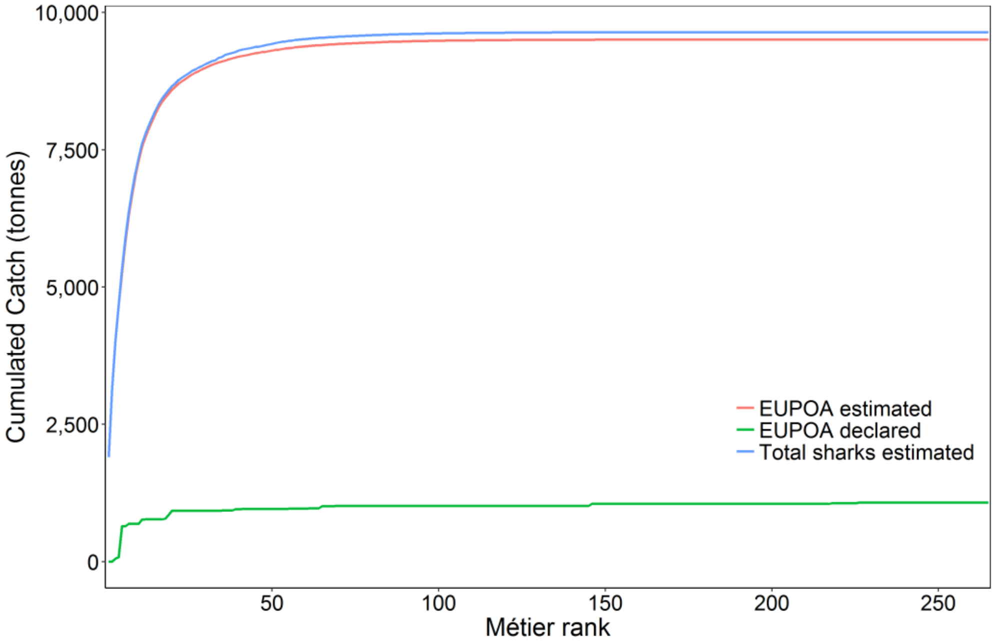


Figure 4.4.9. Cumulative declared catches (tonnes) and "High" estimation scenario reconstructed catches (tonnes), ranked by *métier* (from *métier* with higher estimated EUPOA catches to *métier* with lower estimated EUPOA catches). "EUPOA" refers to the 18 species originally considered in the EUPOA project and "Total sharks" refers to all shark species combined.

In terms of fleets and *métiers*, in the Mediterranean Sea the impact on pelagic sharks is distributed by a few fisheries (Figure 4.4.12). The Moroccan gillnet fleet, the EU longline fleets, particularly Spain and Italy, the Moroccan and Tunisian longline fleets are the five fleets with most catches, and the main captured species are blue shark (BSH), thresher sharks (THR) and shortfin mako (SMA).

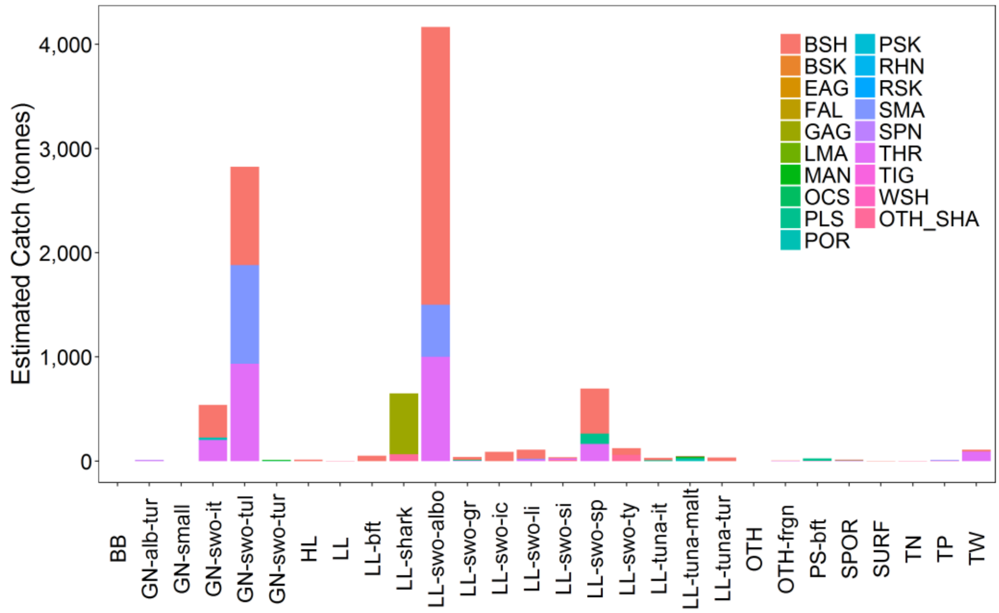


Figure 4.4.10. Estimated catch (tonnes) by *métier* and by species in the Mediterranean Sea (ICCAT), for the "High" scenario estimation. See Appendix I for acronyms list.

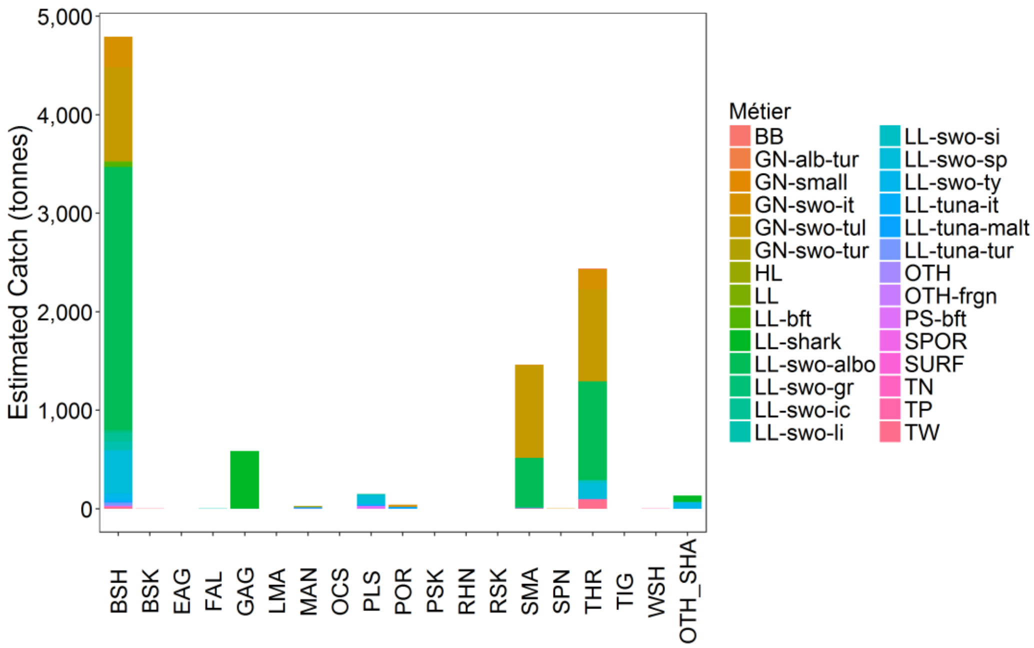


Figure 4.4.11. Estimated catch (tonnes) of the EUPOA shark species and other sharks by *métier* in the Mediterranean Sea (ICCAT), for the "High" estimation scenario. See Appendix I for acronyms list.

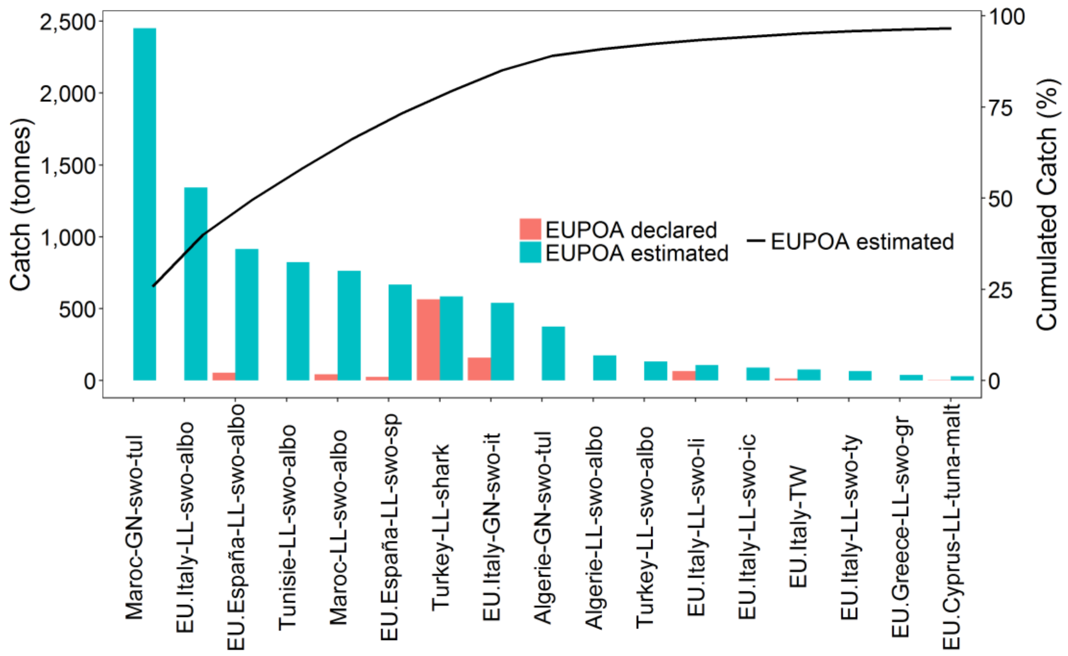


Figure 4.4.12. Declared and estimated catch (tonnes) and cumulative percentage of estimated catch of EUPOA shark species for the main fisheries (flag and *métier*) responsible for catching pelagic sharks species in the Mediterranean (EUPOA shark species), under the "High" estimation scenario. See Appendix I for acronyms list.

One important note on these results is that these fleets/*métiers* were identified on the basis of tuna and tuna-like reported catches to ICCAT. Such data are based on the national reports from the national fisheries agencies, and can have significant limitations due to data collection, reporting efficiency and problems related with species identification. As such, the presented estimates are affected by possible under- or non-reporting of the main targeted tuna and tuna-like species by each country.

IOTC

The collection and reporting of catches of sharks caught in association with species managed by IOTC has been in general very incomplete over time, and as such the IOTC database for sharks and other bycatch is thought to be very incomplete. The catches of sharks, when reported, in most cases represent only the catches of species and specimens retained onboard and there is very limited information on discards (see subtask 1.2 bellow). They refer, in many cases, to dressed weights and no indication on the type of processing that the different specimens underwent. Whilst for the EU vessels there is now in place a fin-attached policy for sharks that allows a better monitoring of the total retained catches, this policy does not apply to other (non EU) fleets and therefore the information on how the fins and carcasses are processed separately is usually not reported. It is noted, however, a new IOTC regulation that has recently implemented the fins-attached policy in the fresh operating fleets (IOTC Res. 17/05[4]). However, the implementation level of such recent measure is still unknown, and as such there are currently substantial difficulties in estimating the total catches of sharks in the Indian Ocean.

The IOTC databases that are available are:

- Nominal catches data: This dataset contains annual catches (measured in live weight) for each IOTC statistical area, by species and fishing gear for each vessel flying the flag of the reporting country. These data are aggregated by calendar year for tuna, tuna-like species and non-target species (by-catch). The data set extends back to the 1950's when industrial longlining started in the Indian Ocean. If these data are not reported, the Secretariat attempts to estimate a total catch, although this is not possible in many cases due to the lack of sufficient detail in the available data. A range of sources are used for this purpose, including: partial catch and effort data, data in the FAO FishStat database, catches estimated by the IOTC from data collected through port sampling and data published through web pages or other means.
- Catch and effort (CE) and size sampling: Those data are more detailed in terms of geographic area information, but often reflect only partial coverage (or sampling) compared to nominal catches data. Catch is usually reported in weight (purse seine) and/or numbers of fish (longline) of tuna and tuna-like species, preferably raised to the total nominal catch and fishing effort by month, species and gear. The maximum spatial aggregation should be by 1°x1° grid area for purse seine and 5°x5° grid area for longline. This is not, however, the case with all CE data available: CE data recorded for most artisanal fleets refers to irregular areas (e.g. CE data recorded per port of unloading). When recorded, the catches in these datasets might represent the total catches of the species in the year for the fleet and gear concerned or represent simply a sample of those. This data is obtained from logbooks, and reported per fleet, year, gear, type of school, month, grid and species. Information on the use of fish aggregating devices (FADs) and supply vessels is also collected.

[4] IOTC Resolution 17/05. On the conservation of sharks caught in association with fisheries managed by IOTC.

In general, the global statistics on shark catches have been improving, but are still considered insufficient to permit IOTC to provide robust quantitative advice on stock status with sufficient precision to guide fishery management toward optimal harvest levels.

Another major issue with shark species, particularly relevant in IOTC, is historically many species have been reported in aggregated form (without species-specific information) by a considerable number of fleets, although the species-specific reporting rate has been increasing (Figure 4.4.13). Those "unclassified" sharks can include general codes as RSK: Requiem sharks *nei*; CWZ: *Carcharhinus* sharks *nei*; SKH: Sharks various *nei*; MAK: Mako sharks; SPY: Bonnethead and hammerhead sharks; SPN: Hammerhead sharks *nei*; SHXX: Selachimorpha (Pleurotremata); among others, and can represent about 50% on average of the total shark catches in recent years. The IOTC Working Party on Ecosystems and By-Catch (WPEB) has been trying to split these catches by species as much as possible, but there is a need of continued inputs from CPCs and the progress has been very limited.

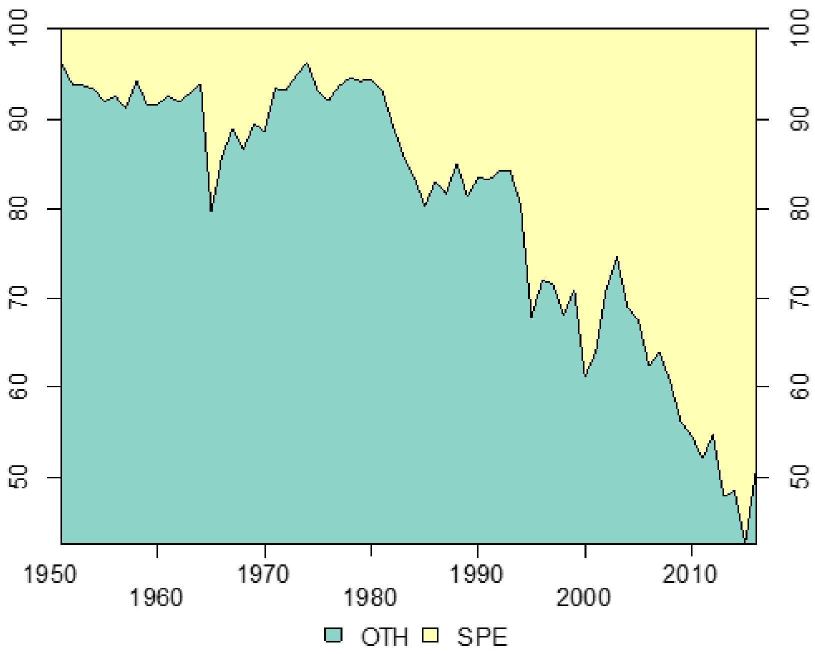


Figure 4.4.13. Proportion of shark catches reported by species and as aggregate catch (OTH) to IOTC (source: IOTC, 2016a).

The 7 shark species that IOTC lists as main sharks are:

- blue shark (*Prionace glauca*)
- shortfin mako (*Isurus oxyrinchus*)
- silky shark (*Carcharhinus falciformis*)

- oceanic whitetip shark (*Carcharhinus longimanus*)
- scalloped hammerhead shark *(Sphyrna lewini*)
- bigeye thresher (*Alopias superciliosus*)
- pelagic thresher (*Alopias pelagicus*)

On this particular list, we need to note that the inclusion of scalloped hammerhead shark as the only hammerhead species seems quite confusing. The scalloped hammerhead is the most coastal of the hammerheads (genus *Sphyrna*), while other species as the smooth hammerhead (*Sphyrna zygaena*), currently not listed by IOTC, is the most oceanic species of the genus. The reasons for not including the three hammerheads from the *Sphyrna* genus in the IOTC shark species list are not clear.

Due to the current limitations in data submission and availability, several recommendations have been put in place in IOTC to address this issue and try to improve data collection and reporting on shark catches, as well as improved research and advice. A full list of the CMMs currently in place in IOTC is presented in Appendix VIII, including those that explicitly request for data as well as reporting obligations.

Even though many recommendations have been prepared and are currently active and in place, the data limitations in IOTC are still very significant. Due to these limitations, the Working Party on Ecosystems and By-Catch needs to carry out regular substitutions on shark catches to be used in the stock assessments, offering the highest source of uncertainty in the work carried out by the Working Party.

Catch reconstruction for IOTC - Indian Ocean

Given the continued lack of sufficient quantitative information for stock assessment purposes, there is an interest in using alternative methods for reconstructing alternative catch histories, especially for the main shark species. The original outputs of the EUPOA Project were presented to the Working Party on Ecosystems and Bycatch in the 2013 (Murua et al., 2013c), showing the overall estimated shark species catches for the period 2000 to 2010. An update for the period 2000 to 2015 is presented below.

Based on information provided in nominal catch, the major fisheries (country/fleet/gear) targeting tunas, swordfish and sharks in the Indian Ocean were identified. According to the aggregated total catch available in the IOTC database, in the Indian Ocean during the last 16 years (2000-2015), the largest shark catches (all species) have been declared by Indonesia, followed by Pakistan, Yemen, Iran and Sri Lanka. The list of flags that account for 90% of the catches are listed in Table 4.4.3. Figure 4.4.14 shows the total sharks reported landing (main sharks and other species) for the period of 2000 to 2015.

Table 4.4.3. Sharks (all species) total reported catches by fleet from 2000 to 2015. Only fleets until cumulative catches of 90% are shown (source: IOTC nominal catches database).

Flag	Total catch (t)	%	Cum %
Indonesia	299,040.8	18.5	18.5
Pakistan	197,164.0	12.2	30.7
Yemen	162,617.0	10.1	40.8
Iran Islamic Rep.	159,573.4	9.9	50.6
Sri Lanka	146,402.6	9.1	59.7
Oman	92,310.7	5.7	65.4
Madagascar	91,000.3	5.6	71.0
Taiwan,China	66,421.5	4.1	75.1
EU.Spain	63,791.0	3.9	79.1
Maldives	61,611.3	3.8	82.9
Tanzania	41,770.4	2.6	85.5
India	36,172.7	2.2	87.7
Un. Arab Emirates	29,298.5	1.8	89.5

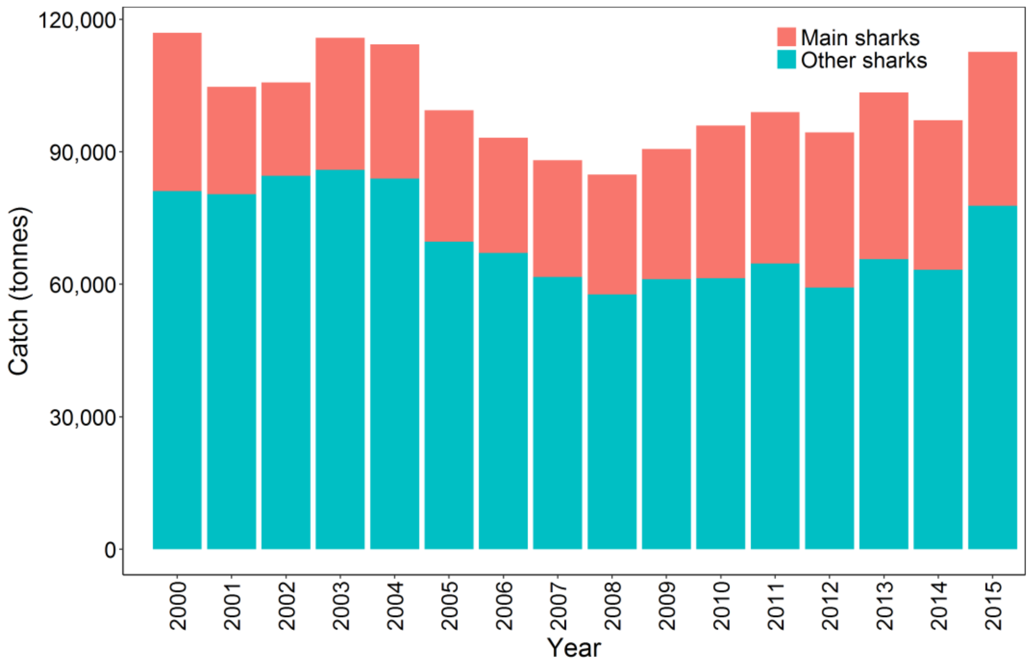


Figure 4.4.14. Reported landings of sharks (t) between 2000 and 2015 in the Indian Ocean (IOTC) for main sharks (BSH, SMA, FAL, OCS, BTH, PTH, SPL) and other shark species.

The estimated "potential" shark catches are around 130,000 t, for the High estimation scenario (see methods, for Low estimation scenario results see Appendix III). This contrasts to the currently reported shark catches of around 100,000 t presently declared in IOTC for the Indian Ocean (Figures 4.4.15). Among the different *métiers* identified, gillnets combined with longlines (GN-LL) is the most impacting with the majority of the total estimated studied shark species catches (Figures 4.4.16). This is followed by other/unknown gears (OTH), general longline (LL) and longlines targeting swordfish (LL-swo).

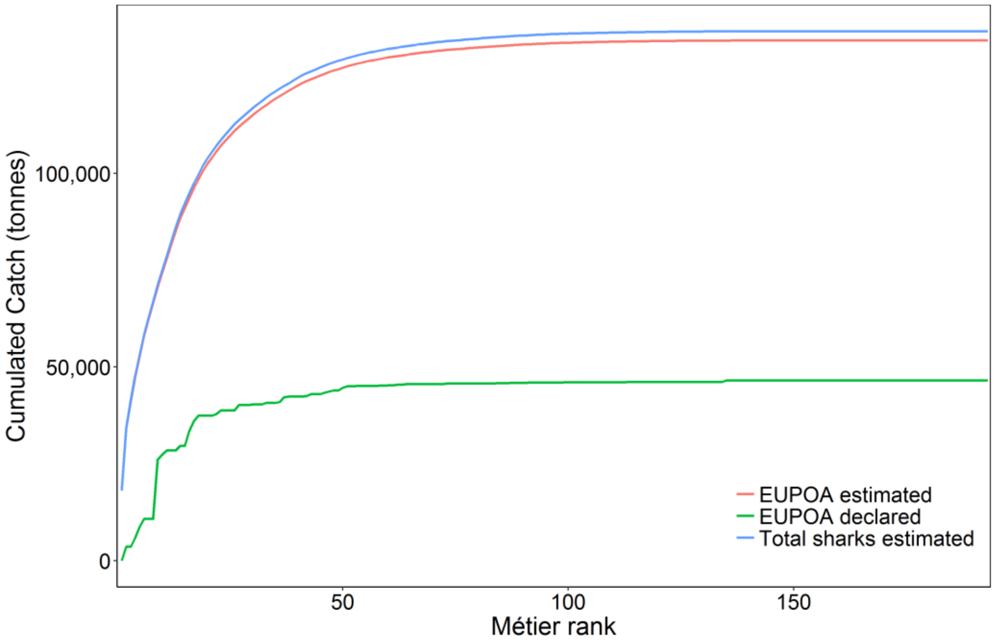


Figure 4.4.15. Cumulative declared catches (tonnes) and "High" estimation scenario reconstructed catches (tonnes), ranked by *métier* (from *métier* with higher estimated EUPOA catches to *métier* with lower estimated EUPOA catches). "EUPOA" refers to the 18 species originally considered in the EUPOA project and "Total sharks" refers to all shark species combined.

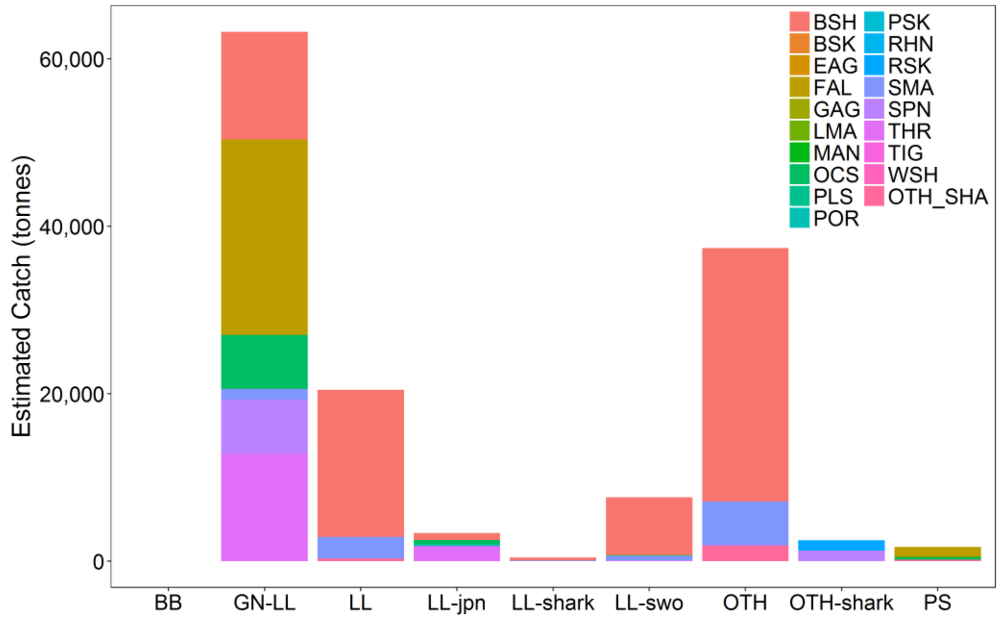


Figure 4.4.16. Estimated catch (tonnes) by *métier* and by species in the Indian Ocean (IOTC), for the "High" scenario estimation. See Appendix I for acronyms list.

In terms of species, the five shark species with the highest estimated catches are blue shark, with the majority of the catches, followed by silky shark, thresher sharks, shortfin mako and hammerhead sharks. Blue shark and shortfin mako are mainly impacted by other/unknown gears (OTH) and longline fishery (LL). The other 3 species are mostly impacted by gillnet fisheries (GN-LL) (Figures 4.4.17).

In terms of fleets and *métiers*, the impact on pelagic sharks in the Indian Ocean is highly concentrated in just a few fisheries (Figures 4.4.18). The Sri Lanka gillnet combined with longlines fishery, the Iranian gillnet fishery, other Indonesian fisheries (not longlines, gillnets, baitboats and purse-seiners) and Taiwanese longliners accounts for around 50% of the catches.

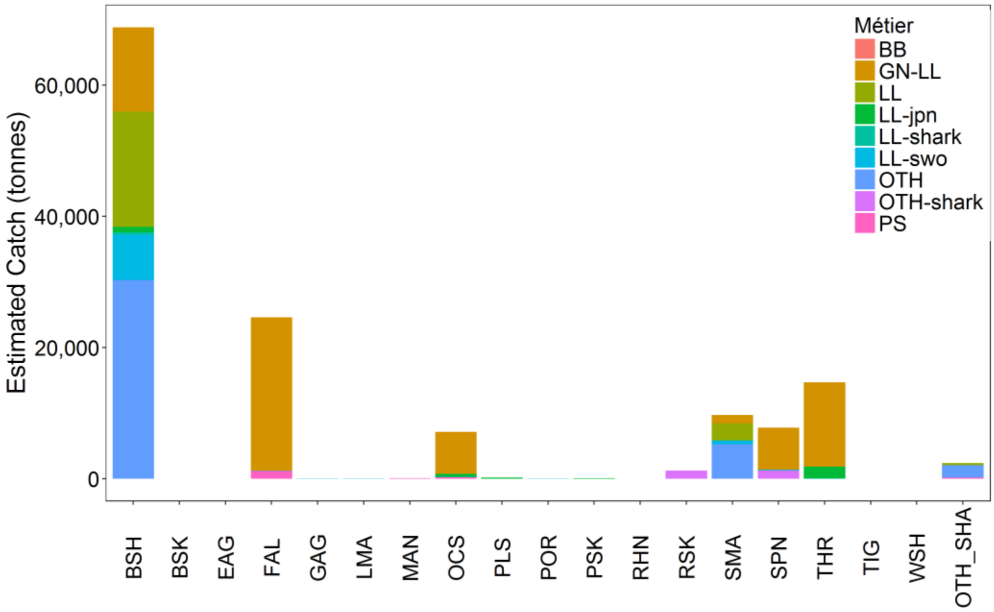


Figure 4.4.17. Estimated catch (tonnes) of the EUPOA shark species and other sharks by *métier* in the Indian Ocean (IOTC), for the "High" estimation scenario. See Appendix I for acronyms list.

One important note on these results is that these fleets/*métiers* were identified on the basis of tuna and tuna like catches reported to IOTC. Such data is based on the reports from the national fisheries agencies, and can have significant limitations due to data collection, reporting efficiency and problems related with species identification. As such, the presented estimates are affected by possible under or/and non-reporting of the main targeted tuna and tuna like species by each country.

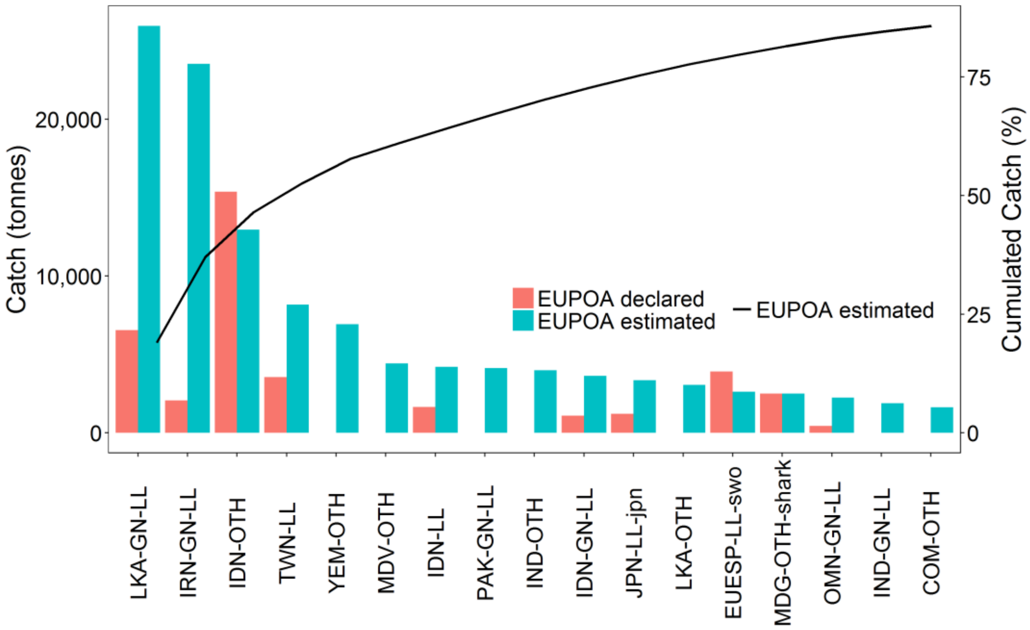


Figure 4.4.18. Declared and estimated catch (tonnes) and cumulative percentage of estimated catch of EUPOA shark species for the main fisheries (flag and *métier*) responsible for catching pelagic sharks species in the Indian Ocean (EUPOA shark species), under the "High" estimation scenario. See Appendix I for acronyms list.

IATTC

The collection and reporting of catches of sharks caught in association with species managed by IATTC has been scarce, and as such the IATTC database for sharks and other bycatch is thought to be very incomplete. The catches of sharks, when reported, in most cases represent only the catches of species and specimens retained onboard and there is very limited information on discards (see subtask 1.2). The data refers, in many cases, to dressed weights and no indication on the type of processing that the different specimens underwent. Additionally, non-EU fleets do not have the fins attached policy and as such the information on how the fins and carcasses are processed separately is usually not reported, especially with species identification issues. As such, there are currently substantial difficulties to estimate total catches of sharks in the IATTC area.

The IATTC databases that are available are:

- Catch by year and flag: This dataset lists annual catches by species and fishing gear made by vessels flying the flag of the reporting country in live weight equivalent. The data set extends back to 1918. Data sources for 1918-1930 reported catch as "principally" pole-and-line, and for 1954 to 1958 as combined from pole-and-line and purse seine.

- Catch and effort (CE): Catch and effort is reported for longline and purse seine fisheries. Catch is reported in weight and/or numbers of fish by year, month, flag or set type (purse seine) and number of hooks (longline). The maximum spatial aggregation is by 1°x1° grid area for purse seine and 5°x5° grid area for longline. Records of purse seiners catch are by on-board observers.

In general the global statistics on shark catches have been improving, but are still considered insufficient to permit IATTC to provide quantitative advice on stock status with sufficient precision to guide fishery management toward optimal harvest levels.

Another major issue with shark species is that historically many species have been reported in aggregated form (no species-specific information) by a considerable number of fleets, although the species-specific reporting rate has been increasing. Those "unclassified" sharks can include general codes as SKH: Various sharks nei; MAK: Mako sharks; SPN: Hammerhead sharks nei; SRX: Requiem sharks, nei; THR: Thresher shark, nei; among others.

The 10 shark species that IATTC lists as main sharks are:

- blue shark (*Prionace glauca*)
- shortfin mako (*Isurus oxyrinchus*)
- silky shark (*Carcharhinus falciformis*)
- oceanic whitetip shark (*Carcharhinus longimanus*)
- scalloped hammerhead shark *(Sphyrna lewini*)
- smooth hammerhead (*Sphyrna zygaena*)
- great hammerhead (*Sphyrna mokarran*)
- bigeye thresher (*Alopias superciliosus*)
- pelagic thresher (*Alopias pelagicus*)
- common thresher shark (*Alopias vulpinus*)

Due to the current limitations in data submission and availability, several recommendations have been put in place in IATTC to address this issue and try to improve data collection and reporting on shark catches, as well as improved research and advice. A full list of the CMMs currently in place in IATTC is presented in Appendix VIII (appendix from Task 5), including those with explicit requests for data and science and well as reporting obligations.

Even though many recommendations have been prepared and are currently active and in place, the data limitations are still significant.

Catch reconstruction for IATTC – Eastern Pacific Ocean

Given the continued lack of sufficient quantitative information for stock assessment purposes, there is an interest in using alternative methods for reconstructing alternative catch histories, especially for the main shark species. The original outputs of the EUPOA Project (Murua et al., 2013c) presented the overall estimated shark species catches for the period 2000 to 2010.

The current study aimed to update for the period 2000 to 2015, however was not possible due to the reporting rates and ratios of target *versus* shark species. While the reported catches of tunas have been more or less constant (Figure 4.4.19), the reporting of shark catches has increased in the last few years (Figure 4.4.20), which creates discrepancies in the ratios. Therefore, the ratio of target species catch to shark catch no longer applies and the catch is underestimated if this method is used. Furthermore, elasmobranch catches in the public nominal database is aggregated in two categories SKH (Various sharks nei) and SRX (Rays, Skates, nei), hindering the evaluation of which species are most impacted by the fisheries operating in this RFMO.

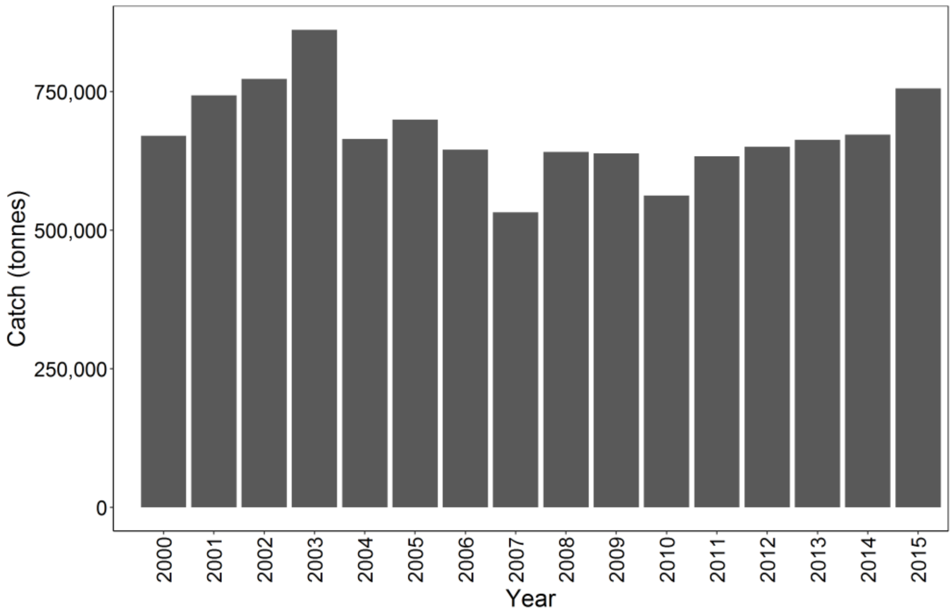


Figure 4.4.19. Reported landings of major tuna (t) between 2000 and 2015 in the Eastern Pacific Ocean (IATTC).

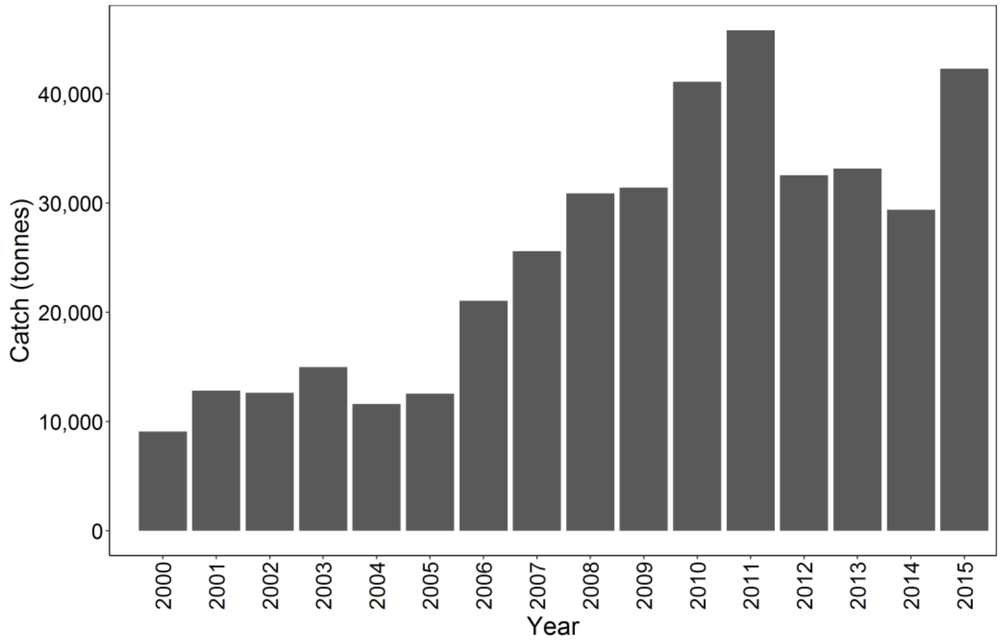


Figure 4.4.20. Reported landings of sharks (t) between 2000 and 2015 in the Eastern Pacific Ocean (IATTC) for all shark and rays species.

WCPFC

The collection and reporting of catches of sharks caught in association with species managed by WCPFC deficient, with database for sharks and other bycatch thought to be incomplete. The catches of sharks, when reported, in most cases represent only the catches of species and specimens retained onboard and there is very limited information on discards (see subtask 1.2). They refer, in many cases, to dressed weights and no indication on the type of processing that the different specimens underwent. As such, there are currently substantial difficulties to estimate total catches of sharks in the WCPFC area.

The WCPFC compiles and maintains databases containing several different types of scientific data, covering annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data.

The WCPFC database that is publicly available is:

- <u>Catch and effort</u>: The WCPFC have compiled a public domain version of aggregated catch and effort data using operational, aggregate and annual catch estimates data. The public domain version does not include data for cells in which less than three vessels were active. Statistics showing how much data have been removed according to this requirement are provided in the documentation for the longline and purse seine public domain data. All public domain data have been aggregated by year/month and 5°x5° grid for driftnet, longline, pole-and-line and purse seine

In general, the global statistics on shark catches have improved, but are still considered insufficient to permit WCPFC to provide robust quantitative advice on stock status with sufficient precision to guide fishery management toward optimal harvest levels.

Another major issue with shark species is that historically many species have been reported in aggregated form (no species-specific information) by a considerable number of fleets, although the species-specific reporting rate has been increasing. Especially after 2011, as data provision for the species designated by WCPFC as key shark species is mandatory, however thresher and hammerheads are each considered as a species complex for reporting purposes.

The 14 shark species that WCPFC lists as main sharks are:

- blue shark (*Prionace glauca*)
- shortfin mako (*Isurus oxyrinchus*)
- longfin mako (*Isurus paucus*)
- silky shark (*Carcharhinus falciformis*)
- oceanic whitetip shark (*Carcharhinus longimanus*)
- scalloped hammerhead shark *(Sphyrna lewini*)
- smooth hammerhead (*Sphyrna zygaena*)
- great hammerhead (*Sphyrna mokarran*)
- winghead shark (*Eusphyra blochii*)
- bigeye thresher (*Alopias superciliosus*)
- pelagic thresher (*Alopias pelagicus*)
- common thresher shark (*Alopias vulpinus*)
- Whale shark (*Rhincodon typus*)

Due to the current limitations in data submission and availability, several recommendations have been put in place in WCPFC to address this issue and try to improve data collection and reporting on shark catches, as well as improved research and advice. A full list of the CMMs currently in place in WCPFC is presented in Appendix VIII (referring to task 5), including those with explicit requests for data and science and well as reporting obligations.

Even though many recommendations have been prepared and are currently active and in place, the data limitations are still significant. Due to these limitations, there is the need to carry out regular substitutions on shark catches to be used in the stock assessments, particularly for BSH (Takeuchi et al., 2016; ISC, 2017), FAL (Rice & Harley, 2013), OCS (Rice & Harley, 2012) and SMA (ISC, 2015).

Catch reconstruction for WCPFC – Western and Central Pacific Ocean

Given the continued lack of sufficient quantitative information for stock assessment purposes, there is still an interest in using alternative methods for reconstructing alternative catch histories, especially for the main shark species. In the original outputs of the EUPOA Project (Murua et al., 2013c) it was not possible to estimate the shark species catches for the period 2000 to 2010 due to the lack of disaggregated nominal catch. The present study aimed to estimate shark catches for the period 2000 to 2015, however the same difficulty was encountered and it was not possible to estimate shark catches. Therefore, in the EUPOA project no ratios were produced for the WCPFC area, so it was not be possible in this study to estimate shark catches.

Sub-task 1.2 - Discard levels

ICCAT

The ICCAT Secretariat receives quantitative information of sharks discards from two sources: First, nominal catch information in weight submitted by CPCs; and second, information from the different national observer programs. The first is used to generate bycatch and discards data available as Task 1 in ICCAT database (Appendix III - Table III.1). This figure shows that the reporting of discards has increased in the recent years, especially for blue shark. Note that Canada started reporting blue shark and porbeagle discards to report discards for the North stock as recently as 2015. For shortfin mako, the reporting of discards for the North stock has remained relatively stable from Mexico.

With regards to national observer programs, since data collection forms were developed in 2012, these have increased the amount of information submitted in the recent years. However, the SCRS noted that the observer data submission forms should be simplified in order to increase their reporting rates. This was completed in 2017 (Anon., 2016b, page 368) with the new simplified forms will be used since the start of 2018. In 2016, only eight CPCs submitted information on bycatch species of sharks (including discards) from their observer programs, specifically Belize, Canada, China, Chinese Taipei, EU, Korea Rep., US and Venezuela. This information is extremely useful for scientific purposes for the management of Atlantic oceanic sharks. For example, the habitats of silky shark (*Carcharhinus falciformis*) have been modelled using Spanish observer data (Lopez et al., 2016). However, the very limited number of CPCs that are collecting and reporting this data which is problematic and needs urgent improvement.

IATTC

The catch of shark species in 2015 from the purse seine and longline fleets are publicly available in the IATTC website. Data are available for the Eastern Atlantic Ocean purse seine and longline fleets aggregated per species, year, month, flag or set type and 1°x1° (PS) and 5°x5° (LL). The information available combines data in numbers and weight. Discards information is collected through observer programs and is available for PS since 1993 and for longlines since 1979 (Appendix III - Tables III.2 and III.3).

WCPFC

The shark species considered in this study are listed as key sharks in the WCPFC. Estimates of annual sharks catch for longline fleets are publicly available in WCPFC database. Data are aggregated per gear and flag and include information for blue, mako, silky, oceanic white-tip, thresher, porbeagle and hammerhead sharks. In addition, in the provision of 2015 annual catches estimates to the WCPFC (see 2016 SC Report), estimates of discards are provided in aggregate catch/effort data, operational catch/effort data and observer data provisions. Estimates of discards are available for Australia (LL, PS, PL, HL, TR), Cook Islands (LL, TR), Federated States of Micronesia (LL, PS), Fiji Islands (LL, PL), French Polynesia (LL PL, OT), Kiribati (LL, PS, OT), Republic of Korea (LL, PS), Marshall Islands (LL, PS), New Caledonia (LL), New Zealand (LL, PS, TR, PL), Papua New Guinea (LL, PS), Philippines (PS), Samoa (LL), Salomon Islands (LL), Tonga (LL), Tuvalu (LL, PS, OT), United States (LL, PS, TR, HL, PL) and Vanuatu (LL, PS).

In particular, with regards to observer information collected by The Pacific Community - Oceanic Fisheries Programme (SPC-OFP) database (as a continuation of the Regional Observer Program - ROP), the proportion of sharks recorded in longlines as finned,retained or discarded dead versus alive are available. Also, the Pacific Island Forum Fisheries Agency (FFA) processes observer data for the US Multilateral Purse Seine Treaty and these data are incorporated into the ROP. Other WCPFC members have contributed to the ROP databases including Australia, China, Japan, New Zealand, Chinese Taipei and the USA. The majority of the observer data processed by the SPC are ROP-defined purse seine trips which have been designated as the highest priority for processing since 2010. However, the WCPFC requirement for 5% observer coverage in the longline fishery (established in 2012) has resulted in increased submission of observer longline data in recent years, and these data are now assigned equal priority for data processing than the purse seine observer.

Clarke (2011), based on trips covered by observers and provided to the SPC-OFP database, presented data on the fate of sharks caught aboard longline and purse seine vessels. For the purse seine fishery, the proportion of sharks finned has decreased each year since 2006 (0.61, 0.51, 0.40, 0.18), and the proportion of sharks discarded has increased. It is possible that the adoption of CMM 2008-01[5], which was designed as a CMM for bigeye and yellowfin tuna and which included a two-month closure of fishing on fish aggregating devices (FADs), may have influenced the number of sharks caught in purse seine fisheries since most shark catch occurs in sets on FADs (Appendix III - Figure III.13).

In the last years, the Areas Beyond National Jurisdiction (ABNJ) project is aiming at improving and harmonizing the information available in order to monitoring the status of sharks (WCPFC-SC11-2015).

IOTC

The reporting of discards has improved in the recent years. According to Herrera and Pierre in 2011, there was no estimation of shark discards in the IOTC convention area. However, in 2012, Australia reported shark discard levels on its national reports and other several countries followed suit, reporting shark discards levels in various working documents presented to the IOTC WPEB. Since then, the reporting of discards is still poor, though has improved. For example, with regards to discards on longline fleets, the EU (Spain, UK), Japan, Taiwan, China and Indonesia, have not provided estimates of total discards of sharks, by species, but Japan, Taiwan, China and Indonesia are now reporting discards in their observer data (IOTC, 2016a). With regards to purse seiners, the EU-Spain, I.R. Iran, Japan, Seychelles, and Thailand have not provided estimates of total quantities of discards of sharks, by species, for industrial purse seiners under their flag, but EU-Spain and Seychelles are now reporting discards in their observer data (IOTC, 2016a).

[5] WCPFC CMM 2008-01 Conservation and Management Measure for Bigeye and Yellowfin Tuna in the Western and Central Pacific Ocean (replaced by CMM 2012-01)

Also, in IOTC (2016b), the information available for discards for the year 2015 is provided (Appendix III - Figure III.14 and Table III.4). Discard levels are only available for Australia longliners, EU-France purse seine and longliners, Republic of Korea longliners and purse seiners, South Africa longliners (foreign & local fleets), Sri Lanka (all gears), Maldives longliners, the UK Overseas Territories (nil discards), Mauritius purse seiners, Mozambique longliners, China and Taiwan longliners. Discard rates are thought to be high for fisheries using longlines and oceanic gillnets, and moderate for purse seine sets on associated schools (mainly with FADs). However, the nets of FADs may also contribute substantially to ghost fishing.

Sub-task 1.3 - Length frequencies

ICCAT

ICCAT regularly produces data catalogues for the main species, including the three main shark species (blue shark, shortfin mako and porbeagle). Those catalogues are shown in Appendix III (Tables III.5-11) and summarize if Task II data is available for each given year/flag/gear, including data on size frequencies and catch-at-size. In general, the global statistics on sharks, including the reporting on size distributions have been improving, but are considered insufficient to be used effectively to provide scientific advice or to be directly used in th stock assessments. As a result, national scientists have been producing cooperative work within the SCRS/Sharks Species Group for compiling more detailed observer data to be used in the stock assessments. Such analysis was completed in the most recent blue shark (Coelho et al., 2015a, 2018) and shortfin mako (Coelho et al., 2017) assessments (see sub-task 1.5 on size indicators bellow).

IOTC

IOTC regularly presents available data on length for the main species, including blue shark, shortfin mako shark, porbeagle, oceanic whitetip and silky shark in the WPEB meetings. Available size frequency data by species is shown in Appendix III (Figures III.15 and III.16). In general, global statistics on sharks, including the reporting on size distributions have been improving, but are still largely considered insufficient to be used in robust scientific advice or to be directly used in the stock assessments. Because of that, national scientists have been producing cooperative work within the WPEB for compiling more detailed observer data to be used in stock assessments. Such analysis was carried out in 2015 and used in the latest blue shark assessment (Coelho et al., 2015b) (see sub-task 1.5 on size indicators).

WCPFC

WCPFC regularly produces data catalogues for the main species by gear, including the six main shark species/species complexes (blue shark, makos, porbeagle, silky shark, oceanic whitetip and Threshers). Summary[6] longline catalogues are shown in Appendix III (Tables III.12-III.17) and summarize the WCFPC scientific data holdings by gear, species and geographical area; including data on annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data.

IATTC

Although 100% coverage is available for large purse seiners, some of the information is not publicly available, and there is a lack of data on the catch size of key shark species in the IATTC for some vessels. No further update on length data availability held by IATTC has been given since 2013 (Murua et al., 2013c).

Sub-task 1.4 - Biological information

The full revised biological information for the species covered in the study is presented in summary tables in Appendix III (Tables III.17-III.30).

Sub-task 1.5 - Fishery indicators

Information on the currently available standardized CPUE trends, average sizes of catches, and ecological risk assessments are presented below. Table 4.4.5 summarises the availability of each of those indicators for the scope species/stocks in the Atlantic and Indian Ocean. The results from the Ecological Risk Assessments (ERA), from the various tuna-RFMOs, showed that elasmobranch fishes are highly vulnerable to longline and purse-seine fisheries, especially mako sharks, thresher sharks, silky shark and blue shark. For the other indicators (CPUE, size composition and distribution analysis) most shark species presented either stable or decreasing trends. The detailed fishery indicators by tuna-RFMO are presented in Appendix III.

[6] A detailed catalogue is also produced and avaiilable at https://www.wcpfc.int/wcpfc-data-catalogue-0

Table 4.4.5. Summary of available fishery indicators by ocean, species and stock. ERA – Ecological Risk Assessment; STD CPUE – standardized CPUE. ● indicates the presence of the fishery indicator. Note that for SMA and POR (Atlantic) the ERA analysis was performed for the whole Atlantic and not for separate stocks.

Ocean	Species	Stock	ERA	STD CPUE	Size distribution	Distribution analysis
Atlantic	BSH	North	●	●	●	
		South	●	●	●	
	SMA	North	●	●	●	
		South	●	●	●	
	POR	NW	●	●		
		NE	●	●		
		SW	●	●		
		SE	●			
	FAL	North	●			
		South	●			
	OCS	All Atl	●			
	LMA	All Atl	●			
	SPN	All Atl	●			
	THR	All Atl	●			
Indian	BSH	All IO	●	●	●	
	SMA	All IO	●	●		
	POR	All IO	●			
	FAL	All IO	●			
	OCS	All IO	●	●		
	SPN	All IO	●			
	THR	All IO	●			
Pacific	BSH	North	●	●	●	●
		South	●	●	●	●
	SMA	North	●	●	●	●
		South	●		●	●
	POR	South	●	●	●	●
	FAL	East	●	●		
		West		●	●	●
	OCS	East	●			
		West		●	●	●
	LMA	East	●			
		West		●	●	●
	SPN	East	●			
		West		●	●	●
	THR	East	●			
		West		●	●	●

One important final aspect to note in this task is that the Consortium was able to expand the catch reconstruction method (subtask 1.1) and stratify by year in addition to the original method of fleet/gear stratification. Therefore it is now possible to reconstruct and provide species-specific time series that can be directly imputed into stock assessments. The results presented here were already used as sensitivity catch scenarios in the 2017 ICCAT shortfin mako assessment and in the 2017 IOTC blue shark assessment (Coelho & Rosa, 2017a, 2017b).

5. TASK 2 - PROVIDE A CRITICAL OVERVIEW OF RECENT DEVELOPMENTS

5.1. *Key findings and recommendations*

- Shark data availability prior to 2009 varied amongst tuna RFMOs but since adoption of the EU Plan of Action for Sharks in 2009 improvements in data collection and availability have been made in all tuna RFMOs including mandatory logbook reporting of key species and biological data collection by observers. The number of Conservation Management Measures related to shark data collection since 2009 varies between 4 (IOTC) to 8 (ICCAT).
- Despite the improvement in data reporting requirements, data availability remains poor in all tuna RFMOs. Historical catches were aggregated and despite recent improvements reporting by key species, this hampers stock assessments.
    - For IOTC and ICCAT, discards are not usually reported or included in the total removals data. Additionally, data may refer to dressed weight without information on the processing method;
    - For WCPFC data is collected but data gaps associated with certain species or flags still exist, which has limited the ability to undertake stock assessments (e.g., shortfin mako). This was possible for blue shark despite data gaps;
    - IATTC has good data from purse seine, but data from longline is poor and past observer coverage has been inadequate (but note introduction of 5% coverage). Silky shark assessments were poor due to incomplete information.
- Lack of data means that conventional stock assessment methods have not been possible in IOTC and ICCAT or resulted in poor assessment (silky shark, IATTC). Full assessments using stock synthesis have been possible in WCPFC. In ICES, surplus production models have been applied to pelagic sharks but for other species, methods for data limited stocks are applied.
- All tuna RFMOs have adopted CMMS for shark population management that theoretically reach all EUPOA conservation requirements. However most are difficult to monitor and control with more research needed to evaluate their impact. Concerns exist over their implementation by CPCs and there are no CMMS to develop frameworks establishing consultation and involvement of

stakeholders in research, management and educational initiatives between countries.

- It is recommended that proposals are developed for all RFMOs to undertake data gap assessment and enhance shark reporting, as well as for capacity building by addressing objective 4 of the EUPOA, with the aim of improving compliance by CPCs with shark measures.

5.2. *Objectives*

The objective of this task is to undertake a critical review of what has changed and whether improvements were observed regarding 1) data availability, 2) the application of assessment methodologies for assessing conservation status and 3) the adoption and implementation of Conservation and Management Measures (CMMs) for sharks and rays covered by the scope of the study. Changes identified were those that have occurred since the adoption of the EU Plan of Action (EUPOA) for sharks in Feburary 2009. Moreover, and where appropriate, the extent of the observed changes were judged against the additional required measures identified in the text of the EUPOA. This task also focused on changes observed the tuna-RFMOs (ICCAT, IOTC, WCPFC and IATTC) and ICES in each of the geographic regions identified in the scope of the study.

5.3. *Methodology*

The work was completed across three sub-tasks (described below). Information reviewed included reports and outputs from tuna-RFMOs Working Parties and Science Committees, ICES, academic literature and other relevant sources. The sub-tasks also involved consultations (e-mail and telephone interviews), where necessary, with experts in these areas, as well as DG MARE's desk officers, in order to better understand at a qualitative level the challenges in data collection, assessment methods and implementation of management measures.

Sub-task 2.1 - Data availability

This sub-task consisted of a qualitative critical analysis of improvements observed in data collection and reporting since the adoption of the EUPOA for sharks (quantitative information was collected and reviewed as part of Task 1, the outputs of which were also considered in this task). Three main sources of information were consulted. First, relevant EU legislation (e.g. Council Regulations) and RFMO CMMs were reviewed to establish a timeline of new data reporting requirements for each region since February 2009. Second, relevant stock assessment reports produced by RFMOs and ICES within this period were reviewed to ascertain improvements, or lack thereof, in suitability of existing data for assessment. Third, the reports of relevant RFMO and ICES Working Parties, and Scientific Committees were reviewed to glean details of changes in data reporting, quality, gaps and so on. These reports also usually include a summary of plenary discussions regarding data and other methodological issues, which can provide useful anecdotal information. Following the review of these documents for all advisory bodies, the current Working Groups chairpersons were contacted via e-mail to provide clarification or further details as necessary (in the case of IOTC it is noted that the current chair of the WPEB was also the scientific coordinator of this project).

The output of this sub-task provided a summary, for each geographic region, of how data reporting obligations for sharks and rays have changed since the adoption of the EUPOA for sharks, qualitative analyses on the extent that these data are being provided by the Member States or CPCs and the extent to which data are sufficient for undertaking assessments, and a discussion on how these changes and the current state of data availability compares to the required actions that were identified in the text of the EUPOA.

Sub-task 2.2 - Application of assessment methods

This sub-task identified and describes changes in assessment methods used for sharks and rays by tuna-RFMOs and ICES. This list is broken down into organization, species and stock/population. This was based on the reports of stock assessments and other relevant assessment studies that have been used by the advisory bodies to establish stock status.

The output of this sub-task consists of a descriptive list of assessment methodologies in use, a summary of how these methods have changed since the adoption of the EUPOA for sharks, and a discussion on how this compares to the required actions that were identified in the text of the EUPOA (e.g. relating to provision of data for assessment). This sub-task did not consist of an evaluation of assessment methods, which is done for data-poor approaches under Task 4.

Sub-task 2.3 - Adoption of CMMs

This sub-task identified and summarises CMMs relevant to sharks and rays that have been adopted by tuna-RFMOs since the adoption of the EUPOA. These changes were compared against the required actions that were identified in the text of the

EUPOA (e.g. establishment of catch limits, prohibition of shark discards). Moreover, for each CMM the status of its implementation was reviewed qualitatively, both from the reports of tuna-RFMOs (including plenary discussion of the Scientific Committee and Commission meetings) and communication with key informants from within tuna-RFMOs (e.g. Secretariat staff, Working Group chairs).

The output of this sub-task consists of an overview of recently adopted CMMs, analysis of how these align with the required actions of the EUPOA and a discussion on the extent that these CMMs are considered to have been implemented successfully.

5.4. *Results and Discussion*

Sub-task 2.1 - Data availability

A) Timeline of new reporting obligations

This section identifies and provides a brief description of new data reporting obligations for sharks and rays in each RFMO or advisory body that have been implemented since the publication of the EUPOA for sharks in February 2009.

IOTC

In IOTC there are total of four active CMMs that explicitly require or facilitate the collection of data on sharks and rays. These are shown in Table 5.4.1 and their content is briefly summarised in Appendix V. New reporting requirements for sharks and rays since 2009 include:

- Mandatory recording of several shark and ray species in vessels logbooks,including catch in weight and/or number per set/shot/fishing event for each species and form of processing, since 2011. Separate species lists are defined for purse seine, longline, pole-and-line and gillnet and include mandatory as well as optional species;
- Changes in requirements and addition of species for reporting in 2012 and 2013; and
- Recording of catches (all gear interactions including retained or discarded) of all identifiable shark and ray species as part of an observer scheme since 2010, including biological sampling for thresher (from 2012) and oceanic whitetip sharks (from 2013).

Table 5.4.1 Active CMMs in IOTC that explicitly require or facilitate the collection of data on sharks and rays.

CMM #	CMM name
Res. 15/01	On the recording of catch and effort data by fishing vessels in the IOTC area of competence
Res. 11/04	On a regional observer scheme
Res. 12/09	On the conservation of thresher sharks (Family Alopiidae) caught in association with fisheries in the IOTC area of competence
Res. 13/06	On a scientific and management framework on the conservation of shark species caught in association with IOTC managed fisheries

WCPFC

In WCPFC there are total of five active CMMs that explicitly require or facilitate the collection of data on sharks and rays. These are shown in Table 5.4.2 and summarised in Appendix V. New reporting requirements for sharks and rays since 2009 include:

- Mandatory daily logbook recording of all catches of specified key sharks species (including Blue shark, silky shark, oceanic white-tip shark, mako sharks and thresher sharks) by longline, purse seine, pole-and-line and trolling gears since 2013;
- Addition of porbeagle shark (south of 20°S, until biological data shows this or another geographic limit to be appropriate) and hammerhead sharks (winghead, scalloped, great, and smooth) to the list of key shark species in 2010; and
- Reporting of the number sharks released (and their status) and collection of biological samples by fishery observers for oceanic whitetip and silky sharks since 2011 and 2013 respectively.

Table 5.4.2 Active CMMs in WCPFC that explicitly require or facilitate the collection of data on sharks and rays.

CMM #	CMM name
CMM 2013-05	Conservation and Management Measure on daily catch and effort reporting
CMM 2010-07	Conservation and Management Measure for Sharks
CMM 2013-08	Conservation and Management Measure for silky sharks
CMM 2011-04	Conservation and Management Measure for Oceanic Whitetip Shark
CMM 2007-01	Conservation and Management Measure for the Regional Observer Programme

IATTC

In IATTC there are total of five active CMMs that explicitly require or facilitate the collection of data on sharks and rays. These are shown in Table 5.4.3 and summarised in Appendix V. New reporting requirements for sharks and rays since 2009 include:

- Introduction of a research work plan and timeline to deliver silky and hammerhead sharks stock assessments, including identification of data needs to do so, from 2017. Catch reporting on these species exists from January 2018.
- Recordings by fishery observers of catch (including discards) for oceanic whitetip (since 2012), silky (since 2017) and hammerhead spp. (from 2018) sharks, and improved biological sampling for key parameters from key species since 2016.
- Recordings by fishery observers on the interactions of longliners with non-target species, including sharks, since 2012.

Table 5.4.3. Active CMMs in IATTC that explicitly require or facilitate the collection of data on sharks and rays.

CMM #	CMM name
Resolution C-16-05	Resolution on the Management of Shark Species
Resolution C-16-04	Amendment to Resolution C-05-03 on the Conservation of Sharks caught in association with fisheries in the Eastern Pacific Ocean
Resolution C-16-06	Conservation Measures for Shark Species, with special emphasis on the Silky Shark (*Carcharhinus falciformis*), for the years 2017, 2018, and 2019
Resolution C-11-10	Resolution on the conservation of oceanic whitetip sharks caught in association with fisheries in the Antigua convention area
Resolution C-11-08	Resolution on Scientific Observers for Longline Vessels

ICCAT

In ICCAT there are total of eight active CMMs that explicitly require or facilitate the collection of data on sharks and rays. These are shown in Table 5.4.4 and summarised in Appendix V. New reporting requirements for sharks and rays since 2009 include:

- Strengthening of Task I (nominal catch including discards) and Task II (catch and effort) data reporting for thresher spp. and hammerhead spp. (since 2010), silky (since 2011), shortfin mako (since 2014), porbeagle (since 2015) and blue shark (since 2016).
- Recording, by fishery observers, of biological data (and discards) for oceanic whitetip (since 2010), silky (since 2011) and all other prohibited species since 2013.

Table 5.4.4. Active CMMs in ICCAT that explicitly require or facilitate the collection of data on sharks and rays.

CMM #	CMM name
Rec. 09-07	Recommendation by ICCAT on the conservation of thresher sharks caught in association with fisheries in the ICCAT convention area
Rec. 10-08	Recommendation by ICCAT on hammerhead sharks (family Sphyrnidae) caught in association with fisheries managed by ICCAT
Rec. 10-07	Recommendation by ICCAT on the conservation of oceanic whitetip shark (*Carcharhinus longimanus*) caught in association with fisheries in the ICCAT convention area
Rec. 11-08	Recommendation by ICCAT on the conservation of silky sharks caught in association with ICCAT fisheries
Rec. 13-10	Recommendation on biological sampling of prohibited shark species by scientific observers
Rec. 14-06	Recommendation by ICCAT on shortfin mako (*Isurus oxyrinchus*) caught in association with ICCAT fisheries
Rec. 15-06	Recommendation by ICCAT on porbeagle caught in association with ICCAT fisheries
Rec. 16-12	Recommendation by ICCAT on management measures for the conservation of Atlantic blue shark caught in association with ICCAT fisheries

B) Summary of data availability and reporting compliance

Considering the new and existing reporting obligations identified in the section above, this section highlights issues and gaps with respect to the status of reporting and the availability of data for sharks in the RFMOs/advisory bodies.

IOTC

The IOTC Secretariat's most recent review of the statistical data available for bycatch species (IOTC, 2016a), published in August 2016, notes some recent progress in the reporting of shark catches from CPCs, but also identifies concerns in the completeness of data, i.e.: "In addition to the underestimates from lack of reporting, when the catches are reported they are thought to represent only the catches of those species that are retained onboard without taking into account discards (nominal catches). In many cases the reported catches refer to dressed weights while no information is provided on the type of processing undertaken, creating more uncertainty in the estimates of catches in live weight equivalents."

Furthermore, the most recent overview of the status of data holdings in the IOTC Secretariat (IOTC, 2016c) noted the following concerns regarding the quality of shark data: "In spite of the better reporting levels recorded for bycatch data during 2016 [e.g., in 2016 over 90% of nominal catches were reported according to the deadline], few statistics are still available for sharks … for this reason, the quality of the data available is still poor".

Based in part on this observation of the IOTC Secretariat, and their own assessment of the available data, the IOTC Working Party on Data Collection and Statistics noted in November 2016 (IOTC, 2016c) that, for most fisheries, there is still a need to implement minimum data requirements for sharks (noting that those for India are different as it has objected the logbook Resolution).

WCPFC

The WCPFC Data Catalogue, a database containing the different types of scientific data provided by CPCs, shows data is being collected for the key shark species (blue shark, mako shark, silky shark, oceanic whitetip shark, thresher shark and porbeagle shark) with the exception of hammerhead shark for which no data has so far been collected. This database provides information on the total annual catch estimated, aggregate data, operational data and length data. Although this demonstrates that data is being collected in regards to key shark species, data gaps associated with certain flags do exist[7]. A report published by the WCPFC Scientific Committee in August 2016 on Scientific Data Available to WCPFC highlighted that, despite improvements in the data being collected following requirements to submit annual data on key shark species, there are still gaps in the data being provided (Williams, 2016). It was suggested that further recommendations to enhance the shark reporting and data gap assessment process should be considered (Williams, 2016).

A stock assessment for blue sharks was conducted by the International Scientific Committee for tuna and tuna-like species in the North Pacific Ocean (ICS) Shark Working Group in 2014, which provided an update on the assessment undertaken in 2013. Catch data was obtained from ICS member nations and observers and catches were extracted from databases of landings, vessel logbooks, and observer records. When reliable data was not available, catches were instead estimated using independently derived standardised catch per unit effort (CPUE) information.

[7] https://www.wcpfc.int/wcpfc-data-catalogue-0

New sources of catch were also available for this assessment including fisheries operating along the west coast of North America and China (ISC, 2014).

A report produced by the ICS Shark Working Group in 2015 provided a stock assessment on the shortfin mako shark. Catch was estimated from fleets and nations based on the best available information and were made for each fishery on effort, knowledge of species composition of catch, estimated catch per effort and scientific knowledge of operations and catch history. However, data was lacking from major fishing nations and fleets and estimates were difficult to derive as the data was of poor quality and data on discards was not recorded (ISC, 2015).

IATTC

IATTC has detailed information on catches (in number or weight and length), species identification, etc. of all sharks caught by the purse seine fleet since 1993. This is a result of the La Jolla Agreement (1992) and the Agreement on the International Dolphin Conservation Program (AIDCP 1998), the provisions of which include establishment of an international programme of observers on board purse seine vessels (A-99-01)[8]. IATTC Public Domain data provided by IATTC member governments on purse-seine shark bycatch data recorded by on-board observers at sea is available from 1993-2015 and gives number of individuals or weight by vessel in the Eastern Pacific Ocean (EPO)[9].

Data on shark catches for longline vessels is comparatively poor; there is limited and patchy reporting of retained catches and no data are available for shark discards. Public domain data provided by Members and Cooperating Non-Members, has retained catch of sharks, in number of individuals and metric tons, and number of hooks, by year, month, flag, and 5°x5° latitude/longitude, by industrial longline vessels in the Eastern Pacific Ocean. In the past, observer coverage of the industrial longline fleets has been inadequate or non-existent, but the implementation of Resolution C-11-08, which requires a minimum 5% observer coverage of longline vessels, is expected to improve both the quantity and quality of the data on bycatches of sharks by these fleets.

Concerning specific activities related to sharks taking place subsequent to the adoption of the EUPOA, the IATTC has carried out four workshops to date (in

[8] https://www.iattc.org/PDFFiles/A-99-01%20Observer%20Program%20resolution%20Oct%2099.pdf
[9] Shark EPO purse seine catch and effort aggregated by year, month, flag, set type, 1°x1°; https://www.iattc.org/Catchbygear/IATTC-Catch-by-species1.htm

August 2010, May 2011, December 2011 and February 2013). These workshops analysed existing information and data (catches, biological, etc.) in the EPO area with a focus on developing a future assessment on silky shark. A stock assessment covering the 1993-2010 period was attempted using Stock Synthesis model. Unfortunately, the model was unable to fit the main index of abundance adequately, and therefore the results were not reliable since relative trends and absolute scale are compromised in the assessment. The poor performance of the model was probably due to incomplete information on the total catch in the EPO, particularly for the early period of the assessment (1990s and early 2000s) (Anon., 2014). Other reports published since include updates of indicators for silky sharks (Aires-da-Silva et al., 2014; Aires-da-Silva et al., 2015) and a summary of hammerhead shark catch in the tuna fisheries in the EPO (Román-Verdesoto and Hall, 2014).

It is worth emphasizing that, although data shortcomings for silky sharks have been illustrated through attempts at assessment, there is even less knowledge, and numerous gaps or no data at all (both statistical and biological_ for other shark species caught within the EPO (Murua et al., 2012).

C) Comparison of new data availability against EUPOA requirements

With respect to improving data availability, the EUPOA sets out the objective to have reliable and detailed species-specific quantitative and biological data on catches and landings, as well as trade data for high and medium priority fisheries. To achieve this, it sets out a number of actions aimed at promoting the adoption of new or modified CMMs within RFMOs, including:

- To promote improved species specific catch and landings data and monitoring of shark catches by fishery;
- To improve, in cooperation with FAO and relevant fisheries management bodies, the monitoring and reporting of catch, bycatch, discards, market and international trade data, at the species level where possible; and
- To promote the identification and reporting of species specific biological and trade data, at least for the main species.

In practice, all tuna-RFMOs have sought to improve monitoring and associated data collection for most key shark and ray species, either by adding species to minimum catch recording requirements in vessel logbooks (by fishery, or as general requirements) or by adopting species-specific CMMs (typically for the most vulnerable species, e.g. thresher sharks, oceanic whitetip). Prior to this, shark and rays were usually grouped together and recorded as 'other'. These mandatory data collection/reporting requirements have been introduced gradually between 2009 to 2016 (Figure 5.4.1, although this does not illustrate changes within a CMM over time in some RFMOs, e.g. re-classification of a species from optional to mandatory reporting by IOTC).

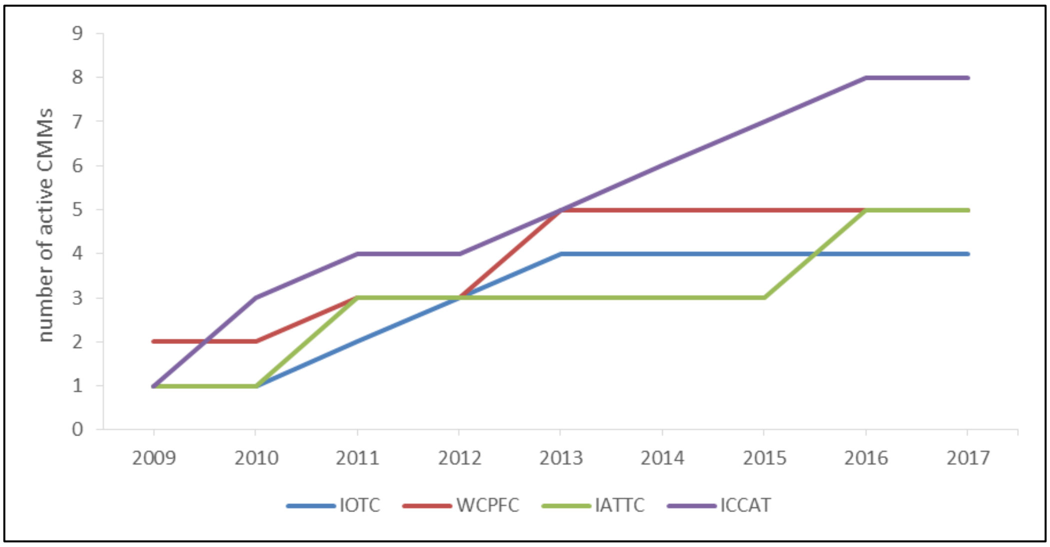


Figure 5.4.1 Number of CMMs that explicitly require or facilitate the collection of data on sharks and rays in ICCAT, IOTC, WCPFC and IATTC adopted since the publication of the EUPOA in 2009.

The changes in catch reporting requirements described above apply to both targeted and incidental catch of sharks. Additionally, all four tropical tuna-RFMOs have introduced the requirement to record discarding of sharks (in most cases specifying alive or dead release), either through species-specific CMMs (see in particular ICCAT, which has adopted seven species-specific CMMs) and/or observer schemes. In terms of promoting the identification and reporting of biological data, all four tropical tuna RFMOs have adopted CMMs to allow biological sampling by onboard observers. Provisions are most commonly included in species-specific CMMs to allow for the collection of biological samples from animals (including prohibited species, e.g. ICCAT) that are dead on haulback.

Despite the improvement in data reporting requirements, data availability remains poor in all tuna RFMOs. In IOTC and ICCAT especially, the catches of sharks, when reported, in most cases represent only the catches of species and specimens retained onboard and there is very limited information on discards. As such, in the Indian Ocean in particular, there are currently substantial difficulties to estimate the total catches of sharks (see Task 1).

The reporting for the major ICCAT and IOTC shark species (BSH, SMA and POR) is considered to be better than for other species; however, there are inconsistencies in the reporting of the fishery statistics even for those main shark species. Data for the blue shark tends to be more complete than for other species, and also for the North Atlantic stock, with porbeagle being the most data-limited species (see Task 1). Similarly, WCPFC highlighted that despite improvements in the data being collected following requirements to submit annual data on key shark species, there are still gaps in the data being provided. In IATTC, although data shortcomings for silky sharks have been illustrated through attempts at assessment, there is even less knowledge, and numerous gaps or no data at all (both statistical and biological) for other shark species caught within the EPO.

Another major issue with shark species in all RFMOs is that historically many species have been reported in aggregated form (no species-specific information) by a considerable number of fleets. Those "unclassified" sharks can include general codes as CVX: Carcharhiniformes; CXX: Coastal Sharks nei; DGX: Squalidae; PXX: Pelagic Sharks nei; SHX: Squaliformes; SKH: Selachimorpha; SYX: Scyliorhinidae. In the case of ICCAT and IOTC, the reporting under these codes represents on average 20% of total shark catches.

On a more a positive note, the reporting of shark and ray discards has improved in recent years. For instance, in the Indian Ocean, according to Herrera and Pierre (2011) there was no estimate of sharks discards in the IOTC convention area in 2011. In 2012, Australia reported shark discard levels on its national reports and other several countries also reported shark discards levels in various working documents presented to the IOTC WPEB. Since then, the reporting of discards is still incomplete but it has improved. For example, with regards to the discards on longline fleets, the EU (Spain, UK), Japan, Taiwan, China and Indonesia, have not provided estimates of total discards of sharks, by species, but Japan, Taiwan, China and Indonesia are now reporting discards in their observer data (IOTC, 2016a).

Sub-task 2.2 - Application of assessment methods

List of changes to assessment methods used for sharks

Table 5.4.5 provides a summary of relevant information on assessment methods used for shark species within the scope of the study. This is broken down into RFMO (including ICES as an advisory body), species and stock/population assessment method, and the date the assessment method was first used.

Information sources used were:

- ICCAT: Detailed reports of the stock assessment of blue shark, shortfin mako and porbeagle[10]:
  - ICCAT, 2015. Report of the 2015 ICCAT blue shark stock assessment session (Lisbon, Portugal, July 2015)
  - ICCAT, 2012. Report of the 2012 ICCAT shortfin mako stock assessment session (Olhão, Portugal, June 2012)
  - ICCAT, 2009. Report of the 2009 ICCAT porbeagle stock assessment meeting (Copenhagen, Denmark, June 2009)
- IOTC: Details on the stock assessment of bluefin shark can be found on the Report of the 12th WPEB[11]:
  - IOTC, 2016. Report of the 12th Session of the IOTC WPEB
- IATTC: Details of indicators and the attempt to apply a conventional stock assessment model to silky shark in: IATTC, 2014. SAC-05-11a. Stock Status Indicators for silky shark in the Eastern Pacific Ocean[12];
- WCPFC: In the report of the 12th Scientific Committee[13] (a summary of the shark assessments is provided in Appendix H of that SC report). Also, a series of working papers present the results of the stock assessments:
  - WCPFC, 2016. Report of the twelfth Regular Session of the Scientific Committee (Bali, Indonesia)
  - WCPFC, 2013. Silky shark stock assessment, SC10-SA-WP-03
  - WCPFC, 2012. Oceanic whitetip shark stock assessment, SC8-WP-03
  - WCPFC, 2014. North Pacific blue shark stock assessment using SS3, SC10-SA-WP-08
  - WCPFC, 2014. Progress on the shark research plan, SC10-EB-WP-04

[10] http://www.iccat.int/en/assess.htm
[11] http://www.iotc.org/documents
[12] http://www.iattc.org/Meetings/Meetings2014/MAYSAC/PDFs/SAC-05-11a-Indicators-for-silky-sharks.pdf
[13] http://www.wcpfc.int/meeting-folders/scientfic-committee

Table 5.4.5. Stock assessment models and other indicators used for management advice. Major shark species as indentified by each RFMO are indicated in bold. See list of acronyms (Appendix I) for full names of the methods. The supra-script values after each method refer to each specific stock (see column with the stocks).

Region / species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Stocks
Atlantic and adjacent seas (ICCAT)															
Blue shark (*Prionace glauca*)				BSP[1,2], ASPM[1]				ERA[1,2]			BSP[1,2], SS[1], BSSP[2]				[1]North [2]South
Shortfin mako (*Isurus oxyrinchus*)				BSP[1,2], CFASPM[1,2], ASPM[1]				BSP[1,2], CFASPM[1,2], ERA[1,2]					BSP[1,2], JABBA[1,2], CMSY[2], SS[1]		[1]North [2]South
Longfin mako (*Isurus paucus*)								ERA[1,2]							[1]North [2]South
Porbeagle (*Lamna nasus*), in conjunction with ICES					BSP[1,2,3], CFASPM[2], ASPM[3]			ERA[1,2]							[1]Northwest, [2]Southwest, [3]Northeast
Silky shark (*Carcharhinus falciformis*)								ERA[1,2]							[1]North [2]South
Oceanic whitetip shark (*Carcharhinus longimanus*)								ERA[1,2]							[1]North [2]South
Hammerheads (*Sphyrna* spp., data often grouped as SPN in ICCAT).								ERA[1,2]							[1]North [2]South
Thresher sharks (*Alopias* spp., especially *A. superciliosus* as the main thresher species of interest in ICCAT).								ERA[1,2]							[1]North [2]South
Indian Ocean (IOTC)															

Region / species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Stocks
Blue shark (*Prionace glauca*)								ERA[1]			BSSP[1], SRA[1], SS[1]		BSSP[1], JABBA[1], SRA[1], SS[1]		[1]All IO
Shortfin mako (*Isurus oxyrinchus*)								ERA[1]							[1]All IO
Silky shark (*Carcharhinus falciformis*)								ERA[1]							[1]All IO
Oceanic whitetip shark (*Carcharhinus longimanus*)								ERA[1]							[1]All IO
Hammerheads (*Sphyrna* spp., especially *S. lewini* as the main hammerhead species of interest in IOTC, but with data often grouped as SPN in IOTC)								ERA[1]							[1]All IO
Thresher sharks (*Alopias* spp., especially *A. superciliosus* and *A. pelagicus* as the main threshers species of interest in IOTC, but with data often grouped as THR in IOTC).								ERA[1]							[1]All IO
Porbeagle (*Lamna nasus*)								ERA[1]							[1]All IO
Western and Central Pacific (WCPFC)															
Blue shark (*Prionace glauca*)									SS[1]	SS[1]		SS[2]	SS[1] BSSP[1]		[1]Northwest [2]Southwest
Mako sharks (*Isurus* spp., data usually grouped as MAK in														SS[1]	[1]North Pacific

Region / species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Stocks
WCPFC)															
Silky shark (*Carcharhinus falciformis*)									SS[1]		SS[1]				[1]WestCentral
Oceanic whitetip shark (*Carcharhinus longimanus*)							SS[1]	SS[1]							[1]WestCentral
Thresher sharks (*Alopias* spp., data usually grouped as THR in WCPFC).												RA[1]			[1]All west Pacific
Hammerheads (*Sphyrna* spp., data usually grouped as SPN in WCPFC)															
Porbeagle (*Lamna nasus*)													RA[1]		[1]Southern Hemisphere
Eastern Pacific (IATTC)															
Blue shark (*Prionace glauca*)															
Mako sharks (*Isurus* spp., data usually grouped as MAK in IATTC)															
Silky shark (*Carcharhinus falciformis*)												Indicators		Indicators	
Oceanic whitetip shark (*Carcharhinus longimanus*)															
Thresher sharks (*Alopias* spp., data usually grouped as THR in IATTC).															
Hammerheads (*Sphyrna* spp., data usually grouped as															

Region / species	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Stocks
SPN in IATTC)															
Porbeagle (*Lamna nasus*)															
ICES															
Spurdog							PW			PW	PW				
Leafscale gulper shark		SPM													
Portuguese dogfish		SPM													
Kitefin shark	SPM														
Porbeagle					BSP, ASPM										
Basking shark															
Blue shark															
Shortfin mako															
Tope															
Thresher sharks															

Summary of changes in assessment methods since EUPOA

This sub-section presents a review of the changes observed in assessment methods used for sharks since February 2009.

ICCAT

Historically, most of the Atlantic shark species have not been assessed using conventional stock assessment methods and alternative methodologies have been applied. Sixteen species (20 stocks) are included in the 2013 Ecological Risk Assessment (ERA). This information aims at identifying those species that are most vulnerable to prioritize research and management measures.

For blue shark, shortfin mako and porbeagle (the three main ICCAT shark species), stock assessments have been completed using surplus production models (2008, 2009, 2012). However, in 2015, the statistical size-based age-structured integrated model Stock Synthesis (SS) was used for the assessment of blue shark, and in 2017 for the shortfin mako (North Atlantic stocks). This represents a major step forward on the assessment of sharks, as SS requires, or can use a range of data on stocks biology and fisheries, which has been made available in the recent years.

IOTC

Most of the Indian Ocean shark species are not assessed with conventional stock assessment methods and alternative methodologies using indicators have been applied. The Ecological Risk Assessment (ERA) conducted for the Indian Ocean by the WPEB and SC in 2012 (Murua et al., 2012) consisted of a semi-quantitative risk assessment analysis to evaluate the resilience of shark species (blue shark, oceanic whitetip shark, scalloped hammerhead shark, shortfin mako, silky shark, bigeye thresher shark and pelagic thresher shark) to the impact of a given fishery, by combining the biological productivity of the species and its susceptibility to each fishing gear type. Also, indicators of abundance from commercial fisheries are used to estimate trends of populations of these stocks.

The first attempt to apply a conventional stock assessment for a shark stock was made in 2015 using a suite of models, ranging from relatively simple Stock Reduction Analysis and Surplus Production Models to the more complex SS model. In 2017, a more complete model was finalized for blue shark using SS, which represents a major step forward on the assessment of sharks in the Indian Ocean.

WCPFC

In the WCPFC, the full stock assessments of sharks have been completed using SS since 2011. However, for other stocks, indicators have been used as indicators of stock status. The indicators used to assess the state of shark stocks in WCPFC are longline and purse seiner logsheets and observer datasets held by SPC-OFP. Four main classes of indicators are assessed: range based on fishery interactions, catch composition, catch rates and biological indicators of fishing pressure (e.g. median size, sex ratio).

IATTC

An attempt by the IATTC staff to assess the status of the silky shark in the EPO using conventional stock assessment models has been severely handicapped by major uncertainties in the fishery data. The reasons behind the failure are two: first, some structural issues were identified in the stock assessment model, and these are difficult to overcome given the major uncertainties in the fishery data, in particular, in assumed levels of the early catch; and second, fishery data for the most recent period are not available for all fisheries assumed in the assessment model. However, this stock assessment attempt has produced a substantial amount of new information about silky shark in the Eastern Pacific Ocean (Aires-da-Silva et al., 2014).

In practice, silky sharks are assessed through a suite of possible stock status indicators (Aires-da-Silva et al., 2014). The indices were updated in 2015 using CPUE information from purse seine sets on floating objects. Indicators of other set types were also explored. The indices examined are bycatch rates in purse seine floating objects, standardized CPUE from purse seine on floating objects (including spatial trends), presence/absence indicators by purse seine type and average lengths.

ICES

In ICES, mostly surplus production models have been used to assess the state of pelagic sharks. Also, a specifically tailored model, the age-length and sex-structured by Punt and Walker (1998) has been used to assess the state of spurdog. In general, ICES sharks are assessed using methods for data limited stocks of category III, stocks for which survey-based assessments indicate trends (ICES, 2012).

Sub-task 2.3 - Adoption of CMMs

List of new CMMs adopted since the EUPOA for sharks

This task compiled existing CMMs, in particular retention bans, adopted by relevant international fora for fisheries that target sharks or have sharks and rays as by-catch or associated species.

A full list of these CMMs is provided in Appendix VIII of this report, including the date of implementation, a description, the origin of the CMM adoption and whether it focuses on main/target or bycatch shark species.

Summary of CMM implementation

CMMs currently in force for each ocean basin (Atlantic Ocean and Mediterranean Sea, Indian Ocean, North East Pacific Ocean and South West Pacific Ocean) through resolutions adopted by tRMFOs are presented in the task 5 of this report. These CMMs were considered following the list of potential generic CMMs published by Fisher et al (2012):

- Input and/or output controls
- Improvements to the design and use of fishing gear and by-catch mitigation devices;
- Spatial and temporal measures;
- Fishing practices and strategy
- Incentives for fishers to comply with measures to manage by-catch

For the input and output controls the specific CMMs are: prohibition of retention (related to species and some gear for all tRFMOs), bycatch/catch ratio limit and limit in the number of juvenile catch (applicable for silky shark LL capture in the EPO-IATTC), minimum size recommendation (applicable for the oceanic whitetip shark in the AO-ICCAT but this CMM is nowadays covered by the prohibition of retention).

For the improvements to the design and use of fishing gear and by-catch mitigation devices the specific CMMs are: prohibition of wire leader for tuna and billfish directed fishery (active in the WPO-WCPFC for LL), non-entangling FAD (active in the EPO-IATTC and IO-IOTC), ban of artificial lights on FAD and vessel (active in the IO-IOTC).

For the spatial and temporal measures, the specific CMMs are: FAD moratorium (active in all tRFMOs).

For the fishing practices and strategy, the specific CMMs are: ban of high sea driftnets (active in all tRFOMs except IOTC), prohibition of intentional setting on whale shark (active in all tRFMOs).

For the incentives for fishers to comply with measures to manage by-catch and reduce discards the specific CMMs are: full utilization (active in all tRFMOs, 5% fin/body ratio active in all tuna RFMOs and discussed in the Task 5, prohibition of finning (implement in the North Atlantic Ocean and Mediterranean Sea by ICCAT and on the fresh longliners in

IOTC), encourage release of live sharks (all tRFMOs), release guidance to increase survival (all tRFMOs except ICCAT for whale shark and related to tRFMOs for other species) and prohibition/control on international trade (all tRFMOs).

It is clear that all tRFMOs have set up CMMs to cover the potential generic CMMs proposed by the FAO (2011) for the sustainability of sharks and rays populations. However, some of them are difficult to implement due to difficulties of their control without additional monitoring measures. For example, the efficacy of the prohibition of the retention of sharks can only be assessed with a compliance inspectors or electronic monitoring system coverage (see Task 5 for a discussion on retention bans measures). At the same time, we do not know currently the efficiency of such measures regarding shark stock reconstructions without a better knowledge of the survival rate of individuals after release for the species concerned. However, some CMMs are dedicated to reduce interactions with gear, like the non-entangling FADs for purse seine fisheries. When the reduction of those interactions is difficult to implement due to the characteristics of the gear, other CMM are implemented to improve the shark survival after release, for example the prohibition of wire leaders. However, this last CMM must be considered cautiously because some works have raised the concern that a decrease of the shark retention level by eliminating wire leaders could hidden a potential negative impact of nylon or multifilament leaders on the shark mortality (see Task 6 - operational and technological mitigation measures).

In conclusion, all tuna-RFMOs have already set up CMMs to be implemented for shark population management. Most of them are difficult to control and/or more research is clearly needed to better assess their impact in relation to the objectives of their implementation.

Comparison of new CMMs against EUPOA conservation requirements

The European Commission's Action plan for the Conservation and Management of Sharks (EUPOA Sharks) is based on the International Action plan for the Conservation and Management of Sharks (IPOA SHARKS) adopted by the FAO (2000).

This shark plan aims to achieve the following objectives (FAO, 2000).

1. Ensure that shark catches from directed and non-directed fisheries are sustainable;
2. Assess threats to shark populations, determine and protect critical habitats and implement harvesting strategies consistent with the principles of biological sustainability and rational long-term economic use;
3. Identify and provide special attention, in particular to vulnerable or threatened shark stocks;

4. Improve and develop frameworks for establishing and co-ordinating effective consultation involving all stakeholders in research, management and educational initiatives within and between States;
5. Minimize unutilized incidental catches of sharks;
6. Contribute to the protection of biodiversity and ecosystem structure and function;
7. Minimize waste and discards from shark catches in accordance with article 7.2.2.(g) of the Code of Conduct for Responsible Fisheries (for example, requiring the retention of sharks from which fins are removed);
8. Encourage full use of dead sharks;
9. Facilitate improved species-specific catch and landings data and monitoring of shark catches;
10. Facilitate the identification and reporting of species-specific biological and trade data.

Nowadays, all tuna-RFMOs have set up resolutions to theoretically reach all EUPOA conservation requirements. Main questions concern their implementation success by CPCs. Several objectives such as 1, 2, 3, 5, 6 and 7 depend on the quality of data reporting. For many fishing countries the quality of data on shark catches is highly deficient and this critically hampers the assessment of shark populations. When data are available, shark catch data are too often reported aggregated by species and sometimes by gears. However, all RFMOs have invested a significant budget to support the development of species identification cards in many languages for observers and fishing officers deployed at landing ports (objectives 9 and 10 of the EUPOA Shark). The retention ban without a large coverage of fishing activities by compliance observers or electronic monitoring systems tends to jeopardize objectives 7 and 8, because for some fisheries the mortality of sharks at hauling is likely significant and the species of concerns by the resolution are discarded dead. Moreover, this CMM might be a barrier for data collection and reporting (catch data, biometrical and biological data) for sensitive species. The lack of fine-scale catch data is always a problem to reach objective 2. Our better knowledge related to this objective concerns only species considered as data-rich species (i.e. mainly blue shark, shortfin mako and porbeagle shark). For the other species, in particular those targeted by retention bans, more data from observers and Electronic Monitoring Systems (EMS) programs are needed. Finally, so far no CMMs are directly dedicated to improve and develop frameworks for establishing and co-ordinating effective consultation involving all stakeholders, management and educational initiatives within and between States (objective 4). Obviously, if such objective is worth for long-term perspectives, shark management in the short term needs simple and realistic CMMs. Some of them are already in place but may be revised to: i) ensure data collection (catch data, biometrical and biological data) necessary to perform stock assessments, ii) avoid loopholes aiming to demean the quality of collected data, and iii) satisfy, as far as possible, science based fishery management.

6. TASK 3 – CATEGORISE STOCKS OF SHARKS AND RAYS

6.1. *Key findings and recommendations*

- For assessment purposes, ICES categorises stocks within one of six categories, specifically Categories 1-2 (data rich) to 3–6 (data limited);
- Pelagic elasmobranchs fall mainly under the data limited categories, particularly Categories 3-4, except for the main species (blue shark and shortfin mako) that could in some cases be considered under categories 1-2;
- Manta and devil rays are all considered Category 6, as almost no information is currently available that could inform stock assessments;
- Currently, only Ecological Risck Assessments (ERAs) can be fully implemented for most pelagic shark species. Other methods, either indicators or stock assessment (data-poor or traditional), can be implemented in some cases but with additional estimations and/or substitutions from other Oceans;
- It is expected that, as more data becomes available (or higher quality data) to move from indicator approaches, to data-limited assessments and eventually data-rich assessments;
- ERAs are mostly useful for ranking susceptibilities of stocks to fisheries, but information about stock status or maximum sustainable yield is not provided. ERAs are therefore mostly useful as a starting tool to highlight priorities in terms of species vulnerability, and also to identify data-gaps in knowledge that should be prioritized. Updating ERAs is important but does not need to be done very frequently; and only if better biology data is available to estimate productivity and/or if susceptibility to specific fisheries has changed;
- Finally, we note that the use of more complex models does not necessarily mean that the assessments are improved, but simply that the methods are more data rich and can use more sources of data. As such, even in cases where complex assessments can be carried out, the quality of the data inputs still remains the most important issue.

6.2. *Objectives*

The objectives of this task were to identify and categorise shark and ray stocks based on data and assessment availability, indicate what hinders scientific advisory bodies to provide quantitative assessments and describe necessary measures (e.g., identify data collection needs/sources/gaps more precisely) that could improve the assessment of these stocks. To accomplish this, the task is divided in two sub-tasks:

- Categorization of shark and ray stocks;
- Additional data needs to improve the assessment of those stocks.

6.3. *Methodology*

Sub-task 3.1 - Categorization of shark and ray stocks

The main pelagic shark species within the scope of this study were categorized according to the type of assessment that is currently carried out, or that could be carried out, for each shark and ray stocks. This was done on a stock basis for each of the tuna-RFMOs.

This information was gathered by exploring the available databases at the tuna-RFMOs websites or by contacting the Secretariats, when necessary. Statistical data reports and scientific documents presented to tuna-RFMOs were reviewed in order to inform the potential use of other methods for stock assessments.

Sub-task 3.2- Additional data needs to improve assessments

In this task, the Consortium indicates what currently hinders the provision of quantitative assessments. Moreover, measures necessary in terms of data collection and biological information that could improve the assessment, especially for the data poor/limited stocks, are listed. This subtask was approached in three steps: 1) identify the several assessment types and possibilities, and their data needs; 2) identify what data is available for each shark and ray stock, based on the previous sub-task and; 3) list of further data collection needs and biological information to carry out each of the previously listed quantitative stock assessments.

6.4. *Results and discussion*

Sub-task 3.1 - Categorization of shark and ray stocks

There are many approaches to evaluating the statuses of fish stocks, ranging from full analytical stock assessments (as used for several data-rich commercial teleosts) to the various data-limited approaches that provide (semi) quantitative evaluations of aspects of stock status and that are often based on the most robust data that are available for the stock in question, whether this be survey, landings, catch or size composition data (e.g., ICES, 2012, 2014, 2015). Besides this fundamental data, models can also use/need biological (growth, age and length- composition data) and fishery information, other information, such as data from mark-recapture can also be used (Hinton et al., 2014). A review of potential stock assessment models that could be used for sharks compiled for the Indian Ocean Year program (IOTC, 2014) is presented in Appendix VI (Table V.1.).

For data-limited stocks here is also the potential for semi-quantitative or qualitative approaches that examine a broad range of species in a fishery, such as an Ecological Risk Assessment (ERA) and Productivity-Susceptibility Analysis (PSA). Such approaches have been developed for a range of fisheries (e.g. Stobutzki et al., 2002; Gallagher et al., 2012; McCully Phillips et al., 2015), including pelagic fisheries (e.g. Arrizabalaga et al., 2011; McCully et al., 2012) and also for sharks in ICCAT (Cortés et al., 2010, 2015) and IOTC (Murua et al., 2012), highlighting the potentially more vulnerable species.

Whilst there has been progress in the estimation of landings (and catch) for some pelagic shark stocks, much of the underlying data are still uncertain. Whilst this can hamper full quantitative assessments and identification of sustainable catch limits, other approaches, including 'indicators', may allow temporal changes in stock status to be examined.

It must also be stressed that within the development of assessments for fish stocks, there will invariably be a progression from preliminary and exploratory assessments to the final assessment, for which the latter may undergo a benchmarking or review process during which the datasets and methods are reviewed more thoroughly. Given that the quality and types of data that are collected can vary over time, due to changes in national data collection programmes, and also management measures in place, it is possible that assessment methods used (or their assumptions) may also change over time, and so further benchmarks or reviews are often required.

An example of stock categorization for assessment purposes is provided by the ICES Categories. ICES currently categorises stocks to be assessed with all stocks assumed to fall within categories 1-2 (data rich) to 3–6 (data limited) (ICES, 2012). Table 6.4.1 summarizes those 6 stock categories and some comment in relation to pelagic elasmobranch. Pelagic elasmobranch species fall mainly under the data limited ICES categories, except for the main species (blue shark and shortfin mako).

In the Atlantic, blue shark and shortfin mako can be considered Categories 1-2, while in the Indian and Pacific Ocean only blue shark is under these categories. These stocks have been assessed recently with integrated stock assessments, and with the calculation of quantitative projections under various catch limit (TAC) scenarios. Most of the remaining species in ICCAT fall under Categories 4-5 as it is possible to estimate catches. However, there are no stock trend indicators available, except for porbeagle which is Category 3.

In the Indian Ocean, SMA and OCS fall under Category 3, as for these species nominal catch and standardised CPUE are available, but not size frequency time series. SPL in the Indian Ocean is considered Category 5 since catch data series is considered not reliable, while it is considered that this can be reconstructed for the other species. In the western and central Pacific Ocean most species fall under Category 3. Hammerheads and threshers catch series are more difficult to reconstruct because the majority of the catch reported is not species-specific (i.e., reported as those species complexes) and as such those species fall in Categories 4-5.

For the eastern Pacific Ocean, shortfin mako, porbeagle and silky shark can be considered Category 3. The remaining species for the Eastern Pacific Ocean were categorized as Category 5, although some data on catch, effort and size is most probably available for fisheries in the IATTC area it is not possible to evaluate to what extent this data exists because no report or information was found on this availability. However, Duffy et al. (2016) mentions that information on non-target species catch is limited for small purse seine vessels, longliners and pole-and-line; the exception being the large purse-seine vessels (carrying capacity >363 metric tons) for which non target species catch is collected by onboard observers. This is summarized in Table 6.4.2.

Globally manta and devil ray catches are poorly known, therefore it is not possible to estimate catch per unit of effort, and even fewer data exist on the size frequency and distribution of catches. All species belonging to the *Mobula* genus are considered Category 6 (Table 6.4.3).

Table 6.4.1. Summary of stock categories used by ICES (ICES, 2012) with comments on their applicability in relations to pelagic elasmobranchs.

Category	Definition (ICES, 2012)	Application to elasmobranch within ICES	Comments in relation to pelagic elasmobranchs
Category 1 Data-rich stocks (quantitative assessments)	*These are the stocks that are not considered data-limited and this category includes stocks with full analytical assessments and forecasts as well as stocks with quantitative assessments based on production models.*	Spurdog *Squalus acanthias* has a benchmarked Category 1 assessment	Given data limitations, there are no fully quantitative assessments for oceanic sharks that have been benchmarked. However, there have been assessments applied to pelagic elasmobranchs with quantitative projections which are used to provide advice on stock status and quantitative management options
Category 2 Stocks with analytical assessments and forecasts that are only treated qualitatively	*This category includes stocks with quantitative assessments and forecasts which for a variety of reasons are merely indicative of trends in fishing mortality, recruitment, and biomass.*	None	
Category 3 Stocks for which survey-based assessments indicate trends	*This category includes stocks for which survey indices (or other indicators of stock size such as reliable fishery-dependant indices; e.g. lpue, cpue, and mean length in the catch) are available that provide reliable indications of trends in stock metrics such as mortality, recruitment, and biomass.*	Fishery-independent trawl surveys are used to provide indices of stock abundance for a range of demersal elasmobranchs, including some stocks of skate (Rajidae), catsharks (Scyliorhinidae) and smooth-hound (Triakidae).	Fishery-independent CPUE data are in general not collected or available for most pelagic sharks, except occasional surveys that may catch those pelagic sharks in parts of their stock areas. However, the spatial coverage of such surveys, in relation to the overall stock areas, is invariably very restricted and the effort is low, and so the catch rates are not likely to be informative of genuine temporal trends in abundance. Fishery dependent data are more commonly available for some fleets, especially pelagic longline fleets in some tuna-RFMO areas. Whilst covering a larger proportion of the stock area, there can be issues of data quality and standardisation of data. Furthermore, given that baited lines can attract fish, and most commercial fishing effort tends to be concentrated in areas of

Category	Definition (ICES, 2012)	Application to elasmobranch within ICES	Comments in relation to pelagic elasmobranchs
			high catch rates of marketable fish, it is still unclear as to whether commercial CPUE data can be standardized in a way that it represented proportionally the stock abundance and trends. Size frequency data are available for some species, especially for the main shark species in tuna-RFMOs and the main industrial fleets. Length-based indicators could usefully be explored for case study species. Data quality checks (e.g. the approaches to measuring sharks, see Francis (2006)) are needed to ensure consistency in underlying data (e.g. potential differences between sampling programmes and over time). Spatio-temporal changes in fisheries (e.g. hook type, bait, depth, leader material) may also influence the size distributions and retention of sharks caught (sampled).
Category 4 Stocks for which reliable catch data are available	*This category includes stocks for which a time-series of catch can be used to approximate MSY.*	None: discard levels and discard survival are often poorly known	Given that both 'landings' and 'catch' are arguably the main data limitations for most oceanic elasmobranchs, time series data typically have to be estimated/reconstructed as much as possible using various approaches.
Category 5 Data-poor stocks	*This category includes stocks for which only landings data are available.*	Available landings data are used for selected species, including tope *Galeorhinus galeus* and some skate stocks	
Category 6 Negligible landings stocks, and stocks caught in minor amounts as bycatch	*This category includes stocks where landings are negligible compared with discards. It also includes stocks that are part of stock complexes and are primarily caught as bycatch species in other targeted fisheries. The development of indicators may be most appropriate to such stocks.*	This category may not be suitable for some elasmobranchs if stock abundance is greatly depleted. This category should consider historical information, value of the species and vulnerability.	There are some pelagic elasmobranchs (e.g. crocodile shark, pelagic stingray) that could be attributed to such a stock category.

Table 6.4.2. Species categorization according to ICES (2012) by data availability (nominal catch; standardised CPUE and size frequency data series) for tuna-RFMOs. Colours: green- data available; yellow- partial data available; red- no data available.

Ocean	Species	Nominal Catch	STD CPUE	Size frequency	ICES Category
Atlantic (ICCAT)	BSH	yellow	yellow	yellow	1-2
	SMA	yellow	yellow	yellow	1-2
	POR	yellow	yellow	yellow	3
	FAL	yellow	red	red	4-5
	OCS	yellow	red	red	4-5
	LMA	yellow	red	red	4-5
	SPN	yellow	red	red	4-5
	THR	yellow	red	red	4-5
Indian (IOTC)	BSH	yellow	yellow	yellow	1-2
	SMA	yellow	yellow	red	3
	POR	yellow	red	red	4-5
	FAL	yellow	red	red	4-5
	OCS	yellow	yellow	red	3
	SPN	red	red	red	5
	THR	yellow	red	red	4-5
Western and Central Pacific (WCPFC)	BSH	yellow	yellow	yellow	1-2
	SMA	yellow	yellow	yellow	3
	POR	yellow	yellow	yellow	3
	FAL	yellow	yellow	yellow	3
	OCS	yellow	yellow	yellow	3
	LMA	yellow	yellow	yellow	3
	SPN	red	yellow	yellow	4-5
	THR	red	yellow	yellow	4-5
Eastern Pacific (IATTC)	BSH	yellow	yellow	yellow	1-2
	SMA	yellow	yellow	yellow	3
	POR	yellow	yellow	yellow	3
	FAL	yellow	yellow	yellow	3
	OCS	red	red	red	5
	LMA	red	red	red	5
	SPN	red	red	red	5
	THR	red	red	red	5

Table 6.4.3. Manta and devil ray species categorization according to ICES (2012) by data availability (nominal catch; standardised CPUE and size frequency data series). Colours: green- data available; yellow- partial data available; red- no data available.

Ocean	Species	Nominal Catch	STD CPUE	Size frequency	ICES Category
All	RMA				Category 6
	RMB				
	RMH				
	RMK				
	RMM				
	RMU				
	RMT				
	RMO				

Sub-task 3.2- Additional data needs to improve assessments

A summary and discussion of the stock assessment methods that have been applied to pelagic sharks by tuna-RFMOs has been provided in Task 2 (see Sub-task 2.2 - Application of assessment methods and Table 5.4.5). A summary of stock assessment methods and stock indicators that could be applied to the scope species by ocean and tuna-RFMO is presented in this task (see Appendix VI Tables V.2-V.5 for full details).

Based on the data needs for each model, and according to the currently available information, only an ERA could be fully implemented for some species. All other methods, indicators or stock assessment (data-poor or traditional), could not be fully implemented for all shark species in all Oceans. However, some methods are possible to implement (as is being currently done) with additional estimations of some parameters, or substitutions from other Oceans.

In terms of species, the blue shark and porbeagle are the species for which it would be possible to conduct a more detailed analysis, including stock indicators (CPUE standardisation), data-limited and traditional stock assessments in all oceans. For the shortfin mako shark in the Atlantic and Pacific Oceans all analysis could be conducted. In the Indian Ocean it would be possible to carry out CPUE standardisation, data limited assessments and production models (assuming that the catch data series could be reconstructed) for the shortfin mako. For silky sharks in the Atlantic and Indian Oceans data limited assessments could be conducted while in the Pacific Ocean, for either tuna-RFMO it would be possible to carry a more detailed analysis. A more detailed analysis could possibly be conducted for longfin mako in the WCPO, however, in other tuna-RFMOs only stock indicators and data-limited analysis are possible. For oceanic whitetip shark in the WCPO it is possible to conduct analysis from stock indicators to traditional stock assessments, in IOTC, from traditional stock assessment models, only production models could be attempted, while for the Atlantic data only supports data limited model. Hammerheads and thresher sharks are the most hindered in terms of stock assessment as it is common that these species are reported as generic taxonomic group complexes, which makes it difficult to obtain species- specific catch, effort and size data. As mentioned before, data for IATTC might be available for oceanic whitetip, longfin mako, hammerheads and threshers, however no such data was found.

It is expected that, as more data is available (or higher quality data), to move from indicative approaches, as stock indicators, to data-limited assessments and eventually data-rich assessments (see Section 7.4 - subtask 4.3 for possible models to use in the near future by stock). In tuna-RFMOs there has been an effort to move to quantitative stock assessments for pelagic sharks, focusing on the main shark species.. In the Atlantic Ocean three species are assessed, while in the Indian Ocean a blue shark stock assessment was conducted in 2015 but without stock status due to the large uncertainty in the models. This was updated in 2017 and due to the integration of new data sources and modelling approaches it was possible to establish a best base case final model and provide, for the first time, advice on stock status and quantitative management options. It should be noted, however, that the use of more complex models does not necessarily mean that the assessments will be improved, but simply that the methods are more data rich and could therefore use more sources of data.

7. TASK 4 – EVALUATE METHODOLOGICAL APPROACHES

7.1. *Key findings and recommendations*

- Most of the shark species covered by the four tuna-RFMOs are not assessed using conventional stock assessment techniques due to data limitations;
- Alternative assessment methodologies that have been employed include Ecological Risk Assessment, Stock Status Indicators, Maximum Impact Sustainable Threshold, IUCN Red List criteria, and Productivity-Susceptibility Analysis;
- The IUCN Red listing process, as well as other similar approaches, are not directly comparable to quantitative stock assessments. However, they provide a useful way of categorising stocks by threat level and for highlighting where further study and/or precautionary management may be warranted.
- There is a wealth of quantitative approaches that could be employed to determine the status of the stocks. Those include, starting from the simplest to the more complex approaches: catch only methods, stock production or surplus production models, mark-recapture analysis, and age or length-structured models with or without (e.g. Stock Synthesis) inter-annual age-length variability adjustment or spatial disaggregation;
- In addition to models simulating the dynamics of data-poor stocks/fisheries, there is also the option to employ Bayesian statistical approaches or test the robustness of scientific advice through management strategy evaluations;
- Most pelagic elasmobranchs fall under the data limited categories, except for the main species (blue shark and shortfin mako) in some regions;
- Several shark species that are currently in ICES Category 4 or 5 are expected to move one category up if the quality of catch and/or CPUE data improves and some information about biological processes becomes available;
- Species in ICES Category 3 require a more multifaceted approach to move higher on the ICES scale. This involves improvements in historical catches/effort (including standardisation) and better quality of biological data and processes (e.g., natural mortality, growth, etc);
- The level of improvements needed in each of these facets varies among shark species. However, ICCAT and IOTC appear to have slightly more data (both length/quality of time series and type of data) than the other tuna-RFMOs;
- As it is not clear whether significant improvement in data can be made in the short term, it might be of more value, as a first step, to support efforts to improve the data that would achieve more robust implementation of the models

already used for the assessment of each species (e.g. improve completeness of data already submitted by Member States).

7.2. *Objectives*

This task describes and evaluates methodological approaches that are used for the assessment of the status of data-limited stocks/populations. It builds on work done under Task 2 to describe assessment methodologies used for stocks of sharks and rays by relevant scientific bodies and other organisations (e.g. IUCN). Furthermore, it explores alternative methodological approaches that could be considered specifically for data-poor and assessment limited stocks of sharks and rays, and outlines the strengths and weaknesses of adopting those approaches to guide management of elasmobranch species.

7.3. *Methodology*

This task has been delivered through three sub-tasks, as follows:

Sub-task 4.1 – Existing data poor methods for sharks/rays

This sub-task reviews data poor methods currently used by international scientific bodies to assess the conservation status of shark and ray stocks and discuss their limitations and potential. This is put in the context of current conservation needs, data availability, and management actions using material from tasks 2 and 3. The description is also broken down into organisation, species and stock/population. In addition to material gathered from RFMO technical reports and ICES documents, this work also refers to academic work and publications on relevant topics to provide a more comprehensive picture of technical analysis used to assess elasmobranch stocks.

Sub-task 4.2 – Evaluation of data poor assessment methods

This sub-task involves the identification and evaluation of data poor stock assessment and risk assessment methods used by national and international scientific bodies - including RFMOs, leading fisheries advisory bodies (e.g. ICES, NOAA) and other relevant organisations (e.g. IUCN, TRAFFIC, MSC) - for determining the conservation status of fish stocks/populations. This sub-task is not limited to sharks and rays. We build on evaluation work and research done around the world to ascertain the limitations of different approaches but also suggest ways in which those methods could be used and combined with management strategies to maximise their value and effectiveness. This sub-task considers assessment techniques currently used for different species (or group of species) and their data limitations and potentials. This helps to understand whether they are fit-for-purpose and identify improvements or opportunities to improve the assessment covering aspects such as representativeness, incorporation of uncertainty and robustness of findings, and flexibility of assessment frameworks. Both quantitative and semi-quantitative approaches are considered to provide the basis for examining a broader spectrum of methods under sub-task 4.3. In addition to technical reports and other scientific publications identified in the previous sub-task, this and subtask 4.3 makes use of specialised knowledge and experience of the researchers involved in this task.

Sub-task 4.3 – Alternative data poor methods for sharks/rays

This sub-task considers assessment methods that are not currently used for the assessment of certain pelagic shark and ray populations (or for certain species) but may have the potential for it. For this part, we combine information from previous tasks and outputs from the two previous sub-tasks with global stock assessment research and knowledge gained through its application on data-limited species to recommend alternative methodologies. The recommendations take into account data availability for each species, recognizing constraints but also opportunities to fill gaps that previous tasks might have identified. This also includes a discussion on more advanced assessment methods that could be appropriate for each species if certain data gaps could be filled. This latter part aims to inform data gathering and discussions on research priorities.

The work involves reviewing and summarising technical reports and outputs of tuna-RFMO Working Parties and Science Committees and the academic literature, as well as the assessment approaches employed by other scientific bodies both at a national and international level to assess and provide management advice for data-limited fish stocks.

The three-sub-tasks are partially informed by the outputs of task 2 (i.e. changes in assessment methods used for sharks) and task 3 (i.e. categorisation of shark and ray stocks) and support work that has been done under some of the other tasks including tasks 7 and 10.

7.4. *Results and discussion*

Sub-task 4.1 – Existing data poor methods for sharks/rays

A short overview of the situation with tuna-RFMOs with regards to data-limited approaches that are used for sharks and rays at present is first presented. Following this, approaches used by other organisations (e.g., IUCN and TRAFFIC) to assess the status of shark species are reviewed. Finally, we present some of the findings from the DRuMFISH project, which reviewed methods to assess shark stock status around the world. This covers both data-poor and data-moderate methods.

ICCAT

Most of the Atlantic shark species are not assessed with conventional stock assessment methods. Ecological Risk Assessment (ERA) analysis has been used as an alternative methodology and 16 species (20 stocks) were included in the analysis using ERA in 2013 (see section 4.4 – sub-task 1.5 and Appendix III). ERA assesses the risk associated with exploitation based on two factors: biological productivity and susceptibility to a particular type of fishery. Its application can make use of different type of data from pure qualitative to quantitative depending on the level of ERA.

Level 1 (Scale, Intensity, Consequence Analysis) evaluation of the risk is mostly based on perception from interaction with stakeholders, while a semi-quantitative approach relying on sound scientific research forms the basis of level two (Productivity Susceptibility Analysis, PSA). Level 3 is fully quantitative (Full stock assessment and Analysis of uncertainty).

Level 2 was used for the ICCAT analysis, with biological parameters used to identify the most productive species and the susceptibility of each stock to a particular fishery calculated on the basis of 4 factors (Cortés et al., 2015): availability of the stock to the fishery (i.e., horizontal overlap between the stock and fleet distributions), encounterability of the stock with the fishing gear (i.e., vertical overlap between animal distribution and depth at which the gear fishes), selectivity (i.e., the probability of the animal getting caught if it encounters the gear), and post-capture mortality (i.e., probability that the animal will die once it has been caught). The results for productivity are then combined with those for susceptibility to provide an overall vulnerability ranking for the species/stocks considered.

This approach is not a substitute for stock assessments, but can be used to identify those species that are most vulnerable and, therefore, help determine appropriate management action/priorities and research recommendations. Also, it can be undertaken at different levels (from purely qualitative to semi-quantitative to quantitative), which provides flexibility. The quality of the ERAs is conditional on the biological parameters used to estimate productivity as well as the susceptibility values for the different fleets.

IOTC

The ERA was also conducted for the Indian Ocean in 2012 (Murua et al., 2012), consisting of a semi-quantitative risk assessment analysis (ERA level 2, PSA), to evaluate the resilience of several shark species (see section 4.4 – sub-task 1.5 and Appendix III). As previously mentioned in (ICCAT), the ERA provides an assessment of the impact of a given fishery, by combining the biological productivity of the species and its susceptibility to each fishing gear type.

Also, indicators of abundance from commercial fisheries are used to estimate trends of populations.

IATTC

An attempt by the IATTC staff to assess the status of the silky shark in the Eastern Pacific Ocean (EPO), using conventional stock assessment models has been severely handicapped by major uncertainties in the fishery data. Therefore, silky sharks are assessed through a suite of possible stock status indicators (SSI) (Aires-da-Silva et al., 2014). SSIs are useful when conventional stock assessments cannot be produced, but an indication of stock status is still needed for management.

The index proposed as the best indicator to represent trends in abundance for silky shark is based on standardized CPUE in purse-seine sets on floating objects. This choice was made for two reasons: the fishery on floating objects has a wider spatial coverage in the EPO than other *metiers*, and silky sharks of all sizes (although mostly juveniles) are caught in sets on floating objects.

Indicators of other set types were also explored. The indices examined were bycatch rates in purse seine floating objects, standardized CPUE from purse seine on floating objects (including spatial trends), presence/absence indicators by purse seine type and average lengths.

WCPFC

A number of shark stocks in WCPFC have been assessed using highly sophisticated stock assessment methods (e.g. Stock Synthesis, see Section 5.4- sub-task 2.2). The indicators used to assess the state of shark stocks in WCPFC rely on information from longline and purse seine logsheets, and observer datasets held by SPC-OFP. Four main classes of indicators are assessed: range based on fishery interactions, catch composition, catch rates and biological indicators of fishing pressure (e.g. median size, sex ratio) (Clarke et al., 2011).

For the remaining shark species, much simpler approaches such as Stock Status Indicators (see description in the IATTC sub-section above) are employed as a full stock assessment is not possible. The maximum impact sustainable threshold (MIST) approach was also explored recently and results were presented in 2017 (WCPFC, 2017a). We provide a detailed description of this approach in subtask 4.2 below.

<u>IUCN Red List assessments</u>

The International Union for the Conservation of Nature (IUCN) was created in 1948 and has undertaken assessments, or classifications, of the conservation status of species for several decades, with regular updates using the IUCN Red List of Threatened Species (IUCN, 2012). The IUCN and its Species Survival Commission (SSC) oversees the work of various specialist groups, including the Shark Specialist Group (SSG), established in 1991.

The SSG produced an overview of the statuses of many elasmobranch fish using preliminary Red List assessments undertaken by scientists in the preceding years (Fowler et al., 2005). Since then, there has been progress in relation to the consistency in the approaches used by IUCN Red List Assessments.

The SSG has attempted to address all species of chondrichthyan fish (as opposed to the focus on charismatic or favoured species). Recently, the IUCN-SSG has convened workshops to address both regional and taxonomic/ecological groups, with the SSG helping produce reports for the North-east Atlantic (Gibson et al., 2008), Mediterranean Sea (Cavanagh & Gibson, 2007), European waters (Nieto et al., 2015), North America (Kyne et al., 2012) and Australia (Cavanagh et al., 2003), as well as reports for ecological groups such as pelagic sharks (Camhi et al., 2009).

It has often been viewed that if a species was on the Red List, then it was in need of conservation action. However, the SSG has proactively undertaken Red List Assessments for nearly all Chondrichthyan species. The main emphasis of the Red List should, therefore be on highlighting those species that have been identified under any of the Threatened categories (Critically Endangered (CR), Endangered (EN) or Vulnerable (VU)), and the potential need for improved monitoring and assessment. It should be highlighted that the IUCN Red List classifications are meant to indicate which taxa may be considered as threatened and for which more detailed population status and threats are required, rather than indicating where conservation management actions are required (Mace et al., 2008; Webb, 2008; IUCN, 2017).

The species for which there is most conservation concerns will typically be CR and EN, and are often species of limited commercial interest. In contrast, many commercially-exploited elasmobranchs that may be of more interest to fisheries managers are often found to be ‘Vulnerable’ or ‘Near Threatened’.

The IUCN Red List also has a category for listing data-deficient (DD) species. Those are species that have been evaluated against the listing criteria, but for which the available information is not sufficient to list them in one of the categories. The DD species are of particular concern, as those are usually species with extremely limited information (data-poor), meaning that some could have very poor conservation status which will remain unknown and not possible to fully determine in the short term. In general, pelagic sharks do not fall under the DD category, which mostly applies deep-sea sharks and species endemic to remote and poorly studied areas.

The IUCN classifications were designed for nature conservation, and so are usually more precautionary, which can result in species being listed in categories more conservative than their actual status (Mace et al., 2008). The approach of the Red Listing process is to make the best use of available data and analyses. Therefore, it is important to note that the choice of evidence to which more credence will be given can be quite subjective (see below).

IUCN Methodology

The assessments conducted through the IUCN process do not necessarily make full use of quantitative stock assessments undertaken by RFMOs and other bodies, but are rather based on approaches that consider a range of published and grey literature sources to quantitatively or qualitatively evaluate the status of a species.

Its aim is to assign species into a range of categories that reflect their status (see Appendix VII), with the assumption that species of ‘Least Concern’ are of limited risk of becoming ‘Extinct’, whilst ‘Critically Endangered’ species are at a high risk of becoming ‘Extinct’.

Each species is evaluated by one or more assessors. The assessors consider what appropriate data are there to gauge trends in the five Red List Criteria (including population size, geographic range (i.e. extent of occurrence and/or occupancy area), estimates of population size, and the probability of extinction). The assessors may undertake their own, new analysis or, more commonly, simply use the results that are available from other sources (e.g. fishery reports and peer-reviewed papers), with expert opinion used for the interpretation of these data.

Whilst the reader is referred to IUCN (2012) for detailed information on the IUCN criteria, the five criteria (A–E) available address:

(A) Reductions in population size;
(B) Geographic range in the form of either the extent of occurrence (B1) or area of occupancy (B2);
(C) Population size estimated to be <250 (mm) mature individuals;
(D) Population size estimated to be <50 (mm) mature individuals; and
(E) Quantitative analyses indicating that the probability of extinction in the wild is at least 50% within 10 years or three generations, whichever is the longest.

Whilst geographic range size is an important criterion for many coastal and demersal elasmobranchs, IUCN assessments for oceanic sharks are typically based on Criterion A (reductions in population size). The criterion for population decline has attracted much debate, as it may not be a reliable indicator of extinction risk (Webb, 2008). In relation to commercially exploited species, an agreed harvest strategy could potentially result in a decline that could lead to a threatened listing (IUCN, 2017).

For each criterion, there are defined thresholds which would identify the final IUCN Red List category (see Appendix VII). The data (or knowledge) used to interpret the criteria for the magnitude of any decline can be either 'observed' (e.g. population census), 'estimated', 'inferred' or 'suspected'. The use of these terms allows managers to infer the reliability of the data used, for example an 'observed' decline may be given more credence than a 'suspected' decline.

However, the thresholds for the percentage declines associated with the IUCN categories (and assumed to relate to the threat of extinction) are not strictly analogous with the traditional framework of fisheries management, for which population status in relation to virgin biomass is related to the concepts of Maximum Sustainable Yield/Maximum Economic Yield; inside/outside Safe Biological Limits.

The advantages of the IUCN Red List criteria and the approach of the SSG Red Listing Workshops are that it:

- Attempts to provide a consistent approach to evaluating the current statuses of all chondrichthyan species, many of which would not be considered by fisheries bodies (e.g. if data-limited or non-commercial);
- Provides a forum for the rapid and cost-effective appraisal of the various species;
- Uses a consistent list of criteria for which the status of all taxa can be appraised;Makes best use of a wide range of information, from peer-reviewed published studies and fisheries reports to local knowledge and expert judgement.

There are, however, several disadvantages:

- It typically examines species either globally or regionally, which may or may not relate to biological stock units or management units;
- The assessments may not be updated in a timely fashion, even if new data and/or analyses provide a different perception of the species (which may provide a more optimistic or pessimistic perception);
- The IUCN criteria are typically phrased in relation to 'extinction risk', which has often been questioned by fisheries bodies;
- Historical declines over three generations may not be an appropriate rationale for inferring a risk of global extinction in the future (Webb and Carillo, 2000);
- There is limited information available as to how 'uncertainty' is incorporated when making IUCN classifications (Akçakaya et al., 2000);
- Where there are a range of information sources on population trends (Criteria A), which may give differing trajectories, cover different spatial and temporal scales, and have varying scientific caveats. The IUCN process does not always indicate clearly how sources were considered when deciding whether specified thresholds had been met.

The latter point is a very important issue when considering IUCN assessments and classifications, as this is also where individual assessors can differ (Collen et al., 2016). Some assessors may be more precautionary (e.g., using the worst-case scenario), or other assessors may be guided more by the most robust assessments of population trends. It has also been recognised that members of advocacy groups can be involved in IUCN assessments, and there is the potential that "*exaggerating risks of extinction*" may be "*an effective political strategy for achieving conservation outcomes and the end justified the means*…" (Webb, 2008).

The potential for subjective decisions on IUCN classifications was emphasised by Regan et al. (2005), who provided the same data for 13 species to 18 assessors and found that there could be poor agreement between assessors (although less so for species in the highest and lowest risk categories). Whilst such subjectivity may affect IUCN classifications for taxa assessed by a single person, of limited number of assessors, the use of multiple assessors from different fields and attempts to achieve consensus should, theoretically, reduce subjectivity in assessments.

Reconciling the potentially different population trends for a given species that may be available from disparate sources is a key issue to be addressed when appraising the validity of IUCN Red List status. As such, some of the potential mismatches between fisheries assessments from IUCN assessments may reflect the more precautionary stance of conservation bodies (Rice and Legacè, 2007) and willingness of some of the assessors to base a Red List assessment on worst-case scenarios (i.e have more 'false alarms' by listing a species at a higher level of threat than it should have been) than risking a 'miss' (i.e. listing a species at a lower level of threat than it should have been).

Overall, whilst the IUCN Red List Assessments provide a useful initial appraisal that highlights potential species of conservation concern, they should be treated with a degree of caution, depending on whether there are more robust analyses available that may have not been available or, if considered, underweighted in the original Red List assessment. As indicated above, whilst the IUCN listings clearly identify those species for which more robust assessments are required, they were not designed to prioritise where conservation actions are required.

TRAFFIC

The wildlife trade monitoring network developed a rapid risk assessment framework (M-Risk) for evaluating exposure and management risk, and applied it to 46 shark species. The M-Risk Assessment has two components: the first focuses on the management regime that is relevant to the species (i.e., global catches, gears, IUCN status, relevant management bodies) and the second is a risk assessment process that considers three criteria (i.e., stock status, species-specific management, and generic management) each of which receives a different weight in the assessment.

Indicators are used to assess each of the elements and those cover considerations such as the status of the stock, data collection activities, existence of compliance regimes, and fishery management measures and consistency between scientific advice and management measures.

Each indicator receives a score from 1 to 4 with the highest score reflecting better management and lowest risk. This is a semi-quantitative approach that can help identify species of greater concern and thus, support prioritisation. Another use of the M-Risk framework is to highlight specific areas of management where improvements might be needed.

This is an example of a rapid application of a semi-quantitative tool to a large number of shark species that also aims to capture the influence of trade or high market value on the risk that the species is exposed to. However, it has not been extensively tested and it is not clear whether the indicators currently chosen and the associated weightings are appropriate to provide a representative picture of the risk situation for each species.

As the developers of the approach point out (Lack et al., 2014), it should be seen as a tool to guide a more detailed investigation and further work is required if it is to be used as a mainstream tool. Such further work could include, for example, testing the sensitivity of the results to various parameterisations of the framework.

DRuMFISH revision of methods

The "DRuMFISH" DG MARE project has provided a review of several assessment and management approaches for data-poor stocks with its focus primarily being on mixed fisheries. The review makes a distinction between three approaches, namely data limited, data-moderate and data-rich approaches. Data-moderate approaches typically include indices of biomass/abundance in addition to catch data and life history information, while data-rich approaches include full analytical assessments. The information available for sharks and rays will most typically be in the "data-limited approaches" or "data-moderate approaches".

In the DRuMFISH review, data-limited approaches cover catch-based approaches (catch-only methods with supplementary information), life-history, per-recruit and length-based approaches, and qualitative and semi-quantitative approaches. The DRuMFISH project reviewed 24 different assessment methods in these categories. These assessment methods include those used in ICES WKLIFE (ICES, 2017). Below we highlight a few that have already applied to shark and ray case studies.

Brooks et al. (2010) evaluated analytical methods for calculating biological reference points using estimates of the maximum lifetime reproductive rate. This rate was calculated directly from biological parameters of maturity, fecundity, and natural mortality. Alternatively, a distribution for this rate was derived from appropriate metadata. The ability to directly calculate reference points from biological data, or a meta-analysis, without the need of a full assessment model or fisheries data, makes the method an attractive option for data-poor fisheries. The method was applied to dusky shark for which biological information was available to calculate the SPR-based (i.e. spawning biomass per recruit-based) reference points, and a fisheries-independent index of abundance was available to provide information on relative depletion. The analytical prediction was compared to results from multiple stock assessment methodologies and it was found that they were in agreement with the results of those stock assessment methodologies.

The Productivity-Susceptibility Analysis (PSA) offers another solution to data-limited species and has already been used to evaluate the status of data poor stocks in some tuna-RFMOs. Patrick et al. (2009) used productivity and susceptibility indices to determine stock vulnerability for six U.S. fisheries, including those that had sharks as part of their catches. The PSA methodology scores attributes on a three-point scale (i.e., 1 = low, 2 = moderate, 3 = high). The weighted average of each factor's attributed scores was plotted in an x-y scatter plot and the vulnerability score of the stock calculated by measuring the Euclidean distance of the datum point from the origin of the plot. Stocks that received a low productivity score and a high susceptibility score were the most vulnerable, while stocks with a high productivity score and low susceptibility score were considered to be the least vulnerable. The vulnerability of non-target stocks was not significantly different from target stocks for three of the example applications (Hawaii longline-tuna sector, Hawaii longline-swordfish sector, and Atlantic shark complex), highlighting the need to carefully examine non-target stocks when determining ecosystem component stocks.

In the DRuMFISH data-moderate category, several assessment methods have been used for sharks. For example, Jiao et al. (2011) used hierarchical Bayesian methods that allowed poor-data species to "borrow" strength from species with good-quality data. They used a hammerhead shark complex as an example. Within the complex there are three species: scalloped hammerhead (*Sphyrna lewini*), great hammerhead (*S. mokarran*), and smooth hammerhead (*S. zygaena*). The scalloped hammerhead comprises 70% to 80% of the catch and has high quality catch and abundance data, whereas great and smooth hammerheads have relative abundance indices that are both limited and of low quality, presumably because of low stock density and/or limited sampling. Hierarchical Bayesian state-space surplus production models were developed to simulate variability in population growth rates, carrying capacity, and catchability of the species. The results from the hierarchical Bayesian models were considerably more robust than those of the non-hierarchical models.

The idea of "borrowing data" as in the example of Jiao et al. (2011) was coined "The Robin Hood approach" in Punt et al. (2011). This borrowing of information from data-rich stock assessments can be, for example, for trends in fishing mortality, values for parameters of selectivity functions, or life history characteristics, to improve data-poor stock assessments. This leads to stock assessments for the most data-limited stocks being informed by those for the most data-rich stocks.

<u>Sub-task 4.2 – Identification and evaluation of data-poor stock assessment and risk assessment methods used by national and international scientific bodies</u>

This section goes beyond stock assessment methods already used for elasmobranchs. It considers all data-poor assessment methods used in tuna RFMOs and other bodies around the world to support discussions about methodologies that can be appropriate for the assessment of elasmobranchs. First, a clarification building on some of the information for the IUCN approach presented in the previous section is provided. Then, we focused on data-poor (and some data-moderate) methodologies used in each of the four tuna-RFMOs, covering methods used for species other than elasmobranch or are currently being considered for use in elasmobranch species. We provide a short description of each model, its use, basic data requirements, and type of outcomes/insight it can produce and discuss strengths and shortcomings of each model. We also revise the processes employed in two other bodies, namely ICES and NOAA Fisheries. For ICES, we look at approaches used to classify stocks in terms of the quality of their data and produce advice on future catches. For NOAA fisheries, we focus on the NOAA Fisheries Toolbox that provides a variety of models that are readily available for fisheries scientists to download and use.

We also examine methodologies not applied on sharks reviewed by the DRuMFISH project and at two alternative approaches (MSC Risk Based Framework and close-kin Mark recapture) that could be an option when conventional stock assessment methods cannot be employed.

The last part of this section presents a few examples of methodologies available to support Management Strategy Evaluation (MSE) which has been increasingly used to provide management advice for both data-rich and data poor species.

IUCN assessment interpretation

There are differences in the way in which the term "assessment" is used in different approaches and we would like to highlight that, particularly in relation to IUCN analyses. This is because the term 'assessment' used by IUCN does not always relate to a fully quantitative stock assessment of the population, as declines (in population of geographical extent) can be 'inferred' or 'suspected'. Furthermore, the IUCN assessments drafted at Red List workshops are often drafted in a comparatively short time frame and are often heavily reliant on published information and/or reports from fisheries bodies. This process can give equal credibility to studies of higher and lower quality, and the IUCN process will generally take the more precautionary view (i.e. if a 'lower quality' study shows a larger decline and the assessors are unaware of data quality issues, then IUCN may apply the larger decline and thus give a higher listing than may be warranted).

Consequently, some species listed as 'Threatened' have subsequently been down-listed to lower categories when further studies have been undertaken. Conversely, species classified as one of the 'Threatened' categories have been given higher listings when more data were collated. Overall, IUCN Red Lists are a useful way of categorising stocks by threat and for highlighting where further study and/or precautionary management may be warranted. Managers could usefully consider IUCN Red Lists, but should also critically evaluate assessments on a case-by-case basis to determine whether the listing is appropriate (noting that the population could be in a worse or better state than the IUCN assessment).

Assessment methods used in IOTC

A variety of models are explored in IOTC and here we describe models applied to what could be considered data-poor stocks managed by IOTC:

1) *Billfishes*: Most of the stocks within this group are assessed using biomass dynamic models (ASPIC and BSP-SS).
    - ASPIC (A Stock Production Model Incorporating Covariates) is a software that allows fitting catch and abundance indices data to a biomass dynamic model (Logistic or Fox). ASPIC is a non-equilibrium implementation of the well-known surplus production models of Schaefer and Pella-Tomlinson (Schaefer, 1954; Schaefer, 1957; Pella and Tomlinson, 1969). ASPIC can fit data from up to 10 data series of fishery-dependent or fishery-independent indices, and uses bootstrapping to construct approximate non-parametric confidence intervals and to correct for bias. In addition, ASPIC can fit the model by varying the relative importance placed on yield versus measures of effort or indices of abundance. The model has been extensively reviewed and tested in the context of various applications to tuna stocks via ICCAT by Prager (Prager, 1992; Prager, 1994).
    - BSP-SS (Bayesian state-space production model) was adapted from the Bayesian Surplus Production Model (Meyer & Miller, 1999; McAllister and Babcock, 2003; Babcock, 2014) to allow using multiple CPUE time series as calculated based on different fleets. BSP is a lumped biomass model, which does not require catches for separate fleets. In addition, it is possible to use available biological information about fish stocks to set up a Bayesian informative probability density function for the rate of population increase, which constrains the model to estimate parameter values that are biologically plausible. This can be useful when abundance index data are not very informative. This model has been used in tuna RFMOs because it is not as data demanding as more sophisticated models. BSP requires catch and at least one CPUE index of abundance.

We revisit these two methods in the ICCAT sub-section below where we cover advantages and limitations of these methods.

2) *Neritic tunas*: The neritic tunas of IOTC are seldomly assessed using conventional stock assessment methods. Most of the management recommendations are provided using indicators analysis and catch-based models. With regards to the latest, two are used for this group of tunas:

   - *Optimised Catch Only Method (OCOM):* This method relies on a catch time series dataset without necessary knowledge of prior distributions (Zhou et al., 2013). The idea behind this approach is to use unconstrained priors on both r (maximum rate of population increase) and K (carrying capacity), that is $0 < K < \infty$ and $0 < r < \infty$. Because the two parameters are negatively correlated, the maximum K is constrained by r = 0 and maximum r is constrained by the minimum viable K. The aim of this approach is to identify the likely range of both r and K and the most likely r ~ K combination on the curve which retain a viable population over time (i.e. where $B_t > C_t$, $B_t \leq K$ and $B_t > 0$ always hold true). This approach produces results from a number of trials and the improbable values are then excluded, so the method is referred to as a posterior-focused catch-based method for estimating biological reference points (Zhou et al., 2013). The approach uses an optimisation model to estimate the feasible r value corresponding to a fixed final depletion level and a sampled K value by minimising the difference between the final biomass and the given depletion level.
   - *Catch MSY*: One of the simplest model-based methods for estimating MSY are production models such as that of Schaefer (1954) as they only require a time series of relative or absolute abundance and of removals to estimate two model parameters: the carrying capacity, K, and the maximum rate of population increase, r, for a stock (Martell and Froese, 2012). Abundance estimates can be difficult and costly to obtain and therefore, methods that require only a time series of removals are sometimes necessary. Without abundance estimates, Schaefer models output a range of r-K combinations which can be used to approximate MSY. This method can be applied to obtain plausible MSY estimates and other biological parameters from catch only data, based on assumptions on resilience (corresponding to the intrinsic growth rate r in the stock production model). For each plausible r-K pair, an estimate is obtained as MSY=1/4 r K. This MSY estimation algorithm has been validated against analytical fish stock assessment estimates of MSY.

Assessment methods used in WCPFC

Data poor methods for assessment in WCPFC primarily focus on sharks and have only really been developed in recent years. For example, the ABNJ project funded two recent assessments that applied the maximum impact sustainable threshold (MIST) approach to data poor species, specifically the southern hemisphere porbeagle shark and bigeye thresher shark (WCPFC, 2017b; WCPFC, 2017c). The risk assessment methodology employed used the spatial overlap of fishing effort and population density to derive a risk metric. These assessments provide an estimate of the level of fishing mortality expected to lead the population to extinction in the long term.

The analytical approach is a risk-based and spatially explicit framework. Sustainability status is assessed relative to current impacts from fisheries (relative Fishing Mortality) and a maximum impact sustainable threshold (MIST) limit reference point (LRP):

$$S = Impact/MIST \sim F/LRP$$

Uncertainty in all parameters is quantified and propagated through the assessment framework. In this context, sustainability risk R is the probability p, given the uncertainty, that the total impact exceeds the MIST.

MIST is the sustainable reference threshold for the species. The MIST is defined based on population productivity inferred from life history data. Life history parameters are used to estimate a maximum intrinsic population growth rate (r), with uncertainty. In turn, r is used to derive sustainable impact thresholds similar to the fishing mortality-based sustainability reference points (Fcrash, Fmsm, Flim) described by Zhou et al. (2011). A summary of data inputs, analytical methods and key parameters is presented in Figure 7.4.1.

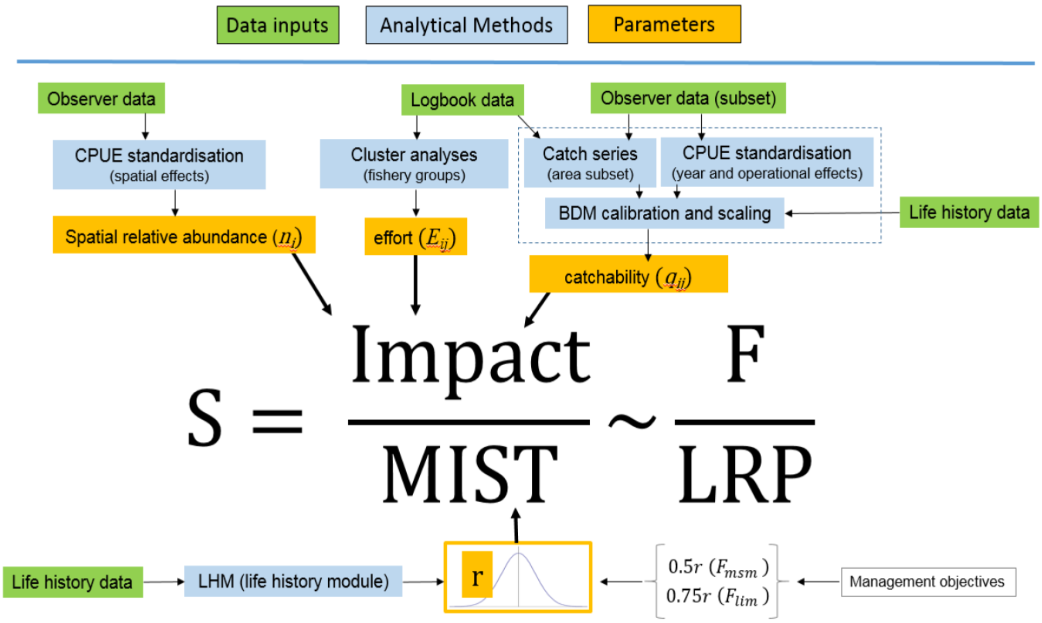


Figure 7.4.1. Conceptual representation of data inputs, analytical methods and key parameters used in Pacific-wide spatially-explicit sustainability assessment of bigeye shark. BDM=Bayesian state-space biomass dynamics model. The dashed outline box represents analytical methods applied to an area subset of the available data (WCPFC, 2017b).

MIST is considered to be a useful tool that can help 1) source and synthesise available information on sharks; 2) identify important data gaps (e.g., density distribution and life-stage specific vulnerability and overlap with fishing activities); 3) calculate productivity-based reference points for the species; and 4) prioritise fishery areas for monitoring and management (Clark, 2017).

This approach differs from traditional stock assessments because it evaluates whether the population's ability to withstand fishing pressure is exceeded, rather than evaluating biomass and whether the population is overfished. Therefore, the studies that have used MIST examine the question of whether overfishing is occurring but do not answer questions regarding whether the stock is depleted. It is not per se, a stock assessment model but a method to quantify fishing pressure relative to stocks productivity to help determine whether (additional) management actions are needed.

The risk assessment results are based on strong assumptions about the population density distribution. For example, these analyses assume separation of the populations into regions, but there is little information available with which to determine appropriate stock boundaries. Furthermore, the density of fish in one area with limited data is extrapolated from other areas where more information is available.

Assessment methods used in ICCAT

The methodologies used in ICCAT for data poor species are very similar to those described for IOTC above; namely ASPIC and Bayesian surplus production models. A recent stock assessment completed for swordfish highlighted strengths and weaknesses of these methods (Anon. 2017a). Both methods have less data requirements than other more detailed assessment methodologies and that makes them easier to apply to data poor species. They are also relatively quicker to run as they use a small number of uncertain parameters in their stochastic calculations (if uncertainty is characterised). However, because of their simplicity, they do not necessarily reflect the true dynamics of the stock/fishery; for example, they cannot capture age-specific processes. Although that does not necessarily reduce their value, it is an important feature to include in model selection to balance the complexity with the extension of data that could inform the model.

Another methodology used in ICCAT is Stock Synthesis (SS); this is a more sophisticated tool but we cover it here as, in its simplified parameterization, it could be an option for moderate-data species. SS is designed to accept both size and age structured data so, it can capture changes in age- or size specific processes over time and can also provide area-disaggregated analyses. However, it needs catch and CPUE data (or other abundance index) and, even in its simplified form, it usually requires considerable tuning and more time to run than production models like ASPIC or Bayesian surplus production approaches.

Assessment methods used in IATTC for data poor species

IATTC publishes an annual stock assessment report summarising the stock assessments completed that year. The most relevant stocks of this tRFMO (bigeye and yellowfin) are assessed using Stock Synthesis (see ICCAT section). However, other stocks (e.g. sharks) are assessed using stock status indicators (see section 5.4 sub-task 2.2).

In the case of skipjack, a range of methods were used to assess the status of the stock. The complexity and data requirements of the five methods increases as we examine the assessment methods, with the first two methods ideal for data-poor ones. All five methods have some potential to be used for shark species in the future and thus, they could help focus work to close key data gaps.

1) *Indicators:* Since the stock assessment and reference points for skipjack in the Eastern Pacific Ocean are uncertain, a series of indicators were investigated using relative quantities. Rather than using reference points based on MSY, some simple indicators of stock status are used to compare current values with their historical values. Eight data- and model-based indicators are evaluated: catch,

catch-per-day-fished by floating object fisheries, catch-per-day-fished by unassociated fisheries, standardised effort, average weight, relative biomass, relative recruitment, and relative exploitation rate.

2) *Analysis of tag data:* The IATTC carried out numerous tagging experiments during the 1950s till the early 1980s, and then resumed tuna tagging, to a limited extent, in 2000. These data have not been used in the stock assessments of skipjack. The tag data were analysed using a tag attrition model comparing observed and predicted tag recoveries. The tag dynamics is modelled using a population dynamics model, similar to those used in stock assessments. The model differs in that recruitment is tag releases and factors such as tag loss, tagging related mortality, and reporting rate are modelled. The model uses the return rates of tags to estimate exploitation rates but the predicted rates are highly uncertain.
3) *Length-structured stock assessment model* (Maunder, 2012)*:* For this model, the EPO was divided into six stocks and each stock was analysed separately. The model was fitted to CPUE-based indices of relative abundance and length-composition data. There was insufficient information in the CPUE and length-composition data to produce reliable estimates of skipjack stock size. In all but one region (off the coast of Ecuador) the estimates of abundance and exploitation rates were unrealistic.
4) *Age-Structured Catch at Length Analysis (A-SCALA):* Maunder & Harley (2005) used an age-structured, catch-at-length analysis (A-SCALA) to assess skipjack tuna in the EPO. This model is based on an age-structured population dynamics model and information contained in catch, effort, and size-composition data are the basis of the assessment.
5) *Spatial Ecosystem and Population Dynamic Model (SEAPODYM):* This model can use a variety of data sources as input and has been applied to skipjack tuna in the Pacific Ocean. This is a two-dimensional coupled physical–biological interaction model at the ocean basin scale, and contains environmental and spatial components used to constrain the movement and the recruitment of tuna. The model combines a forage (prey) production model with an age-structured population model of the target fishery (tuna- predator) species. All the spatial dynamics are described with an advection– diffusion equation. Oceanographic input data sets for the model are sea-surface temperature (SST), oceanic currents and primary production that can be predicted from coupled physical–biogeochemical models, as well as satellite-derived data distributions. Recent improvements include rigorous parameter optimisation using fisheries data (size

composition and abundance indices), which are based on methods used for contemporary stock assessment models (Senina et al., 2008).

ICES

The availability of data for quantitative assessments and forecasts for data-limited stocks and possibilities for assessment of the status of the stock varies among stocks. ICES identified six categories of data-limited stocks from data-rich to truly data-poor (see task 3 - Table 6.4.1 in Section 6.4). The assessment method and approach used to calculate future catches differs depending on that category. For example, at Category 4, a simple method using time-series of catch to approximate MSY is suggested due to limited availability of other data.

Among the 54 shark and ray stocks considered in ICES waters, 25 are assessed using methods for Data Limited Stocks (DLS) in the category 3, "Stocks for which survey-based assessments indicate trends" (ICES, 2012). This category covers stocks for which quantitative assessments are not available but indices of stock abundance are (e.g. fishery-independent surveys) and are considered to give a reliable indication of trends in recruitment and/or abundance. The idea in this case, is that decreasing trends in the indicator in coupled with incremental decreases in the catahes and vice versa. In its simplest form, the rule for defining the following year's catches for such type of fish is:

$$C_{y+1} = C_{y-1}\left(\frac{\sum_{i=y-x}^{y-1} I_i / x}{\sum_{i=y-z}^{y-x-1} I_i / (z-x)}\right)$$

Where I is the survey index, x is the number of years in the survey average, and z > x. However, this is done in the context of an uncertainty cap that will impose a 20% cap in the change between C_{y+1} and C_{y-1} allowed even if the equation above leads to a more than 20% change. Furthermore, the approach used by ICES applies a buffer of a 20% reduction to catch advice (C_{y+1}) when reference points are unknown.

Although ICES relays in the ICCAT assessments for pelagic species, several exploratory assessment models have been used to assess the state of other shark's stocks. More specifically, population dynamic, Surplus, Additive, GLM and Capture and Recapture models have been used to assess the state of spurdog, tope, and deep-water shark stocks. Those models have already been described above.

US Government – NOAA Fisheries Toolbox

There are a variety of fisheries stock assessment models used in the United States for stock assessments and are available from the NOAA Fisheries Toolbox[14]. Those models range from simple surplus production models to highly sophisticated age and length-based models that can combine data from multiple sources to simulate highly-detailed biological and fisheries processes. Some of the commonely used stock assessments are shown in Table 7.4.2, which provides an overview of the key features for each of them.

The simplest ones with the lowest level of complexity are ASPIC (Stock Production Model Incorporating Covariates) and CSA (catch-survey analysis model or DeLury model). The former is a surplus production model and although it cannot capture age and length specific characteristics of the population, it can simulate different recruitment patterns in a non-equilibrium parameterisation. The latter is a two-stage model that can be set up such that the two stages could represent different natural divisions such as age or length groups. Both models require only aggregated catch and index data so are easier to be applied to data-poor species but also have limitations of age/length-aggregated models.

The remaining models are more complex starting with standard forward and backward calculations of age-structured models and moving to more elaborate simulations of population and fleet dynamics. The Stock Synthesis (SS) model represents the most complex end of the spectrum, offering age, sex and area disaggregation capabilities and the opportunity to combine survey data and biological data such as age-length keys to simulate annual variability in growth and its impact on associated indicators. Although the latter type of models are used for data-rich species, with some simplifications, they can also be used for data-moderate species (see, for example, Monk et al., 2017). In the latter case, a simplified version of SS can be used for the assessment that can function as a simple age-structured production model. Using such a flexible and versatile methodology has benefits as it makes it easier to extend the model as new data becomes available instead of migrating to different methodologies. At the same time, even at its simple form, SS is still an age-structured model that requires a certain amount of information. It also makes use of many uncertain parameters and identifying those that are best to switch on is a challenging process. Similarly, there is certain level of expertise and experience required to tune and run the model correctly and efficiently.

In addition to the assessment models mentioned above, management strategy evaluation (MSE) approaches have also been increasingly employed in recent years. They have been used mainly to test the effectiveness of different management

[14] http://nft.nefsc.noaa.gov/

procedures (MPs) for a given fishery, and can include fisheries for data-poor species (e.g., DLMTool, see description below).

Table 7.4.2. Features of the models in the NOAA Fisheries Toolbox and their level of complexity (1=Low, 4=Very High)[15].

Feature	Model					
	ASPIC	**CSA**	**VPA**	**ASAP**	**VPA 2BOX**	**SS3**
Model Complexity	1	1	2	3	3	4
Data / Observation Error						
Total catch (landings + discards)	●	●		●	●	●
Catch at age (CAA)			●	●	●	●
Catch at length (CAL)						●
Address variation in CAA or CAL				●		●
Age specific indices of abundance for tuning			●	●	●	●
Age-aggregated tuning indices	●	●	●	●	●	●
Tag-recapture					●	●
Process / Model Specification						
Stock recruitment function				●		●
Sexual dimorphism in growth rates					●	●
Spatial heterogeneity					●	●
Incorporate long term historical landings	●			●		●
Handle gaps in age or length information				●		●
Multiple fleets				●		●
Handle differences between sexes					●	●
Automatic retrospective analyses	●		●	●		
Independently estimate temporal changes in catchability for surveys				●		●
Address variations in biological sampling intensity over time				●		●
Consider measurement error for individual times series observations				●		●
Uncertainty / Forecasting / BRPs						
MCMC				●		●
Bootstrap	●	●	●		●	●

[15] Adapted from http://nft.nefsc.noaa.gov/index.html

DRuMFISH

Besides the methods described in sub-task 4.1, the DRuMFISH review (De Oliveira et al., 2017) identified two additional methods that have already been used within the ICES advisory system, namely CMSY (Martell and Froese, 2013; Froese et al., 2017) for data-limited cases, and SPiCT (Pedersen and Berg, 2017) for data-moderate cases. These methods produce consistent outputs. A general guideline is that if some index of biomass or abundance is available (from CPUE or fishery-independent data), one should always move to a full biomass dynamic model (e.g. SPiCT, ASPIC, etc.).

SPiCT is a stochastic surplus production model in continuous time which, in addition to stock dynamics, also models the dynamics of the fisheries. This enables error in the catch process to be reflected in the uncertainty of estimated model parameters and management quantities. Benefits of the continuous-time state-space model formulation include the ability to provide estimates of exploitable biomass and fishing mortality at any point in time from data sampled at arbitrary and possibly irregular intervals. In its essence, SPiCT is a Pella and Tomlinson (1969) generalized surplus production model, as in the parameterization proposed by Fletcher (1978). It is modified to include stochastic process noise terms. SPiCT models thus requires catch and abundance indices, which are potentially available for several shark stocks. SPiCT also allows setting priors on its parameters.

Catch-MSY (CMSY) is a Monte Carlo method for estimating fisheries reference points from catch, resilience and qualitative stock status information on data-limited stocks. An extension of CMSY is BSM (Froese et al., 2017), which needs to be fitted to catch and biomass or catch-per-unit-of-effort (CPUE) data. Both methods require priors, for instance for productivity, unexploited stock size, catchability and biomass from population dynamics theory.

The DRuMFISH review also includes simulation-tests of assessment methods. These tests found that quantitative catch-only methods (DCAC, DB-SRA, CMSY, SS-CO etc.) are highly sensitive to assumptions about depletion. Semi-quantitative catch-only methods are more negatively biased on average compared to other methods that explicitly model population dynamics with the use of additional fishing effort data. This suggests that there is high value in including additional information regarding stock depletion, historical fishing effort, and current abundance when only catch data are available, but this information is often lacking.

MSC – Risk-Based Framework (RBF)

The Marine Stewardship Council (MSC) is an independent non-profit organization which sets a standard for sustainable fishing. The Risk Based Framework (RBF) is the MSC's methodology for assessing the risk that a fishery is having an impact on species, habitats and the surrounding ecosystems for data-deficient fisheries. Currently there are two methodologies to assess the stock status of such fisheries (MSC, 2014): (1) Consequence Analysis (CA), which uses any available data to assess trends in the target stocks of a fishery; and (2) Productivity Susceptibility Analysis (PSA), for assessing how likely a stock is to recover when depleted, as well as how likely a species is to interact with fishing gear. Each of the methods produces a score that, after being combined, can be used to assess the stock status relative to MSC criteria.

Within CA methodology, qualitative or quantitative information on the species is required, such as population size, reproductive capacity, age/size/sex structure or geographic range. The main issue is to identify the subcomponent on which fishing activity is supposed to have major impact and score based on the following classification: (1) insignificant change, i.e. changes in the subcomponents are undetectable or if detectable, these are of such a low magnitude that the impact of the fishing activity cannot be differentiated from the natural variability for this population; (2) possible detectable change, i.e. changes are detected and can be reasonably attributable to the fishing activity, but these are of such a low magnitude that the impact of the fishery is considered to be minimal on the population size and dynamics; and (3) detectable change; i.e. changes to the subcomponent can be attributed to the fishing activity and changes are of such magnitude that cannot be considered as minimal.

Regarding PSA, productivity attributes (average age at maturity, average maximum age, fecundity, average maximum size, average size at maturity, reproductive strategy, trophic level and density dependence) and susceptibility attributes (areal overlap –availability-, encounterability, selectivity and post-capture mortality) are scored based on a three point risk scale: low, medium or high. While scoring, where there is limited information available for an attribute, the more precautionary score shall be awarded. Final score is calculated as a weighted average of PSA scores for each fishery affecting the given stock, given the percentage of catches of each fishery.

RBF has not been applied to any elasmobranch species, up till now, within an MSC evaluation. An example of PSA methodology applied to shark and ray species can be found in Micheli *et al*. (2014).

The advantages of the RBF methodology are:

- Provides an alternative approach to assess the status of different stocks for which there is not enough information to score a fishery using the default methodology;
- Makes best use of available information, from peer-reviewed published studies and fisheries reports, to local knowledge and expert judgement;
- However, the use of the MSC's RBF methods will likely result in poorer scores for the assessment of larger scale fisheries, as these methods are highly precautionary. Therefore, the default assessment method is desirable and the RBF should only be applied when data are lacking.

Methodology and data needs for this method are presented in Appendix VI.

Close-kin Mark-Recapture

Close-kin mark-recapture (CKMR) is a new approach for estimating population abundance and other population parameters. This method uses small pieces of tissue, taken from dead or alive specimens to identify parent-offspring pairs (POPs). The number and patterns of pairs is then analysed in a mark-recapture framework as they become the 'recaptures' in a mark-recapture model for parameter estimation (Bravington et al., 2016a; Bravington et al., 2016b). Bravington et al. (2016a) present a successful application of CKMR to the highly migratory and severely depleted southern bluefin tuna (*Thunnus maccoyii*). They detected 45 POPs among 14,000 tissue samples of juvenile and adult tuna collected from the fisheries. In order to estimate population abundance and other population parameters, they developed a length-, sex- and age-structured population dynamics and mark-recapture model for the pairwise POP comparisons and for the adult length/age/sex compositions (Bravington et al., 2016a). One of the advantages of CKMR is that only requires samples from the catch. Survey, fishery catch, or effort data is not needed.

EVALUATION FRAMEWORKS

Evaluation frameworks (such as, MSE) have been employed in recent years to test the effectiveness of different fishery management approaches. MSE can be a useful tool for data-poor species as it helps understand the importance of various uncertainties characterising stock assessment results and robustness of management measures under uncertainty. Below, we present a few examples of tools available to support MSE for data-poor species.

DLMTool

The DLMTool (Data-Limited Methods Toolkit) is a software library implemented in R that includes a range of assessment models and a simulation-evaluation framework to test the performance of management procedures. All the packages that are part of DLMTool are open-source and available for free and there is a dedicated website for the tool[16].

The main components of the MSE function is the operating model which is used to simulate the stock and fleet dynamics. A stock assessment model (qualitative or quantitative) that uses the simulated fishery data from the operating model to estimate the status of the (simulated) stock is also needed. The MSE process also requires a harvest control rule (HCR) that is used to calculate the management advice based on the outcome of the assessment model. This process also incorporates uncertainty to reflect imprecision in observations in real life (observation model)[17].

As the tool is built to support management of data-poor species, it includes several data-poor methods for providing management advice such as catch-only methods, yield per recruit analyses, and surplus production models[18]. However, it also includes packages for data-moderate assessments so, it can be used for a range of fisheries. It also has a number of HCRs already built-in that cover controls on effort, selectivity, catches, etc. Another important feature of this tool is that it uses the input data to identify data-limited methods that can be used (i.e. all the input data they require are available) and also identify other methods that will become available if specific additional data is supplied.

The DLMTool offers all these methods in a single library making them more accessible, and that's also true for the different management rules that are part of the package. Another advantage is that the MSE process allows for different methods to be compared side-by-side using performance metrics that the tool calculates such as biomass trends and long-term yield. This approach could help identify methods that make best use of data for a given fishery hence maximising the value of the data available.

On the other hand, this software is still relative new (been in circulation for 3 years) and therefore, its components are still being tested/improved. Also, despite making MSE more accessible, the DLM Tool is still a sophisticated computing package and therefore, it takes time to understand its features as well as the assumptions that have been hardwired into the software. The latter it is not necessarily a disadvantage but it is important to highlight as limited understanding of the package could lead to misinterpretation of its results.

---

[16] www.datalimitedtoolkit.org
[17] See https://dlmtool.github.io/DLMtool/userguide/index.html for more details.
[18] http://www.datalimitedtoolkit.org/wp-content/uploads/2016/07/NRDC-Data-Limited-Fisheries-Report.pdf

As a note, one of the case studies from this project (BSH - IOTC) uses the DLMTool package for testing an application of an MSE approach to the IOTC blue shark stock (see Task 9 published in a separate volume of this project report).

FLR framework

The Fisheries Library in R (R Core Team, 2017), known as FLR (Kell *et al*., 2007), is a collection of tools for quantitative fisheries science, developed in the R language, that facilitates the construction of bio-economic simulation models of fisheries systems. FLR consists of various packages offering classes, methods and models. All these packages and their source code are freely available at GitHub[19]. Among them, Fla4a and FLBEIA packages allow implementing methodological approaches to assess and/or manage data poor or data limited stocks.

Fla4a

FLa4a (Citores *et al*., 2017; Jardim *et al*., 2015; Millar *et al*., 2015; Scott *et al*., 2016) is an R library, (R Core Team, 2017), that implements the a4a population model (a simple and robust statistical catch-at-age model) for stock assessment and Management Strategy Evaluation (MSE). The main aim of the package is to provide standard methods that can be applied rapidly to a large number of stocks, without requiring a strong statistical technical background, but making use of the technical knowledge on the fisheries, stocks and ecosystem characteristics. This was created due to an increasing demand of estimates of fish stock status.

The framework is flexible enough to be tailored to particular stocks and fisheries and can draw on information from multiple sources to implement a broad variety of assumptions, making it applicable to stocks with varying levels of data availability. In the case of stocks with reduced knowledge base on biology and moderate time series on exploitation and abundance, the first step involves developing a simple stock assessment framework, by generating and conditioning a range of candidate assumptions about the stock (on the biological processes, stock-recruitment relationship, survey catchability and fishing mortality). Then, it develops a forecasting algorithm that takes into account the structural uncertainties in stock dynamics (growth, recruitment, maturity) and exploitation by commercial fleets (selectivity), embedding decision making (management options) into the framework. Finally, simple model averaging (Millar et al., 2014) could

[19] http://github.com/flr

be used to integrate across the results and produce a single assessment that considers the multiple sources of uncertainty.

FLBEIA

FLBEIA (Garcia et al., 2017; Prellezo et al. 2016; Garcia et al., 2013) is a flexible toolbox which facilitates the development of bio-economic impact assessments of fisheries management strategies. It is built under the MSE framework as an R (R Core Team, 2017) library using FLR tools (Kell et al., 2007). A conceptual diagram of the model is shown in Figure 7.4.2. The simulation is divided in two worlds: the operating model (OM, i.e. the real world) and the management procedure model (MP, i.e. the perceived world). The OM is itself divided in 3 components: biological (age-based or aggregated in biomass), fleets and environmental and economic covariates. The MP is also divided in 3 components: observation, assessment and management advice. The model is multi-stock, multi-fleet, multi-métier and seasonal. Uncertainty is included via Monte Carlo simulation and can be introduced in almost any of the parameters used. FLBEIA has been coded in a modular way to make it more flexible, allowing the user to code new functions which could better describe the dynamics of any of the components, if required.

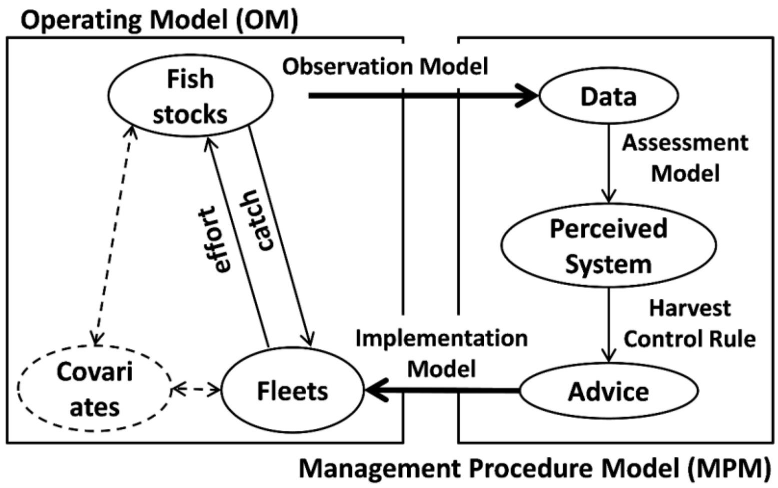


Figure 7.4.2. Conceptual representation of the main components modelled in FLBEIA (García et al., 2013).

In order to condition FLBEIA in data limited situations, the stock has to be assessed, by fitting the best assessment possible to available data. In order to accommodate information on simpler assessments as biomass dynamic models, the biological OM can be aggregated in biomass. FLBEIA should be conditioned using the output of the assessment and additional information on life-history traits (productivity, growth, maturity and natural mortality). Although specific assessment methods are not coded within FLBEIA, it allows calling several data poor assessments, such as a4a and SPiCT

(Pedersen and Berg, 2017) within the MP to obtain the perceived population. Within FLBEIA the ICES Annex IV Harvest Control Rule has been coded. This function emulates the HCRs used by the European Commission and ICES to generate the TAC advice for data-poor stocks. TAC advice is calculated depending on previous year TAC and the trend of an available index. However, as said before, new HCRs could be coded. An example on how to run an MSE with FLBEIA for a data limited stock is shown in http://www.flr-project.org/doc/Data_Poor_MSE_in_FLBEIA.html.

The advantages of the FLR framework are that it:

- Allows different models to be explored prior to implementation, opening the possibility of dealing several distinct models, instead of tweaking small details of a single model;
- Makes best use of the available information coming from different sources (e.g. literature, online databases or life-history information on other stocks);
- Allows the inclusion of different sources of uncertainty (biological parameters, biological models, stock assessment models and model fit), which permits to provide more robust advice as accounting for the overall uncertainty.

There are, however, some disadvantages:

- The framework is not length-based, so there is the need to transform length information (e.g. by modelling growth);
- The flexibility introduced in the a4a model, although considered as an advantage, can lead to a risk of over-parameterisation;
- FLBEIA is a tool to test management strategies for data limited stocks, and not to assess their status.

Sub-task 4.3 – Alternative data-poor methods for sharks/rays

Status quo and possible models for the near future

Several assessments are already being conducted for shark species. This section looks at those assessments and considers possible changes in the models used if we assume that the main improvements in the short term will be in the quality of data rather than the type of data. A summary of the information covered in this section is also provided (Table 7.4.3).

SMA (shortfin mako) - ICCAT

Drawn in ICES category 1/2.

Two stocks, North and South, are defined for assessment purposes. Both stocks were last assessed in 2017. For the North stock, knowledge about lifehistory is fairly comprehensive, several standardised CPUE are available and seem to be fairly consistent. In addition, there is complete information on catch composition (size distributions) for this stock. Since a considerable amount of information is already available (mainly catch series, relative abundance index and catch composition), the next step in the short/medium term for the assessment of the North stock could be on the improvement of information leading to a more robust implementation of the models currently used and a reduction of the uncertainty of the results. For the South stock, uncertainty in the estimates of the absolute level of historic catches has been partially addressed by the improved reconstructed time series of shortfin mako catches in the Atlantic Ocean. Drawing on recent information there is consistency among available CPUE series for the North stock, though there are issues of consistency among CPUE series and catch trends for the South stock. With regards to catch composition, despite collaborative effort to gather all the available information, data on this are still fairly limited.

As such, several pieces of the information needed for SMA assessment purposes (particularly, CPUE series) were incomplete which led to uncertain results in the last assessment. However, catch-based stock reduction models (SRA family) appear particularly useful for improving robustness in the assessment. Improvement of the existing CPUE series should enable a more robust implementation of surplus production models (frequentist or Bayesian) as a feasible alternative that could lead to improved assessment and corresponding advice.

Table 7.4.3. Summary of available data, stock assessment models already implemented, and models feasible to undertake in the short/medium term with the necessary enhancement of the information available at present[20]. (LH: life history; Catch: catch time series; CPUE: abundance trend index; Size: catch composition). See below for an explanation of the model names. See next section for species names.

Species	tRFMO	Stock	Data available	Models used	Future models	Data needing enhancement
SMA	ICCAT	North Atlantic	LH, Catch, CPUE, size	BSSP, SS	SS	LH, Catch, CPUE, size
SMA	ICCAT	South Atlantic	LH, Catch, CPUE	BSSP	SRA, BSSP	LH, Catch, CPUE, size
BSH	ICCAT	North Atlantic	LH, Catch, CPUE, size	BSP, BSSP, SS	SS	LH, Catch, CPUE, size
BSH	ICCAT	South Atlantic	LH, Catch, CPUE, size	BSP, BSSP	BSSP, SS	LH, Catch, CPUE, size
POR	ICCAT	Northwest Atlantic	LH, Catch, CPUE	BSP	BSSP	LH, Catch, CPUE, size
POR	ICCAT	Southwest Atlantic	LH, Catch, CPUE	CFASPM, BSP	BSSP	LH, Catch, CPUE, size
POR	ICCAT	Northeast Atlantic	LH, Catch, CPUE	ASPM, BSP	SRA, BSSP	LH, Catch, CPUE, size
POR	ICCAT	Southeast Atlantic	NA	NA	MSE, PSA, SSI, SRA	LH, Catch, CPUE, size
FAL	ICCAT	Atlantic	LH, Catch	NA	PSA, SSI, SRA	LH, Catch, CPUE, size
SPN	ICCAT	Atlantic	LH, Catch	NA	PSA, SSI, SRA	LH, Catch, CPUE, size
THR	ICCAT	Atlantic	LH, Catch	NA	PSA, SSI, SRA	LH, Catch, CPUE, size
LMA	ICCAT	Atlantic	LH, Catch	NA	PSA, SSI, SRA	LH, Catch, CPUE, size
OCS	ICCAT	Atlantic	LH, Catch	NA	PSA, SSI, SRA	LH, Catch, CPUE, size
BSH	IOTC	Indian Ocean	LH, Catch, CPUE, size	SRA, BSSP, SS	SS	LH, Catch, CPUE, size

[20] Shark species covered in IATTC are not included here as there is limited work on quantitative stock assessment (but see description about silky shark in the previous section). Work so far has employed simple techniques, such as SSI, due to paucity of data.

Species	tRFMO	Stock	Data available	Models used	Future models	Data needing enhancement
SMA	IOTC	Indian Ocean	LH, Catch, CPUE	NA	SRA, BSSP	LH, Catch, CPUE, size
POR	IOTC	Indian Ocean	LH, Catch	NA	PSA, SSI, SRA	LH, Catch, CPUE, size
OCS	IOTC	Indian Ocean	LH, Catch, CPUE	NA	SRA, BSSP	LH, Catch, CPUE, size
FAL	IOTC	Indian Ocean	LH, Catch	NA	MSE, PSA, SSI, SRA	LH, Catch, CPUE, size
SPN	IOTC	Indian Ocean	LH, Catch	NA	MSE, PSA, SSI, SRA	LH, Catch, CPUE, size
THR	IOTC	Indian Ocean	LH, Catch	NA	PSA, SSI, SRA	LH, Catch, CPUE, size
BSH	WCPFC	North	LH, Catch, CPUE, size	BSSP, SS	SS	LH, Catch, CPUE, size
BSH	WCPFC	Southwestern	LH, Catch, CPUE, size	MULTIFAN-CL	BSSP, MULTIFAN, SS	LH, Catch, CPUE, size
BTH	WCPFC	Pacific	LH, Catch, CPUE	PSA	MSE, PSA, SSI, SRA	LH, Catch, CPUE, size
POR	WCPFC	Southern	LH, Catch, CPUE	PSA	MSE, PSA, SSI, SRA	LH, Catch, CPUE, size
SMA	WCPFC	North	LH, Catch, CPUE	SSI	MSE, PSA, SSI, SRA	LH, Catch, CPUE, size
OCS	WCPFC	Pacific	LH, Catch, CPUE, size	SS	SS	LH, Catch, CPUE, size
FAL	WCPFC	Pacific	LH, Catch, CPUE, size	SS	SS	LH, Catch, CPUE, size

SSI: Stock status (stability) indicators; PSA: Productivity-Susceptibility Analysis and/or other risk-based approach (includes MIST); CFASPM: Catch-free age-structured production model; ASPM: Age-structured production model; SS: Length-based, age-structured statistical models (Stock Synthesis and equivalent); BSP: Bayesian surplus production models; BSSP: State-space Bayesian surplus production models (JABBA, BSP2-JAGS); SRA: Stock reduction models (DCAC, DB-SRA, SSRA, XDB-SRA); MSE: simulation testing simple management procedures in the context of management strategy evaluation (MSE); MULTIFAN-CL: size-based, age- and spatially-structured population models.

BSH (blue shark) – ICCAT

Drawn in ICES category 1/2.

Two stocks, North and South, are defined for assessment purposes. Both stocks were last assessed in 2015. Models used in the last assessment included Bayesian surplus production models (including a state-space implementation) and statistical age-structured models (SS), which are catalogued as being data-limited/rich models. There is sufficient understanding about life-history traits. An improved reconstructed time series of catch in the Atlantic Ocean is available to be used in upcoming assessments (TASK 1. Updating EUPOA Sharks Study). Standardised series of CPUE are available and there is considerable information about catch composition (size distributions).

Given the substantial amount of information already available (mainly catch series, relative abundance index and catch composition), the next step in the short/medium term for the assessment of the species could be the improvement of information. This would result in a more robust implementation of the model currently used in the assessment and a reduction of the uncertainty of the results.

POR (Porbeagle) - ICCAT

Drawn in ICES category 3.

There are four stocks for this species: Northwest, Southwest, Northeast and Southeast stocks; delimited for assessment purposes. Three stocks (Northwest, Southwest and Northeast) were last assessed in 2009. Bayesian surplus production models (BSP), catch-free age structured production models (CFASPM) and age structured production models (ASPM) were used.

At present, life-history parameters are reasonably well known for the Northwest Atlantic. Life-history information available for that stock is less detailed. A very limited number of fishery-dependent CPUE series is available for the Northwest, Northeast and Southwest stocks.

For porbeagle stocks in the North Atlantic, a greater focus on implementing a state-space formulation of Bayesian production models that can incorporate variability in key population parameters, in contrast to models without process error (implying deterministic biomass trajectories), would be a way forward.

Regarding both stocks in the South Atlantic, the amount and quality of the information currently available preclude the use of traditional stock assessment methods. There is evidence that some traits (e.g. growth) are not universal among the stocks while other biological parameters are similar (e.g. fecundity). If a substantial improvement in life-history is reached, catch free LH based methods appear to be a feasible option for robust assessment purposes. Improvement of quality in CPUE series would make it possible to use catch free CPUE based models. Enhancement and refinement of total catch series could also help implement catch based stock reduction analysis (SRA) as an alternative way to provide more robust advice.

In addition, assuming a moderate improvement of information on catch and some fishery indicators, simple management procedures that uses time series of catch and fishery indicators (e.g. incrementally adjustment of a TAC, starting from a reference level based in mean recent catches, to reach a target relative fishery index) would be a way to further proceed in search of robust advice.

FAL (Silky shark) - ICCAT

Drawn in ICES category 4/5.

Two stocks, North and South, are defined for assessment purposes. Catch information is incomplete and the composition (size distribution), unknown. No CPUE indices are available, and life-history knowledge is limited. With appropriate caution, enhanced knowledge on both total catch and the life-history of the species would allow for implementation of stock reduction models (SRA).

SPN (Hammerheads) - ICCAT

Drawn in ICES category 4/5.

Currently two stocks, North and South, are delimited but there is growing evidence supporting the existence of a West/East stock delimitation. Catch information is rather incomplete and the catch composition (size distribution) is unknown. No CPUE indices are available. Semi-quantitative evaluation of the risk based on techniques such as Productivity Susceptibility Analysis (PSA), as well as simple stock status or stability indicators would be a way forward in the short term. Improvement of catch statistics would enable the implementation of SRA for assessment of the species.

THR (Thresher sharks) - ICCAT

Drawn in ICES category 4/5.

Catch information is incomplete and the composition (size distribution) unknown. No CPUE indices are available. Semi-quantitative evaluation of risk based on techniques such as PSA, as well as simple stock status or stability indicators, would be a way of moving ahead in the short term. Improvement of catch statistics would enable the implementation of SRA for assessment of the species.

LMA (longfin mako) - ICCAT

Drawn in ICES category 4/5.

Catch information is incomplete and the composition (size distribution) unknown. No CPUE indices are available. Semi-quantitative evaluation of risk based on techniques such as PSA, as well as simple stock status or stability indicators would be a way of moving ahead in the short term. Improvement of catch statistics would enable the implementation of SRA for assessment of the species.

OCS (oceanic whitetip) - ICCAT

Drawn in ICES category 4/5.

Currently two stocks, North and South are delimited but there is evidence supporting the existence of a West/East stock delimitation. Catch information is incomplete and the composition (size distribution) unknown. No CPUE indices are available. Improvement of both stock definition and catch statistics would enable the implementation of SRA for assessment of the species.

BSH (blue shark) -IOTC

Drawn in ICES category 1/2.

This species was last assessed in 2017 using a data-limited catch only model (SRA), two Bayesian biomass dynamic models (JABBA with process error, and a Pella-Tomlinson production model without process error) and an integrated age-structured model (SS3). The IOTC nominal series for sharks are considered extremely incomplete. As such, several alternatives were provided, including one from EU scientists (EUPOA methodology and task 1 of this Project). The series used in the final model was a Generalized Additive Model (GAM) based estimate, while the others were used as sensitivity analysis.

In addition to a several series of nominal catches, there is partial information about the size composition of the catch and six CPUE series (of which three were considered for the base case scenario). There is still considerable uncertainty regarding the representativeness of the spatial coverage of the available CPUE series. In addition, there is evidence of inconsistency between CPUE series.

Since a considerable number of the required pieces of information is already available (mainly catch series, relative abundance index and catch composition), the next step in the short/medium term for the assessment of the species could rely on the improvement in information that would lead to a more robust implementation of the models currently used in assessment and a reduction of the uncertainty of the results.

SMA (shortfin mako) -IOTC

Drawn in ICES category 3.

Catch information is incomplete and the composition (size distribution) unknown. Some information about CPUE indices is available. Given the availability of CPUE, an improvement of catch statistics (estimates of total catch) would enable the implementation of both SRA and production models for assessment of the species.

POR (porbeagle) -IOTC

Drawn in ICES category 4/5.

Catch information is incomplete and the composition (size distribution) unknown. Semi-quantitative evaluation of the risk based on techniques such as PSA, as well as simple stock status or stability indicators would be a way of moving ahead in the short term. An improvement of catch statistics (estimates of total catch) would enable the implementation of both stock reduction (SRA) and production models for assessment of the species.

OCS (oceanic whitetip) -IOTC

Drawn in ICES category 3.

Catch information is incomplete and the composition (size distribution) unknown. Some limited information about CPUE indices is available. An improvement of both catch statistics (estimates of total catch) and CPUE series would enable the implementation of both SRA and production models for assessment of the species.

FAL (silky shark) -IOTC

Drawn in ICES category 4/5.

Catch information is incomplete and the composition (size distribution) unknown. Semi-quantitative evaluation of risk based on techniques such as PSA, as well as simple stock status or stability indicators would be a way of moving ahead in the short term. An improvement of catch statistics (estimates of total catch) would enable the implementation of simple catch-only models (e.g. SRA).

SPN (Hammerheads) - IOTC

Drawn in ICES category 5.

No information is available for assessment purposes. The majority of catches are not reported and information on catch composition is nonexistent or very scarce. CPUE data are also absent, and there is limited information on life-history. In addition, landing these species is prohibited, so obtaining relevant information is subject to monitoring activities on-board fishing vessels.

Given this, even the simplest data-poor approach appears to be excluded. At best, simulations testing extremely simple management procedures would allow some kind of assessment. Depending on the availability of more detailed information on the species life-history, basic PSA/ERA models may be implemented.

THR (Thresher sharks) - IOTC

Drawn in ICES category 4/5.

Current avalible information is limited. Data on partial catch exist, but there is a mixture-of-species underlying issue. Once that uncertainty is resolved, methods for making use of historical catch data in conjunction with estimates of relative stock reduction due to fishing (e.g., SRA) would allow for reconstruction of possible trajectories of stock decline.

BSH (bigeye thresher) -WCPFC

Drawn in ICES category 1.

The North Pacific stock of blue shark was last assessed in 2017 and models used included a fully integrated size-structured model (SS) and a Bayesian State-Space Surplus Production. There is reasonable understanding about life history traits and standardized series of CPUE are available. There is also some information about catch composition (length and sex composition). Improvements in information in the short/medium term (amount of historical catches, data sources and standardisation methods used to develop abundance indices, and life history traits) would lead to a more robust implementation of the models currently used in assessment and a reduction of the uncertainty of the results.

The last assessment for the southwestern Pacific stock took place in 2016 and it was the first attempt to assess this stock. A size-based, age- and spatially-structured population model (MULTIFAN-CL) was used to integrate multiple sources of information. Since catch inputs and CPUE time series were uncertain and there was limited information on biological data and catch composition, this assessment was intended as work in progress. Improvement in information on catches, abundance indices and catch composition, as well as further work on growth, mortality, reproduction and movement should enable a more robust implementation of MULTIFAN-CL or a fully integrated size-structured model (SS3). In the short-medium term, Bayesian State-Space Surplus Production models arise as a viable option as it requires less detailed information about biology and catches.

BTH (*bigeye thresher shark*) – WCPFC

Drawn in ICES category 3.

A substantial lack of data and information for this stock does not support a full stock assessment and therefore, a sustainability risk assessment has been used to assess bigeye thresher shark in the Pacific Ocean. The approach was based on the quantification of the fishing impact and the definition of a reference point (maximum impact sustainable threshold (MIST)) estimated on the basis of the population growth rate for the species. Substantial improvements in catch statistics and catch composition, abundance time series and biology are needed in order to make further progress with the implementation of stock assessment models other than data poor models.

POR (porbeagle) -WCPFC

Drawn in ICES category 3.

The lastest assessment of the Southern Hemisphere porbeagle shark took place in 2017 and used a risk assessment method. The approach combined indicator analysis and a spatially explicit sustainability risk assessment. Data availability and quality was highly uneven between regions. Most catch rate indicators were short and uncertain, and life-history data for the Southern Hemisphere population is obtained from New Zealand and Australian studies.

Substantial improvements in catch statistics and catch composition, abundance time series, and biology are needed in order to make further progress with the implementation of assessment models other than data poor models.

SMA (shortfin mako) -WCPFC

Drawn in ICES category 3

In 2015, an indicator based analysis of the status of shortfin mako shark in the North Pacific Ocean was completed. Both compilation of fishery data and knowledge about shortfin mako life-history is incomplete. Due to recent changes in targeting, it is uncertain which of the available indices of relative abundance (CPUE) represents stock trends.

In the short term, data-poor methods would seem the only realistic option for shortfin mako shark assessment. In the medium term, improvements in catch statistics and catch composition, abundance time series, and biology would enable to move towards age-structured assessment models.

OCS (oceanic whitetip) -WCPFC

Drawn in ICES category 3

Oceanic whitetip shark in the western and central Pacific Ocean was assessed in 2012 using a length-based, age-structured statistical model (Stock Synthesis). While generally available, the input data (catch, CPUE, and size composition) are uncertain. Even if dependable estimates of biological and life-history traits such as growth, natural mortality, and the size at maturity exist, a deeper understanding is needed. In the short-medium term, making gains in those areas would enable to implement Stock Synthesis in a more robust way.

FAL (silky shark) -WCPFC

Drawn in ICES category 3

Silky shark in the western and central Pacific Ocean was assessed in 2013 using a length-based, age-structured statistical model (Stock Synthesis). There are limited fishery-related data (reported landings, CPUE time series, and total mortality) as well as life-history and biology information. Therefore, the analysis is characterised by considerable uncertainty. A significant improvement in both fishery data and life history knowledge would help implement Stock Synthesis in a more reliable and robust way.

Overall trend and options for going forward

There are some species (blue and mako sharks in ICCAT and blue shark in IOTC and WCPFC, oceanic whitetip and silky shark in WCPFC) for which the assessment techniques used are considerably advanced already. More sophisticated models could potentially be adopted or existing sophisticated model could provide more robust results if some further improvement in data quality is achieved in the short term.

For the other species, significant improvements in information will have to be made in the short term if more advanced stock assessment methods were to be implemented. It is not clear whether that could be feasible, efforts to achieve a more robust implementation of the models are already in use or planned to be used for the assessment of those species could deliver more value. Simple or indirect ways for calculating reference points can also be of value for these species. For example, use of Schaefer models could provide first estimates of reference points if catch data and some biological information are available. In cases where no exploitation data are available, another option is to examine species of similar biological characteristics and dynamics, for which reference points have been calculated and use those as a first step towards defining plausible biological reference points.

Broadly speaking, the current situation for sharks and rays is characterized by a general lack of information regarding catch, abundance, and life-history characteristics, which impedes the implementation of any conventional stock assessment models. Under these conditions, simulation modelling of simple management procedures in the context of management strategy evaluation (MSE) could be a promising tool for making progress with extremely data-poor fisheries.

Two different frameworks that implement MSE, already mentioned in the previous section, can be used to test the effectiveness of proposed management policies as applied to a simulated resource over a set period of time. This approach is very valuable because it provides scientists and managers with the opportunity to compare the performance of alternative management procedures running under identical conditions and uncertainties, given a wide range of plausible present and future scenarios. Another advantage of this approach is that it offers an improved understanding of the trade-offs among competing management objectives. For instance, compare trade-offs on how to avoid overfishing and stock depletion while maximizing yield. Therefore, it could help identify actions that would deliver robust outcomes despite high uncertainty in the real state of the system or at least, facilitate further research into areas that create the biggest uncertainty to improve knowledge.

8. TASK 5 – COMPILE AND ANALYSE EXISTING CMMS

8.1. *Key findings and recommendations*

- From 2004 to 2016, tRFMOs (ICCAT, IOTC, WCPFC, IATTC) set up a total of 37 resolutions regarding Conservation and Management Measures (CMMs) for sharks and Rays (8 for IATTC, 12 for ICCAT, 8 for IOTC and 9 for WCPFC). These resolutions concern mainly input and/or output controls, fishing gear modification, fishing practices and incentive to limit finning and discards. The prohibition of retention is in place in all ocean basins for several species (e.g., *Carcharhinus longimanus*, *Carcharhinus falciformis*, *Alopias superciliosus*, *Lamna nasus*) and for some shark families (e.g., Alopiidae, Sphyrnidae, Mobulidae). Additionally, the full utilisation of shark carcass, the 5% fin/body ratio and the prohibition/control on international trade is also in place for some RFMOS and some species. On the other hand, the ban of wire leaders and/or shark lines is in place in the Pacific Ocean (WCPFC, IATTC).

- The compliance control of the application of these resolutions by fishing countries is complex. For such control to be effective there would be the need for compliance officers or other mechanisms to fully cover all fishing activities. As such, and in general, an increase in the monitored coverage levels (human or electronic) is recommended. However, it is also importantly noted that the scientific duties, carried out by scientific observers, and the compliance duties should be kept as fully separated tasks.

- Many tRFMOs have now established non-retention measures for some shark species, often the ones identified as the most vulnerable in Ecological Risk Assessments. It is noted, however, that at-haulback mortality can be high for many species (depending also on the size range and fishing gear), and that post release mortality, often a much less known parameter, can also be high. As such, the efficiency of no-retention measures is highly questionable, especially for species and/or fishing gears where the overall mortality that occurs between capture and release is high, and/or species where the post-release mortality is high. For some species and/or fishing gear, following best-handling practices can improve, to some extent, the likelihood of survivorship after releasing the sharks.

- Wire leader bans have been demonstrated as beneficial for many shark species. However, such measure may have economical impacts on the catches. As such, the benefit for the conservation of shark and ray stocks, and for the possible impact on the economy of some pelagic longline fisheries, still needs to be investigated. Leader materials should also be investigated taking into account the effects of the hook types used, as those interactions are still unknown.

- The shark fins to carcass ratios in place in the tuna-RFMOs are highly dependent on factors such as species/genus and cutting/processing practices. The ratio adopted has been generalized to 5%, but the actual ratios can range from 1.3% to 10.9%, depending on the species, fish processing method (whole carcass *versus* dressed carcass) and fins processing methods (type of cut and wet versus dried fins). As such, we recommend that the natural (or some artificial) attachment of fins to the body of sharks until the landing points should be adopted CMMS for all tuna-RFMOs, which would effectively control the ban of finning and would not be constrained by this variability in the ratios.

- Fins-attached regulations have been established mostly for addressing the finning problem. One additional key advantage of such regulations is the improvement of species-specific identification, improving therefore data collection systems and availability of species-specific fishery data for scientific purposes. In addition to the fins-attached, other measures such as bans on beheading and skinning would further improve the reliability of species-specific identification, and therefore increase the accuracy of collected and reported species-specific fishery data.

- It is also recommended that more CMMs should be based on spatial/temporal closures of fishing for areas with high density of both mature females and juveniles of the most susceptible species. However, it is noted that the proposal of such areas requires more biological and distribution data that is not yet available from the tuna RFMOs.

- Finally, we recommend developing a research program to better assess the impact of the combination hook types (e.g., circle versus J) and leader material (e.g., wire versus monofilament) on 1) shark retention rates, and 2) at-vessel and post-release mortalities in pelagic longline fisheries. Such a project should be conceived using a factorial design, elaborated to allow a comparison of all those factors as well as their possible interactions, both in terms of retention rates and mortality. In this last component, both the immediate (at-haulback) mortality as well as the post-release survival should be considered, taking also into account effects such as hook location and trailing monofilament line.

8.2. *Objectives*

The objectives of this task were to compile and compare existing CMMs, in particular retention bans, adopted by relevant international *fora* for fisheries that target sharks, have sharks and rays as by-catch or interact with some shark species during fishing operations. Their effectiveness was analysed in terms of achieving the conservation objectives that have underpin their adoption. Moreover, this task addresses the question of wire leader in terms on ecological (mortality) and economic impacts. Finally, it addresses also the use of fins to carcass ratio based on updated information.

8.3. *Methodology*

This task was based on desk based work. It consisted of a broad literature review including scientific papers and grey literature from tuna-RFMOs and other International bodies (e.g., FAO, NGOs, ISSF), to describe management measures by métier/fisheries for selected shark and ray species caught as target or by-catch potentially applicable as conservation and management measures at short term and long term.

The list of potential CMMs published by FAO (2011) considered as a guideline was:

- Input and/or output controls;
- Improvements to the design and use of fishing gear and by-catch mitigation devices;
- Spatial and temporal measures;
- Limits and/or quotas on by-catches;
- Bans on discards;
- Incentives for fishers to comply with measures to manage by-catch and reduce discards.

A comparison of the existing CMMs (including total prohibition) was proposed based on the strengths and weakness (including the lack of scientific knowledge) of each of them as well as a time frame for application. This comparison allowed identifying management options with associated risks, advantages and disadvantages regarding conservation and implementation at different stages from fishermen to managers.

In the case of EU longline fleets, two potential management options were assessed through 1) the analysis of fishery-based data to assess the relevance and the impact of a ban in the use of wire leaders and, 2) the use of fins to carcass ratio based on updated information.

8.4. *Results and discussion*

Sub-Task 5.1 – Compilation of existing CMMs

The compilation of existing CMMS was achieved by analyzing the resolutions adopted by all tuna RFMOs (IATTC, WCPFC, IOTC, ICCAT, CCSBT), other intergovernmental fisheries science and management bodies (NAFO, GCFM, SEAFO), documents produced by international agreement between governments (e.g., CITES), by international Conventions (e.g., Convention for the Conservation of Migratory Species - CMS, Bonn Convention) and from political bodies such as the European Union. The table with this compiled information is presented in Appendix VIII of this report and presents the list of CMMs regarding sharks and rays either targeted by fisheries or caught as by-catch.

Sub-Task 5.2 – Comparison of existing CMMs between oceanic basins

Based on the list of CMMs identified above in the prior sub-task, we used the FAO guidelines of CMMs classification to compare CMMs adopted in the different ocean basins: Atlantic Ocean, Indian Ocean, East Pacific Ocean, Western Pacific Ocean and Mediterranean Sea. This comparison of CMMs is presented separately for the main shark species that can be targeted and other species of sharks incidentally captured by fisheries (Appendix VIII).

Sub-Task 5.3 – Analysis on ban in the use of wire leaders

Different pelagic longline configurations are in place and some of them can induce higher catch level of sharks. These configurations are used to intentionally target shark or not. Now other longline configurations can be set up to intentionally reduce shark catches. It is well acknowledged in the literature (both grey and peer reviewed) that the most efficient gear control to reduce visible shark catches is the removal of wire leaders from the terminal gear. This control measure (conservation measures are assessed regarding its impact of the fishing mortality depending on the fate of individuals at release or at escape) is currently implemented for different longline fisheries in various countries such as Australia, Cook islands, Marshall Islands, Fiji, Samoa, Palau and South Africa (Clarke et al., 2014).

In tuna-RFMOs this conservation and management measure is either fully implemented (WCPFC – Res. 2014–05), partially implemented (IATTC - Res. 2016-06) or only mentioned for being deeply explored as a conservation measure to improve the selectivity of the pelagic longline gear to enhance shark conservation (IOTC).

These tRFMOs resolutions are listed below:

WCPFC - Conservation and Management Measure 2014-05

Measures for longline fisheries targeting tuna and billfish:

Paragraph 1. CCMs shall ensure that their vessels comply with at least one of the following options:

a. do not use or carry wire trace as branch lines or leaders; or

b. do not use branch lines running directly off longline floats or drop lines (known as shark lines).

IOTC – Conservation of sharks caught in association with fisheries managed by IOTC – Resolution 05/05

Paragraph 8. CPCs shall, where possible, undertake research to identify ways to make fishing gears more selective (such as the implications of avoiding the use of wire traces).

IATTC – Amendment of resolution C-05-03 on the conservation of sharks caught in association with fisheries in the Eastern Pacific Ocean – Resolution C-16-04

Resolves as follows, in order to amend Resolution C-05-03:

1. Paragraph 8 is replaced by the following paragraph:

“8. CPCs shall, where possible, in cooperation with the IATTC scientific staff, undertake research to:

a. identify ways to make fishing gears more selective, where appropriate, including research into alternative measures to prohibiting wire leaders;

IATTC – Conservation measure for shark species, with special emphasis on the silky shark (*Carcharhinus falciformis*) for the years 2017, 2018 and 2019 - Resolution C-16-06

6. For those multi-species fisheries using surface longlines that have captured more than 20% of silky sharks in weight on average, CPCs shall prohibit the use of steel leaders during a period of three consecutive months each year. The average proportion of silky sharks in the catch will be calculated from data of the previous calendar year. New vessels entering the multi-species fisheries affected by this Resolution and those for which no data are available from the period immediately prior shall be subject to the provisions of this paragraph.

9. CPCs shall notify the Director, before 1 October of each year, the single period of restricted use of steel leaders referred to in paragraph 6 which will be observed for the following calendar year.

On the impacts of the wire leader on shark retention and shark fate

Shark retention on leader

Wire, multifilament and monofilament leaders are all used in pelagic longlining. The use of wire leaders does not always imply that sharks are being targeted, however, it is more difficult for sharks to escapes by cutting wire leader than other materials. Therefore, shark catch rates are generally higher when wire leaders are used. The material used for leader alone, does not determine the success of shark retention on a given leader. The hook type coupled with the leader material was shown to greater influence shark retention. For example, sharks can escape easily on a monofilament leader if the hook is gutted (swallowed) or in the esophagus instead of at the jaw or mouth. Regarding hook shapes, circular hooks resulted in more jaw hooking compared to both tuna and J hooks. Significant differences in shark escape were observed between wire and monofilament leaders for J hooks, with "bite offs" being higher for the monofilament material (Godin et al., 2012) (Table 8.4.1).

1 - Whatever the hook type, wire leaders aim to increase shark retention on the longline and depending on species individuals can be released at haulback (but this

operation might injury the fish or can be dangerous for crew) or by cutting the line without hauling the shark on board.

2 - A combination wire or monofilament leader with a circle hook increases external hooking (i.e., mouth or jaw) (Godin et al., 2012), that likely enhances the survival of shark after release by cutting the line.

Moreover, the status of all sharks caught at release can be observed for wire leader - hook type combinations 1 and 2.

3 – For a combination monofilament leader with J hooks the retention of hooked shark is likely to be less than previous combinations with circle hooks (Godin et al., 2012). This result might be explained by bite-offs. In a study comparing bite-offs between monofilament and wire leaders all equipped with a J hook , a significant difference was observed between leaders with an average of 5.37/1000 hooks and 1.38/1000 hooks, respectively (Santos et al., 2017). However the hidden mortality for sharks with a swallowed hook after bite-off remains unknown.

Table 8.4.1. Summary of the meta-analysis on catchability highlighting the summary effect size (odd ratio, OR) and 95% confidence interval (CI). OR > 1 indicates a higher shark catch was calculated on circle hooks vs. J-hooks. I2 describes the percentage of total variation across studies that are due to heterogeneity rather than chance. Values >25%, 50%, and 75% are categorized as low, moderate, and high, respectively (from Godin et al., 2012).

Species or group of species	# studies	Odd ratio	CI (%)
All sharks combined	18	1.13	0.94 – 1.35
Blue shark	15	1.15	0.92 – 1.44
Shortfin mako	6	1.08	0.69 – 1.71
Other requiem, Carcharhinidae	8	1.13	0.72 – 1.77
Lamnidae	8	0.97	0.33 – 2.83
Thresher	5	0.75	0.46 – 1.22

At- vessel and post release mortalities of sharks in pelagic longlining

Multiple studies have been carried out recently to assess the post release mortality of sharks after release. In particular, meta-analysis published recently (Godin et al., 2012; Ellis et al., 2017) produced a synthesis of results for at vessel mortality (AVM) and post release mortality (PRM) of studies published from 2009 to 2015 for blue shark, shortfin mako, thresher sharks and oceanic white tip shark (Table 8.4.2 and Table 9.4.3). Both AVM and PRM shown large differences for a given species and between species which depend on i) the status of the individual at capture, ii) the manipulation of the fish when it is handled on the deck, iii) the size of the fish and iv) the position of the hook at capture.

Differences between studies also depends on the origin of the data. For the blue shark, if we compare results obtained in the North Atlantic (Campana et al., 2009) and in Hawaii (Moyes et al., 2006), mortalities values vary from 35% to 10% respectively. However, data collected by Campana et al. (2009) came from commercial longline operations, while data from Moyes et al. (2006) comes from scientific experiments. For commercial operations in the North Atlantic both circle and J hooks were used, with J hooks more often ingested leading to more injuries while fish were gaffed on the body to be hauled on board. Mortalities were 16% at hauling and 19% delayed. The post release mortality was estimated by deploying satellite telemetry tags (e.g., PSAT) on sharks selected at random. However, mortality data from Hawaii was collected via scientific experiments. For such experiments, the hauling operation is slower and sharks were cautiously hauled on-board to be tagged and released, resuting in few mortalities compared to which explains the higher mortality recorded for commercial fishing operations compared to scientific experiments.

Table 8.4.2 - Estimates of at vessel and post release mortality for five shark species based on observer data and tagging studies (from Godin et al. 2012).

Species	At vessel mortality range (%)		Post release mortality range (%)	
	Min	Max	Min	Max
Blue shark	3	14	14	19
Shortfin mako	8	36	No studies	
Thresher sharks	12	51	26	
Oceanic white tip	7	30	No studies	

Economic consequences of a wire leader ban

In pelagic longline fisheries, studies aiming to quantify the impact of mitigation measures (MM) were principally driven by an interest in the ecological consequences of such measures. However, there are limied studies that addressed the commercial scale feasibility of the implementation of such MM. Moreover, they do not address either ecological or economic trade-offs that would be required for their implantation. As far as we are aware, only one study partially investigated the economic impact of a wire leader ban in pelagic longline fishery for the Portuguese longline fleet in the South West Indian Ocean (Santos et al., 2017).

Between November 2013 and March 2014, IPMA launched experiments on-board commercial longliners to compare catch rates and mortality rates of sharks, and catch value between two types of terminal gear material: monofilament nylon leader and a wire leader. All leaders were equipped with classical J hooks normally used to target swordfish. All hooks were baited with squid. Moreover, a standardized size of squid was used as unique bait type.

For each longline set, the two types of leaders were deployed alternatively. In total, 82 fishing sets representing 82,656 hooks (i.e., 41,328 leaders of each type) was deployed. No significant differences of the value per unit effort was detected between the two types of leader, because for the wire leader the lower catches of swordfish were compensated by higher retention rates of blue shark. However, as noted by the authors, the economic analysis results were only preliminary. The fish price considered did not reflect the temporal variations of the prices on the market, as well as the fact that the bait type can change according to the target species (fish bait, as mackerel, are commonly used to target sharks) and the cost of replacing and repairing damaged gear which is greater for monofilament. The results also highlighted that the ecological benefits of using a wire leader ban would concern the group of sharks.

Results of works carried out aiming at quantifying the use of wire leaders to increase the retention of sharks (mainly blue shark and shortfin mako for longline fishery targeting swordfish and oceanic whitetip shark, silky shark and shortfin mako for longline fishery targeting tuna) clearly support the ban of wire leaders as an ecological benefit for both shark populations and exploited pelagic ecosystems. However, a visible reduction of sharks caught cannot be directly interpreted as a reduction of the fishing mortality. To be effective in terms of ecological benefits for shark populations the measure must also consider the fate of sharks, taking into account bite-offs and corresponding post-release mortality. As such, more research must be undertaken to:

- Improve our knowledge of major drivers of the post-release survival of sharks by combining instrumented longline fishing experiments (Boggs, 1992; Bach et al., 2003; Bach et al., 2008; Guida et al., 2017) and electronic tagging of released sharks;
- Investigate the economical consequences of a wire leader ban in order to better assess trade-offs between economics and ecological benefits, as well as interactions with hook types.

On the effectiveness of the shark retention ban

The retention prohibition (prohibition from retaining on board, transhipping, landing, storing, selling or offering for sale any part or whole carcass of sharks) is one of the measures already in place for several shark species in tuna-RFMOs (i.e., thresher sharks Alopiidae, bigeye thresher shark (*Alopias superciliosus)*, oceanic whitetip shark (*Carcharhinus longimanus*); hammerhead sharks Sphyrnidae (except *Sphyrna tiburo*), silky shark (*Carcharhinus falciformis*), Mobulid rays and porbeagle shark (*Lamna nasus*)).

A recent paper analysing the positive and negative aspects of these measure has been published (Tolotti et al., 2015). The authors agreed that the shark ban retention measures are positive towards the conservation of pelagic shark species, because they improve conservation awareness among fishers, managers and the public. However, measures that impose total bans may lead to negative impacts also. The majority of pelagic shark catches are incidental and many sharks die before they reach the vessel (at-vessel mortality) or after they are released (post release mortality). The legislation set out by tuna-RFMOs only prevents retention but not the actual capture or the mortality that may occur as a result. Hence, the aim one of the key issue to assess the effectiveness of the measure is to guarantee that both the capture process and release practices set up by fishermen aim to optimize the survival of individuals. Based on our best knowledge, only one published study assessed the effectiveness of the ban retention of sharks for pelagic longline fisheries, this ban retention being coupled with a wire leader ban (Gilman et al., 2016). This study looked at the modification of mortality components of the fishing mortality following the implementation of the measure. The different components of the fishing mortality are: pre-catch mortalities, ghost fishing losses, retained catch, dead discards, post-release mortalities and indirect mortalities (entanglement for example for longline) (Gilman et al., 2016).

Results suggest a significant decline in the shark fishing mortality after the implementation of the measure. The pre-catch mortality might have increased slightly with an increase in bite-offs following the change of wire leader by monofilament and a reduction of 19% in the proportion of sharks that were alive at haulback. The main outcomes of this study were:

- The ban on the retention of sharks and wire leaders encouraged fishermen to adopt fishing strategies that mitigate shark interactions (e.g. setting depth, bait type, etc)
- The retention ban efficiency is strongly related to fishing characteristics of the gear deployment (leader material, leader length, hook type, bait type,

depth and time of the setting). For example, longline fisheries having poor handling and release practices and for size/species showing low post-release survival rates (e.g., thresher sharks) monofilament leaders in combination with hook and bait allowing the shark to bite through the leader might result in lower fishing mortality than using wire leader (Gilman et al., 2016),

- There was a 19% reduction in the proportion of sharks that were alive at haulback. This is due to This also implies that pre-catch mortality may have increased, through bite-offs, as a result on the change of wire leader material (monofilament is less rigid)
- Investigate the post-release survival of sharks with ingested hooks and trailing monofilament line and to assess fishing mortality as a result of bite-offs.

Sub-Task 5.4 – Use of fins to carcass ratio based on updated information

The Council Regulation (EC) 1185/2003 on the removal of fins of sharks on board vessels, established a general prohibition of the practice of shark finning, i.e. the removal of a shark's fins and the discarding of the remaining carcass at sea. Under this Regulation, Member States could issue special fishing permits for the processing of sharks on board. To prevent finning, the Regulation established a so-called fin-to-carcass ratio for processed sharks. This Regulation was amended by Regulation (EU) 605/2013. The major modifications of the EC 1185/2003 adopted in the EU 605/2013 concern:

- the insertion of the following paragraph in the article 3 "Without prejudice to paragraph 1, in order to facilitate on-board storage, shark fins may be partially sliced through and folded against the carcass, but shall not be removed from the carcass before landing",

- the adoption of a new Article 6:

  1. Where vessels flying the flag of a Member State catch, retain on-board, tranship or land sharks, the flag Member State, in accordance with Council Regulation (EC) No 1224/2009 of 20 November 2009 establishing a Community control system for ensuring compliance with the rules of the common fisheries policy and Commission Implementing Regulation (EU) No 404/2011 of 8 April 2011 laying down detailed rules for the implementation of Council Regulation (EC) No 1224/2009, shall send to the Commission, annually, by 1 May, a L 181/2 Official Journal of the European Union 29.6.2013 EN comprehensive report on its implementation of this Regulation

during the previous year. The report shall describe the monitoring, by the flag Member State, of compliance with this Regulation by its vessels in Union and non-Union waters, and the enforcement measures it has taken in cases of non-compliance. In particular, the flag Member State shall provide all of the following information:

- the number of landings of sharks,
- the number, date and place of the inspections that have been carried out,
- the number and nature of cases of non-compliance detected, including a full identification of the vessel(s) involved and the penalty applied for each case of noncompliance, and
- the total landings by species (weight/number) and by port.

2. After the submission by Member States of their second annual report in accordance with paragraph 1, the Commission shall, by 1 January 2016, report to the European Parliament and to the Council on the operation of this Regulation and the international developments in this field.

At the ICCAT annual meeting in 2015, the proposal to strengthen the current ICCAT shark finning regulation to align with "fins attached" policies was rejected. For IATTC, progress to strengthen shark finning regulations to move from fin-to-carcass weight ratios to prohibition on at-sea fin removals are at a standstill.

The finning practices and the 5% fin-carcass ratio

The act of removing valuable shark fins at sea, called as shark finning, while discarding the remainder of the shark carcass is still operated both legally and illegally in fisheries worldwide (Cortés and Neer, 2006). However, the removal of shark fins at port landings is not considered as shark finning (Fowler and Séret, 2010). In general, the most valuable fins usually removed are: the first dorsal, the two pectorals and the lower caudal (Figure 8.4.1). However in some countries secondary fins (second dorsal, pelvic, anal and upper caudal) can also be removed.

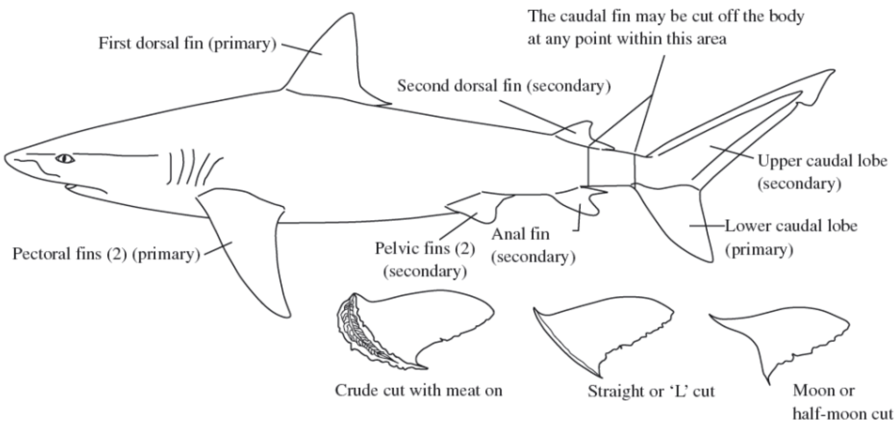


Figure 8.4.1. Diagram of whole shark with primary and secondary fin sets labelled. Three common fin cuts (crude cut with meat on, straight or L cut, moon or half-moon cut) are illustrated.

The practice of finning at sea allows the efficient storage of fins on-board. Indeed, due to the low value of shark meat and the rigidity of shark fins, fishermen consider that is difficult to store shark carcass with fins attached. This storage convenience on-board resulted in a compromised regulation allowing fishermen to remove fins from sharks at sea for separate storages if the weight of fins on board corresponds to a given value of the ratio between the weight of fins and the weight of carcasses kept on board. This enforcement method of the finning ban based on the fin/weight ratio is commonly adopted by RFMOs and countries where a finning regulation ban is active (Appendix VIII). Particularly, it allows landing fins and carcasses separately. All tuna RFMOs have adopted resolutions to eradicate shark finning practices by adopting the same fin/carcass weight ratio of 5%.

The 5% wet-fin-weight-to dressed carcass (fin and head removed) weight was proposed by the U.S. fishery management plan for sharks based on an independent observation of 12 sandbar sharks (*Carcharhinus plumbeus*). In the frame of the U.S Commercial Shark fishery observer program this ratio was validated through an analysis of 27,000 shark individuals for 28 shark species (a mean ratio of 4.9% was estimated). This regulation was adopted by many countries and tRFMOs (Appendix VIII) but the original specification of a wet fin to dressed weight ratio of 5%, was totally omitted in regulations adopted after or adopted with different references as for European Union for which the regulation specifies a wet fin/round (total) weight ratio. Considerable differences in wet-fin-to-carcass-mass ratios exist between species, genera, families due to distinct anatomical features, with fins varying in size, shape and thickness (Table 8.4.3). Moreover, there are also differences between countries explained by fin-cutting practices and fin sets (Hindmarsh, 2007;

Hareide et al., 2007; Biery and Pauly, 2012). Finally, there are differences based on the fin commercialisation mode; wet, dry or dry after freezing. Biery and Pauly (2012) suggested conversion factors for wet versus dry of 0.43 and wet versus dry after freezing of 0.25. Based on these conversion factors and a 5% wet fin ratio, we can estimate that ratios for dry fin to carcass and dry fin after freezing to shark carcass should be 2.15% and 1.25%, respectively.

Before the adoption of the EU regulation 605/2013, principal methods to enforce shark finning bans have been proposed (Fowler and Séret, 2010). We briefly present below the list of those methods:

1. Keeping fins attached

The advantages of keeping shark fins attached include:

- Enforcement is reduced because fins and carcasses do not need to be weighed separately,
- Avoid complex calculations regarding ratios for different species, fisheries and onboard processing techniques,
- Eliminate the mixing of carcasses and fins from different individuals,
- Species-specific monitoring of landings is easier and improves the data quality of landings as well as species-specific identification and data (finned carcasses can be hard to identify, particularly if beheaded),
- Land-based processing of carcasses can improve fin cutting giving an added value to the product,
- In addition to the "keeping fins attached" recommendation, it must be noted that GFCM in its recommendation "*GFCM/36/2012/3 on fisheries management measures for conservation of sharks and rays in the GFCM area*" declared that CPCs shall ensure that beheading and skinning of specimens on board and before landings shall be prohibited. Such practices raise the issues of species identification and data collection. If permited, they would jeopardise the quality of the biological and biometrical data collected at landings as well as the possibility to verify the nominal catch per species declared on logbooks.

2. Limiting the numbers of fins landed per carcass

This method is ideal for a small fleet and to a small number of well-monitored locations. Compliance is monitored by counting the number of pectoral and/or dorsal fins and comparing these with the number (and size if possible) of carcasses landed. However, there are some limitations:

- Time-consuming enforcement at landing sites (i.e. counting every fin set and carcass to monitor compliance);
- Retention of large fins from large sharks alongside small shark carcasses (high grading),
- Limit of few shark individuals or applied to a small number of vessels in a strictly regulated and closely monitored fishery,
- Feasible at larger scale with 100% human and/or electronic observer coverage.

3. Limiting fin:body weight ratio

The main problem with a ratio defined as a compliance threshold is that this can never be measured by comparing a weight of fins and carcasses landed. The ratio classically applied is 5% of wet fin weight to ‘dressed’ (gutted and beheaded) carcass weight (roughly equivalent to 2% of wet fin weight to whole shark). However, the weight of fins depends mostly of the conservation mode of fins. Moreover, this ratio weight fin/carcass weight is highly dependent on the species and on the carcass weight reference (i.e., whole mass or dressed mass) (Table 8.4.3). Such a difference suggests the importance to define a theoretical correspondence between weights of fins and carcass taking into account the type of fishery, species composition and type of processing and storage.

Table 8.4.3. Mean value of wet-fin-to-round-mass ratio (Ratio 1) by shark genus. The total number of species considered within each genus is indicated (modified from Biery and Pauly, 2012). The wet-fin-to-dressed-mass ratio (Ratio 2) is estimated following the 2.5 ratio between the percentage of wet fin weight versus the round mass (5%) and the percentage of wet fin weight versus the dressed mass (2%).

Genus	N species	Ratio 1 (%)	Ratio 2 (%)
Carcharias	1	1.34	3.35
Galeocerdo	1	1.41	3.53
Scymnodon	1	1.50	3.75
Squalus	1	1.69	4.23
Rhizoprionodon	2	1.87	4.68
Centroscymnus	1	2.00	5.00
Alopias	1	2.06	5.15
Lamna	1	2.20	5.50
Carcharhinus	21	2.44	6.10
Eusphyra	1	2.47	6.18
Dalatias	1	2.50	6.25
Sphyrna	4	3.07	7.68
Mustelus	2	3.10	7.75
Isurus	1	3.14	7.85
Centroscyllium	1	3.40	8.50
Loxodon	1	3.69	9.23
Centrophorus	1	3.80	9.50
Centroselachus	1	4.00	10.00
Negaprion	2	4.00	10.00
Galeorhinus	1	4.50	11.25
Deania	1	5.40	13.50
Nebrius	1	5.40	13.50
Prionace	1	5.65	14.13
Pristis	1	10.90	27.25

9. TASK 6 – ANALYSE BEST PRACTICES AND POTENTIAL ALTERNATIVE MEASURES

9.1. *Key findings and recommendations*

- Management interest in elasmobranchs has notably increased in recent years, especially considering mitigation measures for unwanted bycatch.

- Most of the mitigation measuresstill need more research before being implemented at a commercial level. Some measures directly from research have already been adopted by the industry, mainly best practices aiming to enhance the survival of discarded fish (mainly for purse seine fisheries). But in general, more studies are needed and incentives will be required to facilitate the adoption of mandatory mitigation measures by the industry.

- There are several studies investigating the at-vessel mortality of elasmobranchs for both pelagic longline and purse seine fisheries, but those types of data and studies for gillnet fisheries are crucially lacking.

- Post-release mortality data collected for some species varies considerably depending on biological factors (species, size, sex and mode of gill ventilation) associated with the capture (gear type, soak time, handling, catch mass and composition). However, there is the need to develop research programs to improve data collection on post-release mortality, particularly for species banned for retention.

- We recommend further reseach assessing the impact of technical mitigation measures for sharks in tuna fisheries, including more studies focused on biodegradable FADs for purse seine, hook type (shape and size) and leader material for longlines, mesh size and material for gillnet fisheries.

- We also recommend increasing the level of the observer coverage (both human observers and/or electronic monitoring) for all tuna fisheries. However, we also note that within the tuna-RFMOs most CPCs do not achieve the minimum percentages currently adopted, and in some cases do not have observer programs. The first step would be to ensure all fleets achieve the minimum coverage ratios and submit the data, and then increase the coverage as needed, possibly by complementing with electronic monitoring. We also emphasise the need for scientific duties to be carried out by scientific observers and any compliance duties to be carried out by other mechanisms in order to assure that they are keep as fully separated tasks.

9.2. *Objectives*

The objectives of this task were to outline and analyse best practices and other alternative measures that could be adopted in the short and long term by tuna-RFMOs to reduce catches and/or post-release mortality of unwanted catches of sharks and rays, (for fisheries that do not target sharks) and highlight their strengths and weakness.

9.3. *Methodology*

Within this task, the Consortium performed an analysis of best practices as well as potential alternative measures to reduce bycatch and enhance the post-release mortality of oceanic sharks and rays incidentally caught by major open ocean fisheries (purse seine targeting free schools, purse seine on drifting fish aggregating devices (dFAD), pelagic longline and gillnets) operating in different tuna RFMOs (t-RFMOs). A literature review was carried out 1) on scientific papers, 2) grey literature from relevant t-RFMOs as well as other International bodies (FAO, NGOs, ISSF), 3) by searching on By-catch Mitigation Information System (BMIS) Website[21] and 4) by questioning the data base of the Consortium for Wildlife Bycatch Reduction[22].

Two sub-tasks were identified: 1) mitigation measures (MMs) reducing interaction of elasmobranchs (principally species in scope) in tuna-RFMO fisheries; and 2) best practices aiming to reduce post-release mortality (BPRMs). MMs and BPRMs were assessed at the level of fishing gears and practices: purse seine on free schools, purse seine on fish aggregating devices (FADs), pelagic longline targeting swordfish, pelagic longline targeting tunas, and gillnets operating in different tuna-RFMOs.

<u>Sub-task 6.1 - Mitigation measures to reduce interaction of sharks in tuna-RFMO fisheries</u>

This sub-task mainly considered the improvements to the design and use of fishing gear and by-catch mitigation devices. We broadly reviewed the relevant literature

---

[21] www.bmis-bycatch.org/mitigation-techniques
[22] www.bycatch.org/

(scientific papers and grey literature from tuna-RFMOs and other International bodies (e.g., FAO, NGOs, ISSF)) of MMs that are currently being applied by each tuna-RFMO for pelagic sharks as well as other MMs used by other International bodies to reduce the interaction between fisheries and elasmobranch species (mainly sharks). MMs were reviewed based on i) their expected efficiency; ii) their feasibility for implementation and iii) their observed efficiency when implemented. A summary of the strengths and weaknesses of the identified MMs was produced.

Sub-task 6.2 - Best practices to reduce post-release mortality

This sub-task considered best practices available for purse seiners, longline and gillnet fisheries to increase post-release survivorship (BPRMs). We carried out a broad review of literature (scientific papers and grey literature from tuna-RFMOs and other International bodies such as FAO, NGOs, ISSF) of those BPRMs. BPRMs were reviewed based on i) their expected efficiency; ii) their feasibility for implementation and iii) their observed efficiency when implemented. A summary of the strengths and weaknesses of best practices aiming to reduce post-release mortality on elasmobranch species in large pelagic fisheries was also produced.

9.4. *Results and discussion*

The challenge in mitigation science applied to fisheries is to find the optimal balance between technical measures (e.g., deterrent systems) and spatial management measures (e.g., avoidance). Mitigation issues for fisheries typically involve different and often conflictive stakeholder interests, and are too often contaminated with *a priori* assumptions.

In general, spatial management solutions comprise of area/season closures in habitats of particular ecological relevance for target or by-catch species (for example, for spawning, nursing or growth). Management solutions also control fishing effort according to knowledge on the dynamics of the species, and, if possible, they also control for the impacts on the habitat. Many by-catch problems can be resolved via technological solutions.

Sub-task 6.1 - Mitigation measures to reduce interaction of sharks in tuna RFMO fisheries

Management resolutions or recommendations for elasmobranchs adopted by the main RFMOs considered in this specific contract to mitigate the effects of tuna fishing on elasmobranch populations have been listed in task 5. Most measures are recent, with five having been adopted between 2004 and 2005 and about 25 since 2009. During the literature review, we identified 11 generic MMs that have been recommended irrespective of the fishing gear, and 14 operational and technical MMs for the pelagic longline gear.

Generic management measures (MMs)

The 11 management measures identified vary from input controls to limitations (e.g., species, sizes) on what can be retained onboard. They also consider the involvement of fishermen in a by-catch mitigation scheme through fleet communication and trainings. The limitations include: 1) Legal constraints in fishery for fin cutting and removal, 2) Quotas for by-catch species, 3) Species retention prohibition, 4) Minimum landing size (MinLS: the minimal length at which it is legal to retain the species), 5) Maximum landing size (MaxLS: the maximum length at which it is legal to retain the species), 6) compensation mitigation/industry self policing, 7) spatial/temporal closure, 8) input control (fishing effort reduction), 9) by-catch management, 10) real-time fleet communication and 11) participation in workshop and training on good handling and fishing practices and species identification.

All those generic MMs have advantages and drawbacks. While their primary intent is to promote conservation of the species, they are difficult to employ due to the need for reinforcing policy and compliance regulations, and eventual negative economic impacts on the fishing sector and the difficulties to assess their efficiency as discussed in the Task 5 for the retention ban measure. However it has been suggested to promote.

The application of co-management approaches between fishermen and managers such as "compensation mitigation", can foster collaborative works between fishing gear technologists, fishery biologisst and fishers, to develop both operational and technical mitigation measures. Moreover, fisheries involved in such types of co-management may benefit from a sustainability certification allowing a better value for the fish products with advantages on competitive markets. Moreover, positive outcomes from fishermen participations in workshops and training on good handling and fishing practices and species identification have been pointed out (Poisson et al., 2014).

Operational and technological mitigation measures

A comprehensive review of existing operational and technological mitigations measures (OTMMs) for longline, purse seine and gillnet fisheries and a qualitative assessment of their success in terms of reducing bycatch (or dead discards) of elasmobranchs is provided, including their advantages and disadvantages is assessed using defined criteria. A global view and the potential impacts of MMs on target species, other bycatch groups and the environment are proposed in Appendix VIII.

Fourteen potential MMs were identified for longline fisheries, comprising 11 for "Fishing gear modification", six for "Fishing practices and strategy" and three for "Practices to increase survival rates after release".

Longline fishing gear potential mitigation measures

1 - Prohibition of light attractors: Light attractors, including chemical light sticks and battery-powered light-emitting diodes (LEDs) or "electrolume", are attached near baited hooks on branch lines to attract prey of fish and fish itself towards the bait. Chemical light-sticks are plastic made, contain harmful chemical products and have a limited lifespan of a day or two and are not reusable. LEDs are powered with batteries and are a common component of swordfish longline gear.

+	-
Positive response on sea turtle bycatch but few knowledge on shark responses to light attractors, reduced pollution (plastic containers, chemical components, batteries), easy to implement if acceptance by fishermen.	Opposition from the fishing industry as this MM leads to a reduction of the catch rate of target species (mostly swordfish). May lead to an increase in fishing effort and to the negative impacts related to this. Control of its implementation difficult.

Main references: (Alessandro and Antonello, 2009); (Bigelow et al., 1999); (Bromhead et al., 2012); (Oliveira et al., 2014); (Gless et al., 2008); (Hazin et al., 2005); (Poisson et al., 2010); (Southwood et al., 2008); (Swimmer and Brill, 2006); (Wang et al., 2007)

Remarks: Already in place in the western Pacific[23]. No need for immediate additional research.

[23] - 50 CFR 665.813 - Western Pacific longline fishing restrictions.

(d) Vessels registered for use under a Hawaii longline limited access permit may not have on board at any time during a trip for which notification to NMFS under § 665.803(a) indicated that deep-setting would be done any float lines less than 20 meters in length or light sticks. As used in this paragraph "float line" means a line used to suspend the main longline beneath a float and "light stick" means any type of light emitting device, including any fluorescent "glow bead," chemical, or electrically powered light that is affixed underwater to the longline gear.

2 - Prohibition of wire traces/leaders: The branchline consists of several sections connected with a swivel. The terminal part/section of the branchline (gangion), where the hook is attached, can be rigged with wire instead of usually used monofilament nylon material in order to reduce the rate of fish escapement (i.e., bite-offs) and to maximize fish retention. Fish with powerful jaws and cutting dentition (e.g., sharks) are better able to bite through nylon leaders.

+	-
Reduction in numbers of sharks retained, catch rates of other valuable tuna and billfish species are higher on nylon than on wire leaders (but results may change depending on field trials).	Difficult to implement on fishing grounds where sharks are targeted, possible negative impact on some target species by the shift of the fishing effort from shark to other species.

Remarks: Already in place in some fishing areas (tuna RFMOs). This mitigation measure is being analysed in detail in the sub-task 5.4 (previous Task 5).

3 - Circle hooks: Correspond to a hook style distinguished for having a rounded shape with the point oriented to the shank, as a means to reduce post release by-catch mortality the hooking being preferentially located on the jaw. Proposed to replace J-hooks, which tend to be fully ingested more frequently and thus likely to increase post-release mortality.

+	-
Expected to reduce post release mortality of sharks by reducing deep-hooking. Reduce catch rate of pelagic stingray, crocodile shark and juvenile sharks. Reduce impact on other sensitive species such as sea turtles.	Many results are fisheries, species and fishing area dependent. Fishermen complained that baiting circle hook is more time consuming. Circle hooks can increase shark retention rates and reduce valuable billfish catches.

Main references: (Coelho et al., 2012b); (Epperly et al., 2012); (Fernandez-Carvalho et al., 2015); (Ferrari and Kotas, 2013); (Forney et al., 2011); (Godin et al., 2012); (Graves and Horodysky, 2008); (Graves et al., 2012); (Kaplan et al., 2007); (Gilman et al., 2012); (Pacheco et al., 2011); (Piovano et al., 2009); (Piovano et al., 2010); (Prince et al., 2007); (Read, 2007); (Rice et al., 2012); (Richards et al., 2012); (Sales et al., 2010); (Serafy et al., 2012); (Serafy et al., 2009); (Stokes et al., 2012); (Ward et al., 2009); (Watson and Kerstetter, 2006); (Wilson and Diaz, 2012); (Yokota et al., 2006); (Yokota et al., 2012)

Remarks: Very efficient for reducing interactions in sea-turtles, especially hard-shell species, but there are conflicting results regarding the effect on the decrease of interactions with some elasmobranch, with possible higher retention for sharks in some cases. The effectiveness of the measure must be better assessed in particular with the combination of other factors such as bait type and leader materials.

4 - Corrodible hook: Corresponds to a fishing hook composed of material other than stainless steel commonly used for hooks. Material used may be different alloys with different coatings thus having an effect on the hook longevity. The hook may dissolve quickly (few days) or more slowly (over weeks or months).

+	-
Reduce the mortality of most bycatch released or escaped with a hook attached. Faster recovery (less negative health impact) of individuals released with hook. Positive for protected species such as sea turtles and toothed whales.	Fishermen complain that more time and money is necessary for gear maintenance (need to replace hooks more often than with stainless hooks). Financial implications on having to constantly replace the gear.

Main references: (McGrath et al., 2011); (Patterson and Tudman, 2009); (Watson and Kerstetter, 2006).

Remarks: More studies are needed to better assess the efficiency and economic impacts of this MM

5 - Weak hook: Corresponds to a hook made with a round stock wire that is thinner-gauge than traditional hooks used in pelagic longline fisheries. The weak hook is more likely to bend when large fish or toothed whales are hooked. The difference between the weak hook and traditional hooks is barely detectable to the naked eye.

+	-
Permits a decrease of incidental retention of large fish. Positive for protected species such as sea turtles and toothed whales.	Fishermen complain that more time and money is necessary for gear maintenance (need to replace hooks more often than regular stainless hooks). Ability for weak hook to release large fish healthy is questionable. The escape rate of large target fish could increase compared to traditional hooks.

Main references: (Bayse and Kerstetter, 2010); (Bigelow et al., 2012); (Patterson and Tudman, 2009).

Remarks: More studies are needed to better assess the efficiency (reduction of incidental catch and impact on catch rate of target species) and economic impacts of this MM.

6 - Magnetic, E+ metals, electrical deterrent: The use of permanent magnets, electropositive rare earth metals (EPREM, mostly lanthanide elements), and other electrical deterrent for deterring sharks has been tested. Permanent magnets are made from magnetised material and create their own persistent magnetic field. EPREM react with seawater to create such fields. Sharks are able to detect the Earth's geomagnetic field using their ampullae of Lorenzini. Electropositive metals or magnets appear to generate an aversive response in some species of sharks through an overstimulation of their ampullae, which are sensitive electroreceptors.

+	-
Potential effect to reduce interactions between sharks and longline.	Materials fragile, costly and as tested so far difficult to implement or not efficient as a shark mitigation measure at an operational level.

Main references: (Cosandey Godin et al., 2013); (Huveneers et al., 2013); (Kaimmer and Stoner, 2008); (McCutcheon and Kajiura, 2013); (Meyer et al., 2005); (O'Connell et al., 2011); (O'Connell et al., 2012); (O'Connell and He, 2014); (Rigg et al., 2009); (Robbins et al., 2011); (Stoner and Kaimmer, 2008); (Tallack and Mandelman, 2009).

Remarks: Conflicting results concerning the efficiency of magnetic deterrents and the impact on target species is still largely unknown. Overall there is very little information on the effect that magnet and metal could have as repellent on pelagic sharks commonly caught by commercial longliners. Recently, some trials were carried out aiming to use electrical fields to deter sharks. Some preliminary tests were carried out in a few selected locations (UK and Australia) and have shown a reduction of shark attacks and shark hooking (Fishteck, 2015).

7 - Artificial bait: Corresponds to an experimental technology in pelagic longline fisheries. Prototype artificial baits can rely upon olfactory attractants alone or in combination with a visual attractant (bait shape), each with different physical properties. Natural and/or synthetic materials can be used to fabricate the baits.

+	-
Possible increase the species-selectivity of the gear. Possible reduction of shark, sea turtle, bird, marine mammal bycatch. Reduce or stabilize the overall cost of bait through improved gear efficiency (e.g. by reducing bait lost during soak time). Costs and supply less variable than natural bait. Possible reduction of the pressure on species exploited for bait. No ecological printing if materials are environmental-friendly. Possibility to use fish waste and other sub-products from the fishing industry as olfactory attractant.	Potential impact on catch rates of target species. Could induce additional time for baiting the longline gear. Artificial baits may also have environmental impacts that need assessment, depending on the material used and degree of biodegradability.

Main references: (Bach et al., 2012a); (Bach et al., 2013); (Erickson and Berkeley, 2008); (Løkkeborg, 1990); (Løkkeborg, 1991); (Løkkeborg and Johannessen, 1992); (Løkkeborg et al., 2014); (Mejuto et al., 2005); (Mejuto et al., 2008); (Tryggvadóttir et al., 2002)

Remarks: Research in this field is still very limited, with mixed success. More research remains to be done before artificial baits become a viable alternative to natural baits.

8 - Bait type (squid vs. fish): Squid and fish (mostly mackerel, sardine and scads) are the most common baits used in pelagic longline fisheries.

+	-
Potential reduction in bycatch of some shark species by using squid bait. Reduced sea turtles bycatch by using fish.	Conflicting results of shark responses between squid and fish for sharks. Use of fish cheaper than squid reduces the exploitation cost.

Main references: (Amorim et al., 2015); (Bach et al., 2008); (Coelho et al., 2012b); (Foster et al., 2012); (Gilman et al., 2008); (Watson et al., 2005); (Yokota et al., 2009).

Remarks: Conflicting results concerning the responses of sharks to bait types. Need for experiments of this MM in combination with hook types and leader materials.

9 – Dyed bait: Dyeing bait blue is expected to reduce the contrast between the bait and the surrounding seawater making it more difficult for foraging seabirds to detect. Alternative theories suggest that seabirds are simply less interested in blue-dyed bait compared with undyed controls. At the origin, in 1970's fishermen experimented blue dyed bait to improve their target catch rate.

Main references: (Boggs, 2001); (Gilman et al., 2007); (Løkkeborg, 2011) (Swimmer et al., 2005); (Yokota et al., 2009)

Remarks: No research has been dedicated to analyse shark responses to this MM. At this stage it is not considered as a promising MM as regards mitigating shark catches.

10 - Olfactory repellent: Semiochemicals are chemical messengers or "clues" sharks may use to orient, survive and reproduce in their specific environments. Certain semiochemical extractions have the ability to trigger a fight reaction in sharks, but these trace chemicals present unique difficulties for isolation and detection. Shark necromones have been identified recently as potential repellent for sharks.

+	-
Shark necromones deter sharks. Some semiochemical might deter others sensitive species such as sea turtles or marine mammals.	Shark necromones might have a negative impact on catch rate of target species. Deterrent effect might be not efficient after habituation.

Main references:(Jordan et al., 2013); (Sisneros and Nelson, 2001); (Southwood et al., 2008); (Stroud et al., 2013)

Remarks: More fundamental research must be implement to i) identify the potential of semiochemicals to deter sharks and ii) if responses occurred to assess applications in the field of fishing gear technology. Such kind of research might be carried jointly to research on the development of artificial baits.

11 - Soaking time: The pelagic longlines are often soaking for long periods, in some cases for more than 24 hours, depending on the vessels characteristics and target species. Longer soaking time usually results in higher proportion of sharks caught in relation to target species catch. The proportion of fish alive at haulback is inversely related to time on the line, hence the mortality of fish caught increased as soak time increased.

+	-
Reduced catch of sharks. Reduced catch of other bycatch. Limited impact on the catch rate of some target species (e.g., swordfish). Decrease in at-vessel mortality and potential increase in post-release survival of discarded bycatch. Improved quality of the target species. Potential reduction in the depredation of target species.	Potential decrease of catches of target species and commercial bycatch. Negative impacts on fisher safety if it reduces the resting time for the crew. Difficult to monitor as the haulback time (and soaking time) increases with quantity of fish caught and sea conditions.

Main references: (Auger et al., 2015); (Bach et al., 2012b); (Carruthers et al., 2011); (Erickson and Berkeley, 2008); (Løkkeborg and Pina, 1997); (Poisson et al., 2010); (Ward and Myers, 2007).

Remarks: Optimal soaking duration depends on the fishery (target species, fleet characteristics) and specific environmental conditions. More data collection must be done to define an optimal soaking duration scheme regarding target species and related fishing strategies.

12 - Deep setting (i.e. eliminating shallower hooks): Corresponds to a longline fishing technique where hooks are set below a critical depth, out of range of most epipelagic by-catch species (some sharks species, sea turtles, billfishes, epipelagic bony fishes) but within the range that target species are usually captured (i.e. tuna).

+	-
Significant reduction of epipelagic shark catches. Positive effect for reducing bycatch of epipelagic fish and megafauna (including billfishes and sea turtles).	Risk of increasing catches of deeper-dwelling shark species in some areas. Economic consequences due to the potential reduction of some commercial species (e.g., swordfish). Possible reallocation of the fishing effort on target species to offset the decrease in income.

Main references: (Beverly et al., 2009); (Cambiè et al., 2013); (Patterson and Tudman, 2009); (Walsh et al., 2009); (Watson and Bigelow, 2014).

Remarks: Applicable for pelagic longline fisheries targeting tuna for large longliners and deep-frozen commercialized fish. Might not be feasible to use in shallow setting longliners targeting swordfish.

13 - Management of offal discharge: Offal is produced by the process of capture and processing of the fish catch on board. With regard to sharks, if this offal is discharged while hauling the gear, it may have an attractant effect and increase the catches.

+	-
Controlling the offal to avoid discharge during hauling can potentially reduce catches of scavenging species such as sharks, as well as reduced interactions with seabirds. When doable for some vessels, it is easy to implement with no extra cost. General positive support from the fishing industry.	Difficult to put in place on small longliners (LOA < 15 – 17 m).

Main references: (Gilman et al., 2008)

Remarks: Little is known about the potential impact of this MM upon shark catch rates. More studies (data and analysis) are needed to better assess the potential efficiency of this MM. Observer might be involved to encourage uptakes of offal as a best practice to reduce shark bycatch and seabird interactions.

14 - Prohibition of live bait: Farmed fish, *Chanos chanos*, is a common commercial bait used alive in some Asian countries for pelagic longlining.

+	-
Possible reduction of bycatch of large pelagic species (shark, billfishes, seabirds). Transfer of aquaculture activities on species economically more profitable.	Reduce the catch rate of target species and some commercial bycatch, but not particularly for sharks.

Main references: (Fitzgerald, 2004); (NMFS, 2008).

Remarks: More studies are needed to assess the potential impact of this MM upon shark catch rates. However, the use of live bait in pelagic longlining is limited to few Asian countries and this practice is already banned in several countries.

Purse seine fishing gear potential mitigation measures

In recent years numerous multi-ocean research projects have focused on purse seine fishery shark mitigation by testing new concepts at sea (e.g. FADIO, MADE, ECOFAD and ISSF Bycatch Project). Preference was initially given to bycatch mitigation options that take place before encirclement in the net, as this ensures minimum physical damage and maximum survival of individuals. One example is the use of non-entangling FADs (NEFADs) to prevent passive entanglement of sharks and turtles. Work by Filmater et al. (2013) estimated that in the Indian Ocean, drifting FADs constructed with open panels of large mesh netting (e.g. > 4 inches) were ghost fishing 5-10 times more sharks than those bycaught in the purse seiners' nets during fishing operations. Joint efforts between scientists and fishers to design prototypes of NEFADs constructed with either small-mesh net (e.g. < 3 inches) or no netting were successful in the Indian and Atlantic Oceans (Goujon et al., 2012; Goñi et al., 2015). Most fleets in the Indian, Atlantic and Eastern Pacific Ocean now operate with those prototyped NEFADs. This transition has been greatly favoured by t-RFMO recommendations and measures in these regions. At present, the only remaining region which lacks NEFAD resolutions and has no or little adoption of these lower impact FADs is the WCPFC in the Pacific Ocean (Murua et al., 2016). A recent industry-based resolution by ISSF to carry out transactions only with boats using NEFADs from 2018 onwards (conservation measure 3.5) may incentivise a change to NEFADs in all oceans. Recently, scientific groups and some fleets are testing NEFAD built with biodegradable materials (e.g., Moreno et al., 2016) to tackle FAD impacts of ghost fishing and marine pollution at the same time.

Another bycatch mitigation option "before the set" initially studied was to catch target tuna when it moves, after dawn, away from the FAD, leaving behind other bycatch species including sharks. However, this alternative did not appear viable as the target skipjack aggregation breaks away from the FAD in various schools, making it difficult to catch and resulting in a large reduction in tuna catches (Schaefer & Fuller, 2011). Various recent tagging behavioural studies on FAD-associated fauna have also shown that sharks and tuna tend to follow similar diel movements; both making short nocturnal feeding excursions but returning to the FAD before dawn (Filmalter et al., 2015, 2016; Forget et al., 2015), which is typically the optimal time for setting the floating objects. These behavioural findings appear to discourage mitigation options based on differential presence of sharks near FADs during the day (e.g. modifying the timing of sets to catch tunas while reducing shark by-catch).

Scientists hypothesized that if sharks are present near the FAD before the time of the set, positive stimuli to attract them away or negative stimuli to scare them out from the FAD could be used before deploying a set. Trials using bait-filled bags slowly towed away from the FAD to attract sharks away from the floating object before a set were tested in the Indian Ocean. Some of the sharks showed interest in the bait, but only 30% of the sharks, in one of the five tests, followed the food for up to 500 m. The rest showed partial or no interest and shortly after 0 to 250 m turned back towards the FAD and associated fish aggregation (Dagorn et al., 2012). This attraction distance is clearly insufficient to avoid net encirclement as the diameter of a purse seine net ranges from 500 m to 700 m. Experiments with other more potent attractors like pheromones or other kinds of bait could be worth testing. Deterrent sounds (e.g. predator noises) or electromagnetic fields to scare sharks away from FADs may also be an option. Even in the presence of positive stimuli (e.g. food, prey sounds) sharks can rapidly lose interest (Nelson & Johnson, 1970), thus moving sharks under open ocean fishing conditions (e.g. with boat noise, sound and smell of fish around the FAD, strong currents, etc.) over half a mile away from the FAD could prove a challenge.

For this reason, the second-best option is releasing sharks once encircled in the net before they reach the sac, has been the primary path of research in recent times. When the purse net is first closed, the FAD is often towed out through a small gap between the vessel's hull and the net bow oertza. During this operation many bony fishes such as triggerfish, dolphinfish, etc. escape by following the FAD out. It was thought that sharks could also escape this way, but underwater inspections in the net showed that sharks stop following the FAD when it gets close to the boat, maybe scared by the boat's presence and noise (Dagorn et al., 2012a). Scientists in the Western Pacific diving in the fishing net also noticed that at the start of the set there is often a physical separation of several dozen meters between sharks swimming near the sea surface and deeper-diving tunas closer to the net bottom. Several trials where conducted during ISSF research cruises to test an escape window of approximately 10 m x 10 m near the top of the net, which could be opened to allow sharks to escape out. However, in nearly 30 sets during this cruise, sharks did not move out of the net, perhaps not even recognising there was an escape route there or preferring the "safety" of being closer to other fish in the net (Itano et al., 2012). Subsequent trials in the Atlantic Ocean proved that under conditions such as stronger currents, shallow thermoclines, lower visibility or with smaller nets where shark-tuna separation is limited, there were significant challenges for the use of a shark escape window (Restrepo et al., 2016). A captain at an ISSF Skippers Workshop, where bycatch mitigation options are discussed with fishers (Murua et al., 2014), proposed trying to catch the sharks inside the net by using fishing lines or rods from the speedboat. This idea was tested in the Atlantic, with two persons trying to fish sharks for 30 minutes during net retrieval (with no delay to the normal fishing operation), and thereafter releasing them outside. About 20% of all sharks in the net were caught and released. An important part of the fishing time in these experimental trials was used up by fitting electronic tags to all caught sharks to check post-release survival, which was 100% (Sancristobal et al., 2017). In the case of accidental captures of whale sharks, which are usually released from the net by lowering the corkline and letting them pass over, post-release survival is considered to be very high (Escalle et al., 2016).

In addition to technological measures, there are other management measures with potential to reduce catches of sharks and rays by purse seiners (Gilman, 2011; Poisson et al., 2016). Regulations include the non-retention related measures for specific shark species like silky and oceanic white tip sharks, use of NEFADs, prohibition of sets on whale sharks, or prohibitions on shark finning. A key element of management success for the correct enforcement and application of these measures is having reliable information from observer programs (Gilman et al., 2013). For example, with the prohibition of shark finning so that carcasses are landed if fins are retained, many fisheries lack adequate enforcement (Gilman et al., 2008). There needs to be a high observer coverage, preferably 100%. In the large-class purse seiners there is virtually total observer coverage, either mandatory through the RFMOs or industry-based initiatives (e.g. ProActive Vessel Register Program ISSF). However, given the potential for observer pressures and bribery to avoid reporting some kinds of by-catch (e.g. dolphins, sharks, whale shark, turtles, etc.), the shift towards electronic monitoring systems and electronic catch documentation would be advisable to ensure data quality and integrity (Ruiz et al. 2014; Restrepo et al., 2014).

There are other measures such as the reduction in the number of FADs, FAD-closures, or limitation of supply vessels, which are directed to address overfishing concerns of small bigeye or yellowfin tuna, but which may also have benefits on shark by-catch as it controls fishing effort on FADs. A study by Dagorn et al. (2012b) suggested that, as all FADs tend to have a similar amount of by-catch irrespective of the amount of tuna aggregated, targeting FADs with large tuna schools and avoiding those with small aggregations (e.g. < 10 tonnes of tuna) would result in a significant reduction in by-catch (20-40%) but not in tuna yields (3-10%). Although in theory this is a good option, the reality is that fishers are increasingly setting on small FAD schools as they fear having them intercepted by competitor vessels. Keeping up to date with fleet vessel characteristics and fishing strategies is a crucial element to design best by-catch management options for optimal results (Lopez et al., 2014; Murua et al., 2017). Similarly, studies on the location of shark hotspots and their interaction with the FAD fishery are valuable tools to develop spatio-temporal management measures to protect vulnerable elasmobranch populations (Lezama-Ochoa et al., 2016; Lopez et al., 2017). Marine protected areas are being increasingly created worldwide to preserve marine biodiversity and protect endangered species such as sharks (Koldewey et al., 2010;

Knip et al., 2012). Although RFMOs have not yet adopted shark-directed closure areas in the tuna purse seine fishery, they have evaluated possible scenarios balancing out benefits of shark protection against loss in target catches (Watson et al., 2009). A critical factor is to consider how these closures influence purse seine fleet effort reallocation (Torres-Irineo 2014, 2017) and possible unintended impacts on shark populations overall. Also, in some instances depending on environmental conditions inter-annual variability in pelagic shark distribution in the open ocean may be significant, and can undermine effectiveness of fixed spatio-temporal closures. To overcome the poor responsiveness of permanent closures to stock spatial heterogeneity, real-time closures based on fishers' communications and daily observer data are being employed (Little et al., 2014). This system initially requires a high standard of technology and data reporting, but enables rapid evaluation and adaptive adjustments to by-catch management objectives.

Based on the experience from the above management measures and mitigation techniques there is not a single "silver bullet" which can eliminate shark and ray by-catch in tuna purse seiners, but rather an array of options that when added up can significantly reduce overall impacts of this fishery.

Main mitigation measures to mitigate bycatch of elasmobranchs in tuna purse seine fisheries proposed in the literature with their respective strengths and weaknesses are listed below.

1 - Prohibition of entangling drifting Fish Aggregating Devices (FADs)

+	-
Prevention of shark and turtle ghost fishing caused by the net used to construct the FADs. Easy to modify by tying netting, use small mesh or rope material to make them non-entangling. Does not reduce target tuna catches. General support by the industry.	Requires wide observer coverage (human observer or electronic monitoring observation) for control. Non-entangling DFAD costs are similar or slightly higher.

Main references: (Filmalter et al., 2013); (ISSF, 2015); (Murua et al., 2017)

2 – Biodegradable FAD

+	-
Reduces potential time of FAD ghost fishing. Minimizes marine pollution by FAD materials.	Extra costs and raw material availability issues.

Main references: (Lopez et al., 2016b); (Moreno et al., 2016)

Remark: In 2017, the Specific Contract (SC) N°7 under the Framework Contract EASME/EMFF/2016/008 provisions of Scientific Advice for Fisheries Beyond EU Waters was launched to provide solutions that shall support the implementation of non-entangling and biodegradable DFADs in the IOTC Convention Area through the collaboration with the EU purse seine tropical tuna fishery and International Seafood Sustainability Foundation (ISSF). This SC will aim (1) to test the use of specific biodegradable materials and designs for the construction of DFADs in natural environmental conditions; (2) to identify options to mitigate DFADs impacts on the ecosystem; and (3) to assess the socio-economic viability of the use of biodegradable DFADs in the Purse Seine tropical tuna fishery.

3 - Attract shark away from FAD

+	-
Potential to reduce number of sharks encircled in the net after a FAD set. Reduce crew risk associated with handling sharks arriving on deck.	Requires an additional effort by crew working before the regular fishing operation. May not be effective at long distances required (e.g. > 500 m). School of tuna could be scared by speedboat during shark attraction operation.

Main references: (Restrepo et al., 2014); (Restrepo et al., 2016)

4 - Shark escape window in the net

+	-
Potential to release live sharks before brailing, with high survival rate. Simple and low-cost modification by introducing a net window to the purse seiner net.	Efficiency to release sharks not well proven. Only can be used under certain fishing conditions (e.g. deep thermocline, low currents). Risk of target species escape if tuna is not deep in the net. Can potentially slow down fishing operation.

Main references: (Restrepo et al., 2014); (Itano et al., 2012)

5 - Towing FAD through bow oertza

+	-
FAD usually taken out of net through this gap in the net, and some bycatch exits the net following the FAD. Low risk operation and easy application. No additional cost.	Low efficiency as few sharks cross out through this gap near the boat's hull as scared of its shadow and noise. Deeper tail FADs might require lifting out as there is risk of the FAD's tail entangling over.

Main references: (Hall and Roman, 2013); (Restrepo et al., 2014); (Restrepo et al., 2016)

6 - Fishing sharks in the net

+	-
Reduces mortality of sharks caught in the purse seine net. Very high survival rate, even when hook is left in mouth. Safe for crew, no handling. Does not affect set duration.	Requires one extra crew to conduct the fishing. Not always applicable, for example in rough weather. Large sharks might be more difficult to catch.

Main references: (Restrepo et al., 2016); (Sancristobal et al., 2017)

7 – Double FADs

+	-
Potential to reduce catches of sharks and other bycatch.	Theoretical concept still not examined under fishing conditions at sea. Requires extra effort by crew to separate FADs prior to setting. Low acceptance by fishers. Higher cost in FAD materials.

Main references: (Restrepo et al., 2016); (Schaefer and Fuller, 2011)

8 – Scooping sharks/mantas out of net with the brailer

+	-
Potential to increase survival of shark and manta bycatch. Better safety for crew as animals are not handled directly. Low cost. Easy implementation.	Shark or manta must be floating on the sea surface to be scooped. Bycatch in the middle of the sac cannot be reached; Can slow down fish loading manoeuvre.

Main references: (Restrepo et al., 2016)

Remarks: Measure increasing significantly the post-release survival of large sharks and mantas. Already in place for European purse seiners.

9 – Mandatory use of hoppers

+	-
Facilitates sorting of bycatch during brailing, preventing sharks reaching the lower deck and increasing survival. Safer handling release, especially if fitted with a release ramp. Useful to release other bycatch like bony fish, mantas or turtles.	Sufficient space required on the top deck to accommodate hopper. Cost of hopper. In larger boats might slow down fish loading procedure.

Main references: (Poisson et al., 2014a)

10 – Mandatory safe handling equipment

+	-
Equipment (e.g. stretcher bed, cargo net/canvas for mantas and large sharks) improves crew safety. Increase post-release survival of sharks and other bycatch. Very low-cost equipment.	Training in equipment use and handling technique required. Higher observer coverage to ensure implementation.

Main references: (Poisson et al., 2014a); (Poisson et al., 2014b)

Remarks: Measure increasing significantly the post-release survival of large sharks and mantas already in place for European purse seiners.

11 – Lower deck double conveyor belt

+	-
Potential to facilitate release of sharks and other bycatch reaching the lower deck.	Most sharks reaching the lower deck are usually already dead. Needs a boat with enough space to fit the extra conveyor belt. High equipment and installation cost.

Main references: (Poisson et al., 2014a)

12 – Setting on bigger aggregation associated to FAD

+	-
Reduce total bycatch, including sharks. Easy to implement as fishers pre-estimate quantity of fish under floating object prior to set. Control can be checked with logbook and observer data.	Little support by fishers as they do not want to lose set opportunities, as other vessels can steal their FADs. Requires high observer coverage.

Main references: (Dagorn et al., 2012)

13 – Adoption of best and safe release practices

+	-
Potential improvement of post-release survival of sharks and other bycatch species. No additional cost and improved crew safety.	Would require adequate training of crew (e.g. workshops, guidebooks) and higher observer coverage for enforcement. Might be compromised by lack of space onboard small vessels.

Main references: (Poisson et al., 2014a)

14 – Vacuum pumps

+	-
Could potentially help release sharks and other bycatch directly from the purse seiner net, thus increasing survival. Reduce crew risk by avoiding handling of sharks. Potential to load and unload fish faster.	Experimental trials should be conducted to examine feasibility and efficiency of equipment. High initial costs. Enough space needed onboard to accommodate vacuums and hose.

Main references: (Hall and Roman, 2013); (Feekings et al., 2016)

15 – Avoidance of hotspots, closure areas

+	-
Hotspots or time/area closures would potentially reduce shark and manta population impacts. Hotspot maps already exist for some oceanic regions. Real-time fleet communications to avoid shark high-density patches also possible. Easy to apply.	Requires high observer coverage for enforcement. Possible loss of target species catches. Distribution of sharks in high seas can vary widely with environmental conditions.

Main references: (Lewison et al., 2014), (Lopez et al., 2017a), (Lezama-Ochoa et al., 2016)

16 – Limit number of both natural and artificial floating object sets

+	-
Potential to reduce bycatches of silky and oceanic white tip sharks associated with floating objects. Reduced catches of undesirable catches of small tuna sizes. Easy application and monitoring with logbook and observer data.	Likely economic loss of sustainable target tuna such as skipjack. An important proportion of PS shark bycatch, often adults and sensible species such as Mantas and Mobulids, are associated to tuna free schools. Shifting effort to free school sets might impact these sharks and Mobulids.

Main references: (Davies et al., 2014)

17 – Ban of supply vessels

+	-
Likely reduction of number of FADs deployed and associated reduction in both bycatch and small tuna catches.	Reduction in fishing efficiency and tuna catch rates. Opposition by industry, especially heavy FAD users. Difficult to monitor if other "undercover" non-registered supply vessels conduct similar functions.

Main references: (Arrizabalaga et al., 2011), (Dagorn et al., 2013)

18 – Restriction on whale shark and whale sets

+	-
Potential to reduce post-release mortality of whale sharks or whales. Reduced net damage. Reduce time lost handling megafauna.	Moderate improvement as electronic tag data suggest with appropriate release protocol mortality is extremely low. Requires adequate observer coverage. E-monitoring might not be able to spot individuals before set.

Main references: (Clarke, 2011), (Capietto et al., 2014)

19 – Non-retention of sharks

+	-
Avoid creating a shark market. Can be contrasted with observer data. No associated cost.	Requires full observer coverage. Possible errors in shark catch data.

Principal references: (James et al., 2016)

Gillnet fishing gear potential mitigation measures

FAO defines six major groups of gillnet fisheries characterized by a standard code used in the FAO database referential for fishing gears: GNS = setnets; GNC = encircling nets; GTN = combined gillnets – trammel nets; GND = drift nets; TNR = trammel nets and GNF = fixed gillnets.

In the case of tuna fisheries, the principal type of gillnet concerned is the drifnet (GND). Coastal gillnets are intensively used in most parts of the world, in commercial, artisanal and subsistence fisheries and are responsible for massive bycatch mortality of sharks and rays. Despite this importance of pelagic gillnet fisheries worldwide, those fisheries remain poorly documented to carry out analyses of fishery activities or to at least characterise fishing fleets using gillnets. Highest gillnet fishing countries are: Myanmar, Vietnam, Peru, India, Russia (Pacific), Chile, South Africa, China, Namibia, Greece, Galapagos, Bangladesh, Japan (Main Islands), Western Indonesia, Eastern Indonesia, Pakistan, Sri Lanka, Iran, Norway, Mauritania, United Kingdom, Algeria, and Morocco; and the shark species most exposed are: basking shark, longfin mako, shortfin mako, porbeagle, whale Shark, and white shark (Waugh et al., 2011).

Potential mitigation measures for gillnets were principally proposed for sensitive by-catch groups such as marine mammals, turtles and seabirds (Gilman et al., 2010; Gilman, 2011; Løkkeborg, 2011). Few research and studies have been undertaken to directly identify mitigation measures (MM) for sharks in gillnet fisheries.

Main mitigation measures to mitigate bycatch of elasmobranchs in tuna purse seine fisheries proposed in the literature with their respective strengths and weaknesses are listed below.

1 – Modify mesh tension

+	-
Improvement of the survivorship at hauling. Reduction of gillnet damage caused by wrapped sharks. Reduction of shark bycatch without having a deleterious effect on target catch rates. An introduction of maximum size limit would aim to protect the breeding stock and larger sharks likely have a better chance of surviving after being captured.	Do not reduce the number of interactions with sharks and rays. Marine mammals (i.e. seals) can be affected by gear changes.

Main references: (Hovgård and Lassen, 2000); (McAuley et al., 2007); (Patterson and Tudman, 2009); (Thorpe and Frierson, 2009).

Remarks: Modification at the fishery level (case by case) could hinder their ability to retain sharks.

2 – Magnetic, E+ metals, electrical deterrent

+	-
The use of ferrite magnet blocks appears to repel sharks. No repulsive behaviour observed for target species (e.g. the barramundi *Lates calcarife*) to magnetic field.	The size and weight of the magnets used here may pose difficulties with attaching them to nets while maintaining the fishing integrity and buoyancy of the net into the water.

Principal references: (Rigg et al., 2009).

Remarks: More research is needed to assess the efficiency of this potential MM for sharks and rays in gillnet fisheries.

3 – Use turtle/shark lights

+	-
Illuminated nets seems to be an efficient MM to reduce sea turtles bycatch but could be useful to reduce scalloped hammerhead bycatch.	No negative impacts presumed/observed so far.

Main references: (Southwood et al., 2008); (Wang et al., 2007); (Wang et al., 2010).

Remarks: More research is needed to see the impact of lights on sharks and rays.

4 – Reduced soak time

+	-
Shorter soak times would likely increase the survivorship. May reduce shark depredation on target species.	May encourage an increase of the fishing effort (total length of gillnet deployed) and the number of interactions with bycatch species. Negative impacts on fisher safety if it reduces the resting time for the crew.

Principal references: (Frick et al., 2012); (Patterson and Tudman, 2009).

Remarks: More research is needed to assess the efficiency of this MM. However this MM is certainly difficult to monitor without an observer program. Optimal soaking time should certainly be related to the fishery on concern.

Sub-task 6.2 - Best practices to reduce post-release mortality

By-catch is a well-know issue for all the stake-holders working in the wide fishery domain from fishermen, to fleet owners, fishing industry, eNGOs (environmental Non-Governmental Organizations), tRFMOs, structures involved in eco-labelling certification, managers and fishery scientists.

This issue is particularly important for tuna fisheries interacting with many emblematic and charismatic species of the pelagic realm: marine mammals, sea turtles, whale sharks and seabirds. In particular, for tuna fisheries the first by-catch issue arised in 1960s when the public was informed of the dramatic mortality of dolphins caught by tropical purse seiners in the Eastern Tropical Pacific and promoted "dolphin safe" product. This event introduced profound changes for the fishing industry and highlighted the new role played by the public in the governance of the fishing management. For the public, the main threat impacting those populations is more than the mortality due to the interaction, namely the fate of animals discarded. It is why the "best practices" aiming to decrease the mortality risk of accidentally bycaught individuals while discarding became an essential step of a fishing operation. Of course, species of concern by these best practices are primarily rare, threatened and endangered species which are playing a disproportionate role for the ecosystem functioning. By increasing the survival of discards, the "best practices" contribute to the reduction of both high sensitive wastes and negative reactions of the public and eNGOs.

Moreover, the success of the application of "best practices" requires cooperative and collaborative actions between fishermen and fishery engineers and scientist undertaken to design these best practices (Carruthers and Neis, 2011). Experiences, skills and knowledge of fishermen allows scientist to bind protocols and propose technical solutions before the organisation of trainings. So far, several best release practices (BRP) for sharks and rays were published for both tuna purse seine and longline fisheries (Poisson et al., 2014b; Poisson et al., 2016). As far as we know no similar works have been carried out for gillnet fisheries.

Best practices for tuna purse seine fisheries

Some best release practices of elasmobranchs from a purse seine deck have been developed by scientists collaborating with fishers. These protocols range from safe and adequate manual handling of small sharks to the use of simple and cheap equipment such as stretcher beds or cargo nets to lift and rapidly and safely release heavy large individuals. Some RFMOs have specific measures prohibiting the use of practices such as the use of hooks or gaffes to lift sharks and rays and recommend having onboard specific release equipment.

These techniques are being now applied on a regular basis by much of the European purse seine fleet and fishers think they are useful (Murua et al., 2014; Lopez et al., 2017b). Other equipment like hoppers on deck can be helpful to detect by-catch and release it before it reaches the lower deck. Some modern boats also have double conveyor belts on the lower deck to facilitate by-catch release. However, it is noted that most sharks arriving after the first brail tend to be dead as they are crushed in the sac or being obligate ram ventilators suffocate due to lack of movement. So, even when best release practices are fully applied, only around 15-20% of sharks brought onboard are believed to survive based on electronic tagging data from released individuals (Poisson et al., 2014a; Hutchinson et al., 2015; Eddy et al., 2016), which emphasises the need of elasmobranch technological mitigation measures before the sacking of the fish in the net. An alternative, yet to be tested) is the use of vacuum pumps instead of a brailer (as done in other pelagic fisheries) to bring onboard the catch alive just before sacking up; which will increase post-release survival of sharks (Hall and Roman, 2013). These pumps are already used to move large quantities of farmed salmon between pens in Norway and survival of transferred fish is 100 % (Espmark et al., 2016). Trials would require a new purse seiner is fitted with a vacuum pump and suction hose, or alternatively the pump equipment can be taken in a self-fitted container which could be carried and operated from the boat.

Some experiments have been carried out onboard purse seine vessels to assess the post release mortality of sharks. During three fishing cruises of purse seiner in the Indian Ocean 31 silky sharks (*Carcharhinus falciformis*) considered alive were tagged with satellite tags to investigate their post-release mortality (Poisson et al., 2014a). The majority of individuals (95%) were brought on board using the brailer. Combining the proportion of sharks that were dead (72%) and the mortality rate of those released (48%), the overall mortality rate of brailed individuals was 85%. Few individuals (5%) were not brailed as they were entangled and landed during the hauling process. The survival rate of these meshed individuals reached 82%. However the combination of these two categories led to an overall survival rate of 19%. This value reflects the harsh conditions encountered by sharks during the purse seine fishing process.

During a chartered cruise on board a tuna purse seine vessel conducting typical fishing operations the post-release survival and rates of interaction with fishing gear of incidentally captured silky sharks were investigated using a combination of satellite linked pop-up tags and blood chemistry analysis (Hutchinson et al., 2015). To identify trends in survival probability and the point in the fishing interaction when sharks sustain the injuries that lead to mortality, sharks were sampled during every stage of the fishing procedure. The total survival rate of silky sharks captured in purse seine gear was found to be less than 16%. Survival rapidly declines once the silky sharks had been confined in the sack portion of the net just prior to loading.

The results of these two trials clearly shows that future efforts to reduce the impact of purse seine fishing on silky shark populations should be focused on avoidance or releasing sharks while they are still free swimming.

Skippers and crew on European purse seiners are engaged to find effective practical solution to reduce the post-release mortality of sharks and rays. Best handling and release practices are being now applied on a regular basis by much of the European. Nowadays, EU captains are reporting detailed information on templates developed by fishing companies regarding good practices used for discarding sharks including the whale shark and rays.

Best practices for longliners

The awareness of best practices of fishers on board longliners is difference to that fishers on purse seiners. One major reason is that, for a long time, and still now, sharks on longliners were finned and kept on board with the carcass detached of fins or discarded. The ban of finning has considerably reduced the interest to keep sharks aboard. Few initiatives have been set up by the fishing companies to collect data on the best release practices on sharks and rays. In general, when sharks have not any commercial values, individuals are not loaded on board. The branchline is cut as close the hook as possible and the fish is released with the hook and sometimes with a piece of nylon. The operation of cutting the branchline may present some danger for the crew for weighted branchlines and fishermen prefer to cut the line without exerting too much tension on the line. The development of a tool allowing cutting the branchline near the hook would certainly permit to release shark individuals with a better survival probability while avoiding danger to the crew.

Longline fisheries have a large shark by-catch as much as a quarter of the total catch depending on both fishing grounds and the fishing strategy (Gilman et al., 2007). Moreover mortalities (at-vessel mortality and post-release mortality) of caught sharks are highly variable depending on size and vary between species (Gilman et al., 2008; Ellis et al., 2017). The time spent hooked is an important factor to consider as soak time can be potentially long.

Some studies investigated at vessel mortality in pelagic longlining for some species (Table 9.4.2) as well as post-release mortality (Table 9.4.3). Both sources of mortality vary with a range of biological attributes (species, size, sex and mode of gill ventilation) as well as the range of factors associated with capture (e.g. gear type, soak time, catch mass and composition, handling practices and the degree of exposure to air and any associated change in ambient temperature). In general, demersal species with buccal-pump ventilation have a higher survival than obligate ram ventilators. Several studies have indicated that females may have a higher survival than males. Certain taxa (including hammerhead sharks *Sphyrna spp*. and thresher sharks *Alopias spp.*) are particularly prone to higher rates of mortality when caught.

As current regulations in tuna-RFMOs mandate the release of some shark species, the post- release condition and mortality rates still unknown for a major part of those species and must be urgently investigated.

Table 9.4.2. Summary of studies examining at-vessel mortality (AVM) for pelagic longline fisheries. Data in parentheses corresponds to the number of individuals observed.

Shark species	AVM	Targeted species	Reference
Prionace glauca	4.5% (513)	Swordfish/ Albacore	(Megalofonou et al., 2005)
	0% (21)	Tuna	(Boggs, 1992)
	13.5% (7838)	Tuna	(Francis et al., 2001)
	12.2% (434)	Swordfish	(Francis et al., 2001)
	51.1% (92)	Swordfish	(Poisson et al., 2010)
	14.3% (30168)	Swordfish	(Coelho et al., 2012a)
Isurus oxyrinchus	16.1% (31)	Swordfish/ Albacore	(Megalofonou et al., 2005)
	28.4 % (299)	Tuna	(Francis et al., 2001)
	35% (80)	Swordfish	(Beerkircher et al., 2002)
	35.6% (1414)	Swordfish	(Coelho et al., 2012a)
Isurus paucus	30.7% (168)	Swordfish	(Coelho et al., 2012a)
Lamna nasus	39.2 % (2370)	Tuna	(Francis et al., 2001)
Alopias vulpinus	6.3% (16)	Swordfish/ Albacore	(Megalofonou et al., 2005)
Alopias superciliosus	0 (1)	Swordfish/ Albacore	(Megalofonou et al., 2005)
	53.7% (82)	Swordfish	(Beerkircher et al., 2002)
	50.6% (1061)	Swordfish	(Coelho et al., 2012a)
Alopias spp.	40% (6)	Tuna	(Boggs, 1992)
Carcharhinus plumbeus	0 (2)	Swordfish/ Albacore	(Megalofonou et al., 2005)
	26.8% (112)	Swordfish	(Beerkircher et al., 2002)
	36% (8583)	Shark	(Morgan and Burgess, 2007)
Carcharhinus longimanus	15% (26)	Tuna	(Boggs, 1992)
	27.5 % (131)	Swordfish	(Beerkircher et al., 2002)
	58.9% (17)	Swordfish	(Poisson et al., 2010)
	34.3% (281)	Swordfish	(Coelho et al., 2012a)
Carcharhinus falciformis	66.3% (1446)	Swordfish	(Beerkircher et al., 2002)
	55.8% (310)	Swordfish	(Coelho et al., 2012a)
Carcharhinus limbatus	88% (1982)	Shark	(Morgan and Burgess, 2007)
Carcharhinus obscurus	48.7% (679)	Swordfish	(Beerkircher et al., 2002)
	81% (662)	Shark	(Morgan and Burgess, 2007)
Carcharhinus signatus	80.8% (572)	Swordfish	(Beerkircher et al., 2002)
Galeocerdo cuvier	8.5% (2466)	Shark	(Morgan and Burgess, 2007)
	2.9% (36)	Swordfish	(Coelho et al., 2012a)

Sphyrna lewini	61% (199)	Swordfish	(Beerkircher et al., 2002)
	91.4% (455)	Shark	(Morgan and Burgess, 2007)
	57.1% (21)	Swordfish	(Coelho et al., 2012a)
Sphyrna mokarran	93.8% (178)	Shark	(Morgan and Burgess, 2007)
Sphyrna zygaena	71% (372)	Swordfish	(Coelho et al., 2012a)
Pteroplatytrygon violacea	12% (8)	Tuna	(Boggs, 1992)
	1%	Swordfish	(Coelho et al., 2012a)
Mantas and devil rays	1.4% (145)	Swordfish	(Coelho et al., 2012a)
Myliobatidae	0% (19)	Swordfish	(Coelho et al., 2012a)

Table 9.4.3. Summary of studies examining post-release mortality (PRM) for pelagic longline fisheries. Data in parentheses corresponds to the number of individuals observed.

Shark species	PRM	Targeted species	Reference
Prionace glauca	Healthy - 0% (10) Injured – 33% (27)	Swordfish & Tunas	(Campana et al., 2016)
Lamna nasus	Healthy – 10% (29) Injured – 75% (4)	Swordfish & Tunas	(Campana et al., 2016)
Isurus oxyrinchus	Healthy - 30% (23) Injured – 33% (3)	Swordfish & Tunas	(Campana et al., 2016)
Carcharhinus obscurus	Healthy – 11.1% (18) Injured – 66.6% (3)	Sharks	(Marshall et al., 2015)
Carcharhinus plumbeus	Healthy – 20% (10)	Sharks	(Marshall et al., 2015)

Best practices for gillneters

As mentioned previously for the pelagic longline fisheries the awareness of best practices of fishers on board gillneters is not similar compared to fishers on purse seiners. Compared to purse seine and pelagic longline fisheries, best practices for gillnet fisheries have not been developed or implemented yet. Likewise, information on both at-vessel and post-release mortalities for this gear are also very limited, although it is considered that mortality of elasmobranchs for gillnets should be high. For example, even with short soak times of about one hour, high at-vessel mortality rates have been registered for *Carcharhinus limbatus* (58%) and *Sphyrna* *tiburo* (62%) (Hueter et al., 2006). Whilst elasmobranchs can survive after release some of them may retain fishing material around parts of their body and it is uncertain how this might affect individuals.

On the contrary to purse seine and longline fisheries, in the case of gillnet fisheries there have been very few joint studies between fishery scientists and the industry to gauge which measures would be more effective to mitigate bycatch and fishing mortality of elasmobranch (Ellis et al., 2017).

Summary of best practices

A list of best practices for the safe release of sharks and rays in pelagic purse seine and longline fisheries is presented in table 9.4.4 A. The implementation by tRFMOs of those best practices and/or guidelines for handling and safe release of sharks and rays is presented in the table 9.4.5. A list of references of published guidelines for handling and safe release of sharks and rays for purse seine and pelagic longline fisheries is presented in the table 9.4.6.

Table 9.4.4. Best handling practices for the safe release of Sharks, Mantas and Mobulids (adapted from Clarke, 2018). (Note: *The different handling practices listed below must be set up while ensuring the safety of the crew at all times*).

Gear	Species of interest	Good handling practices	Poor handling practices
Purse seine	Mantas, mobulids, whale shark	Release large individuals while they are free-swimming as soon as possible (e.g. back down procedure, submerging cork).	For purse seiner and longline: For all individuals large, medium or small: Leave an individual on the deck too long; punch holes through the body or wings or fins; gaff, carry, lift or pull a ray by its cephalic lobes; for sharks and rays pull or lift by tail orby inserting hook or hands into the gill slits; cut the tail.
	Large rays and sharks (> 30 kg)	To brail the individuals out of the net and to release by using large-mesh net or canvas sling.	
	Small rays and sharks	Be handled by 2 or 3 crew members and carried by the sides of its wings or with the arms under the body. Or better using a dedicated cradle/stretcher.	
Longline	Large rays and sharks (> 30 kg)	Keep the animal into the water and use a dehooker to remove the hook or a long-handeled line cutter to cut the leader as close to the hook as possible.	For longline: Hit or slam a shark or ray against any surface to remove the animal from the line.
	Small rays and sharks	Bring cautiously on board and remove the hook if possible. If the hook is embedded either cut the hook with a bolt cutter or cut the leader and gently release the animal at sea.	

Table 9.4.5. Implementation by tRFMOs of best practices and/or guidelines for handling and safe release of sharks and rays.

tRFMO	Year	Reference Document and Comments	Species
WCPFC	2018	Clarke S., 2018 - Safe Release Guidelines for Sharks and Rays. WCPFC-SC14-2018/EB-IP-03. Application for sharks and rays	All Sharks and Rays
WCPFC	2015	*Commission decision at WCPFC 13 "Guidelines for the safe release of encircled whale sharks" (based on the guidelines document published in 2012).* *Amended effective 9 December 2016 as a result of the SC12 recommendation to amend title to refer to Whale Shark only.*	Whale shark
WCPFC	2012	Guidelines for the Safe Release of Encircled Animals, including Whale Sharks WCPFC-SC8-2012/EB-WP-19	All sharks, rays and marine mammals
IOTC	2013	Resolution 13/05 "On the Conservation of Whale Sharks" Para 6 - The Commission requests that the IOTC Scientific Committee develop best practice guidelines for the safe release and handling of encircled whale sharks, taking into account those developed in other regional fisheries management organisations including the Western and Central Pacific Fisheries Commission, and that these guidelines be submitted to the 2014 Commission meeting for endorsement.	Whale Shark
IOTC	2014	IOTC–2014–S18–R Best practice guidelines for the safe release and handling of encircled whale sharks SC16.31 (para. 67) The SC RECOMMENDED the following Guidelines for the safe release and handling of encircled whale sharks, that should be added as an additional page in the IOTC shark identification guides. NOT YET PUBLISHED IN THE ID CARDS	Whale shark
IATTC	2014	SAC-05-03c – Proposals for the safe release of bycatches of sea turtles and manta rays. The IATTC currently does not provide any guidance to fishermen for safely releasing large rays caught in purse-seine sets, which can be very difficult due to their large size and vulnerability to injury	Manta Rays

Table 9.4.6. List of references of guideline for handling and safe relase of sharks and rays (modified from BMIS website: https://www.bmis-bycatch.org).

Year	Reference	Gear
2012	UNEP-MAP-RAC/SPA, 2012. Guidelines for shark and ray recreational fishing in the Mediterranean. By S. Fowler and E. Partridge. iv + 36 pages. http://www.rac-spa.org/sites/default/files/doc_fish/gl_shark_ray_en.pdf	Rec.
2012	Anon. (2012) Methods for longline fishers to safely handle and release unwanted sharks and rays. *https://sites.google.com/site/seafoodcompaniestunamanagement/home/WCPO_Tuna_Alignment_Group/training-materials-for-longline-fishers*	LL
2012	Poisson F, Vernet AL, Seret B, Dagorn L (2012) Good practices to reduce the mortality of sharks and rays caught incidentally by the tropical tuna purse seiners. EU FP7 project #210496 MADE, Montpellier, France. *http://ebfmtuna-2012.sciencesconf.org/conference/ebfmtuna-2012/pages/D6.2_Practices_to_reduce_shark_mortality_purse_seiners.pdf*	PS
2012	ISSF (2012) Best bycatch release practices in tuna purse seiners / Cara melepas bycatch pada pukat cincin / Buenas prácticas de liberación de especies accesorias en cubierta. *https://www.bmis-bycatch.org/Best-Bycatch-Release-Practices-in-Tuna-Purse-Seiners.pdf*	PS
2016	Poisson F, Wendling B, Cornella D, Segorb C (2016) Guide de bonnes pratiques pour réduire la mortalité des espèces sensibles capturées accidentellement par les palangriers pélagiques français en Méditerranée. Projets SELPAL et RéPAST, Montpellier, France.	LL
2016	AFMA (2016) Bycatch Handling - AFMA Bycatch handling and treatment Guide 2016/17. Australian Fisheries Management Authority. *http://www.afma.gov.au/wp-content/uploads/2017/03/AFMA-Bycatch-Handling-and-Treatment-Guide_-2016-17_Public-Doc_FINAL.pdf*	LL
2016	Shark and Ray Handling Practices - A guide for commercial fishers in southern Australia. *http://www.afma.gov.au/wp-content/uploads/2014/11/Shark-Handling-Guide-2016-Update.pdf*	LL
2017	NOAA Fisheries (2017) Careful Catch and Release - Atlantic Highly Migratory Species. *https://www.fisheries.noaa.gov/resource/outreach-and-education/careful-catch-and-release-brochure*	LL

10. TASK 7 – DEVELOP A CONCEPTUAL FRAMEWORK FOR MANAGEMENT PLANS

10.1. *Key findings and recommendations*

- Globally, frameworks for the conservation and management of sharks are mostly underpinned by the FAO's International Plan of Action for Sharks (IPOA-Sharks), Examples from Canada and New Zealand offer useful insights for the development of EU management plans including:
    - Plans should be developed by individual EU MSs but harmonised amongst MS that cover the same stocks, and should not be limited to fisheries that target sharks but also those that retain or discard shark by-catch;
    - The conceptual objective should refer to biological, economic and social sustainability;
    - Management plans must fit within the legal framework of any relevant RFMOs and be consistent with Article 10 of the CFP and the objectives of the EUPOA.
- Recommendations for the proposed minimum requirements of management plans details on the species and ecosystem; overview of the fishery; management objectives; conservation reference points; catch and discard limits; by-catch mitigation; indicators; time frame; and, monitoring and evaluation in order to provide feedback and adapt the plans.

10.2. *Objectives*

This task developed and proposed a conceptual framework for elaborating and implementing management plans for sharks (in line with Article 10 of the CFP), including development of a list of minimum requirements and guidelines for evaluating such plans. The work initiated by the EU in Western Central Pacific Fisheries Commission was used as a starting point.

10.3. *Methodology*

This task consists of two sub-tasks that were undertaken as desk-based work, based primarily on information provided in online sources (e.g., WCPFC[24], Fisheries and Oceans Canada[25]). Consultations (e-mail and telephone interviews) were held with fishery managers and relevant experts where necessary to gather additional information on management plans/frameworks.

Sub-task 7.1 - Develop and propose a conceptual framework for elaborating and implementing management plans for sharks, including a list of minimum requirements

This sub-task constructed a conceptual framework for shark and ray management plans that could be considered for implementation at the EU level. This also includes a list of minimum requirements that such plans should include. The content of the conceptual framework is guided by Article 10 of the CFP, in particular paying attention to the scope of the plans, objectives to be met for individual species and/or fishing fleets, quantifiable targets and time frames. Specific design elements related to conservation and technical measures, where required, were informed by the outputs of Tasks 2, 5 and 6.

The development of the conceptual framework recognises and acknowledges management plans/frameworks that have been applied to protect shark and rays in other parts of the world (e.g. USA, Australia, South Africa). A concise description of key details of these plans/frameworks is provided.

There was a need to consider, under this task, how conceptual frameworks can be applied. For example, to determine whether frameworks are designed for individual shark/ray species or for fleets catching sharks; for separate oceans of for global stocks or fisheries; and so on. Furthermore, it is necessary to distinguish between fisheries targeting sharks and those catching them incidentally. These considerations were explored.

Sub-task 7.2 - Guidelines for evaluating management plans

---

[24] https://www.wcpfc.int/node/27830

[25] http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/index-eng.htm

The conceptual framework also recommends on general procedures for the evaluation and possible adaptation of management plans, for instance when taking into account changes in knowledge and scientific advice. These guidelines draw upon elements of the evaluation approaches used by the European Commission advisory bodies, e.g. STECF-ICES.

10.4. *Results and discussion*

Sub-task 7.1 - Review of the WCPFC shark management plan proposal

Overview

The Western and Central Pacific Fisheries Commission (WCPFC) requires longline fisheries that target sharks to develop a management plan (CMM 2014-05). In order to implement this CMM effectively, the WCPFC requested a study to propose i) a range of possible definitions for longline fisheries targeting sharks, ii) a list of candidate solutions to be considered for the development of shark management plans; and iii) a list of elements to be considered for the evaluation of these shark management plans. This study was presented at the 12th Regular Session of the Technical and Compliance Committee, September 2016, in WCPFC-TCC12-2016-19[1] (hereafter referred to as the 'WCPFC document').

A review of the WCPFC document is presented in the following sub-sections, focusing on the proposed minimum requirements for the development of management plans and elements to be considered for their evaluation. Throughout the review, Article 10 of the CFP is used as a reference point for assessing the appropriateness of the proposed management plan elements and for identifying knowledge gaps or weaknesses.

General comments

The WCFPC document provides guidelines on what components should be included *as a minimum* in the shark management plans. The document is an extended development of a list of management plan components provided in Annex G of the document (also reproduced in the covering note), explaining how shark management plans should be developed.

General comments on the WCPFC document are:

---

[1] https://www.wcpfc.int/node/27830

- Except for the case of finning, the guidelines for developing management plans are quite general, and could be applied to any species/stock fishery;
- There are no explicit guidelines on developing objectives for management plans;
- The plan does not require targets or a timeframe for when these should be reached;
- Sustainable exploitation rates appear to be too general, too conceptual and not operational;
- There is no requirement or discussion on numerical objectives or thresholds; and
- The template for the shark management plan (Annex E) seems to mainly look backwards and refers to catch limits based on the historical catches (past 5 years).

Comment on specific management plan components

The following shortcomings are highlighted when the WCPFC shark management plan guidelines are compared against Article 10 of the CFP:

Scope

The WCPFC document includes a relatively extensive proposal for the definition of a target fishery for sharks; however, none of them are used in the final recommendation. Rather, the recommendation given is that all fleets catching sharks should develop a management plan, which is sensible and is in line with general biological, social and economic sustainability objectives. If only target fisheries are considered, this does not provide a clear picture of the overall mortality of sharks, and so bycatch and discards of sharks and rays must also be considered.

Considering the text that is provided in Section 2 of the WCPFC document, the following comments are made:

- Another way of defining target fisheries is using the model of Pelletier and Ferraris (2000), which uses catch and effort for defining fishing strategies;
- With respect to catch based definition of target shark fisheries, the Forum Fisheries Agency (FFA) suggests a shark catch threshold of 25% of total landed catch per trip, but they do not explain what this percentage is based on; it is noted here that catch data should be analysed before setting a threshold; and

- With respect to catches and revenue, this should be analysed at trip level in order to cover potential seasonal fluctuations.

Objective

Conceptual objectives only refer to biological sustainability but not economic and social sustainability, which are identified in Article 2 of the CFP. For these additional objectives to be considered, the social component (i.e., artisanal or coastal communities' dependencies) of the fleets affected by the plan should also be described. Further, separate management for coastal fleets highly dependent on these species may be worthy of consideration.

Quantifiable targets

Targets are not presented or discussed in quantitative terms. Furthermore, two issues are missing to allow for any quantitative assessment:

- Whether a biological component (e.g. population) is defined, and whether this biological component should or should not be used as a management component; and
- Estimates for exploitation rate (i.e., fishing mortality; F) of the biological component.

Regarding the latter point, it is impossible to assess if the catches are high/low with reference to any sustainability objective without comparing it to the total population. If quantitative assessments are not provided, the management should provide recommendations on how to deal with this issue (e.g. data poor approaches).

Timeframes

The management component of the WCPFC document proposes dates over which the management plans should apply. This is not enough. The management plans should be developed to reach all stated objectives, and hence the time required to reach these objectives must be included. Furthermore, these timeframes should be consistent with current or future management measures to reduce fishing capacity, if they exist.

Conservation reference points

Conservation reference points should be a requirement of shark management plans, yet they do not appear in the document. A candidate conservation reference point is a probability that biomass do not fall below a certain pre-defined level (e.g. B limit). This would require a quantitative evaluation of the abundance and an uncertainty assessment around these estimates, for instance using Management Strategy Evaluation (MSE).

Objectives for conservation and technical measures

Conservation and technical measures are described in the mitigation component of the WCPFC document and they appear to be fit for purpose. However, further identification and explanation of other likely candidate measures would be interesting, if not fully required. To fully assess these measures, an overview of the discard mortality rate would also be interesting to evaluate the direct impact and ecosystem consequences of shark discarding. This may also help to design catch reduction strategies in a way in that would minimize the likely impacts of management measures on financial performance of the affected fleets.

Safeguards and remedial action

These are not mentioned in the WCPFC document, probably due to the lack of quantitative targets and management reference points.

Discards

The activity of discarding is sufficiently covered in the management plan guidelines, except with respect to the mortality rate of discarded animals. This information should help in defining more appropriate management strategies, including exceptions to the landing obligation for EU fleets.

Ecosystem

Ecosystem interactions and the consequences of shark exploitation are not considered in the WCPFC document, but are likely to be relevant. Ideally, shark management plans should describe the ecosystem services provided by sharks on the trophic chain and, in contrast, what the ecosystems impacts of overharvesting might be. Also, with respect to catch hotspots, fishing fleets could potentially provide information on this in the management plan and describe how these hotspots will be avoided.

Monitoring indicators

The WCPFC document provides a list of criteria for evaluation of management plans, but not how to monitor the implementation of plans. Furthermore, whilst the guidelines are understood (according to the two plans presented in the annexes) as when and how often monitoring should be undertaken, but not necessarily how. Monitoring and evaluation of shark management plans will require contrasting them against the stated objectives, and, if not known, to compare data on shark catches (or populations) from before the implementation of a management plan against data obtained after its application.

Sub-task 7.2 – Conceptual framework for developing and evaluating EU management plans for sharks

Global examples

Globally, the conservation and management of sharks by most governments and organisations is underpinned by the FAO's International Plan of Action for Sharks (IPOA-Sharks), and the series of national, regional and sub-regional plans that stem from that. Several nations have developed and implemented management plans for sharks, although the scope, extent and quality of these varies considerably. In the following sub-headings, the approach to development of management plans for sharks (and other species/groups) of Canada and New Zealand is described. These examples, which offer useful insight for the development of EU management plans, have been selected from a list of compiled shark management plans based on their merits.

Canada: Integrated Fisheries Management Plans

Integrated Fisheries Management Plans (IFMPs) are also developed for specific fisheries to identify goals and measures for conservation, management and science, of which eight apply to sharks. IFMPs are developed by the Department of Fisheries and Oceans Canada (DFO) to identify goals and measures relating to conservation, management and science for a particular fishery. IFMPs are specific to each fishery, and therefore different species of sharks fall under different IFMPs, according to gear and associated fish species. The following current (or recently expired) IFMPs are applicable to sharks[26], most of which focus on the control of bycatch mortality:

- Canadian Atlantic Pelagic Shark Integrated Fisheries Management Plan
- Integrated Fisheries Management Plan Atlantic Mackerel
- Integrated Fisheries Management Plan Atlantic Bluefin Tuna
- Canadian Atlantic Swordfish and Other Tunas Integrated Fisheries Management Plan
- Dogfish Management Plan For Maritimes Region
- Groundfish Management Plan Scotia-Fundy Fisheries Maritimes Region
- Integrated Groundfish Management Plan for the Gulf of St-Lawrence
- Pacific Region Integrated Fisheries Management Plan Groundfish

The DFO has specified a standard format for all IFMPs, and detailed guidelines for preparing IFMPs are provided online[27].The key elements of each IFMP include:

- Overview of the fishery – including it's history, location and characteristics;
- Stock assessment, science and traditional knowledge - covering the general biological characteristics of those species targeted by the fishery, their role in the ecosystem and the population status;
- Economic, social and cultural considerations – detailing any relevant economic conditions and social, cultural and economic issues;
- Management issues – providing an overview of key management issues and problems facing the fishery, including those related to the target species, as well as by-catch and ecosystem concerns;
- Objectives – including both long-term objectives, which may address issues related to stock conservation, ecosystems, stewardship, culture, compliance and other relevant considerations, supported by one or more short-term objectives, which are specific for the duration of the plan;
- Access and allocation – to avoid uncertainty in access and allocations, and promote a sense of stability and transparency;

[26] A full list of all current and active IFMPs, with links to the full text, is available online: http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/index-eng.htm

[27] http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/ifmp-gmp/guidance-guide/template-app-a-ann-modele-eng.htm

- Management measures - outlining the controls or rules adopted for the fishery for the period of the plan, including the stock conservation and ecosystem management measures;
- Shared stewardship arrangements – including discussion of any co-management and other initiatives (e.g. IOM activities and MPA network planning through the Oceans Program) that support Section 5 Objectives, including increased shared-decision making, and foster a sense of shared stewardship amongst stakeholders;
- Compliance plan – providing a general overview of the compliance program and a summary of issues and strategies designed to help secure good levels of compliance with legislation, regulations and management measures; and
- Performance review - outlining measurable indicators to determine whether or not IFMP objectives are being achieved and known management issues are being addressed.

In addition, every IFMP must include details on (amongst other points):

- The connection of the plan with overarching departmental activities, e.g. Canada's Sustainable Fisheries Framework; this is analogous with the need for EU multiannual plans to be consistent with Article 2 of the CFP;
- The duration of the plan, which may either be 'evergreen' (i.e. multi-year plans) or annual plans, and when information contained within the plan should be updated;
- The approval process, which should be delegated down to the lowest possible management level, and the roles and responsibilities of those involved in plan development and approval; and
- The annual review, which should consider the development of the plan, its implementation and its effectiveness, and include recommendations for improvement.

New Zealand: National Fisheries Plans

New Zealand has developed a cascade approach to shark management. A National Plan of Action for the Conservation and Management of Sharks serves as an overarching management framework. The NPOA guides the development of goals and objectives for sharks in multi-annual National Fisheries Plans, which currently exist for deep-water species, highly migratory species, inshore finfish, inshore shellfish and freshwater fisheries. These plans, which are aimed at species or groups of species rather than being focused on a single fishery, are structured into three parts.

Part 1 establishes a five year enabling framework for the management of the fishery, and is further divided into two parts; Part 1A and Part 1B:

- Part 1A details the overall strategic direction for the applicable fisheries, specifically:
    - The wider strategic context, including legislative and policy context within which the plan operates;
    - The management approach & governance tactics, setting out the management objectives (which include use and environment objectives) for the stocks, performance indicators, key default service strategies and governance tactics; and
    - The implementation of the plan, describing the planning and service delivery processes the plan drives, and setting out how the Ministry of Fisheries will engage with stakeholders.
- Part 1B comprises the fishery-specific chapters of the National Fisheries Plan, which provide greater detail on how fisheries will be managed at the fishery level, in line with the management objectives. These chapters also describe any harvest strategies that have been agreed for the relevant species.

Part 2 of the National Fisheries Plan consists of an Annual Operational Plan, which provides the management actions scheduled for delivery during the financial year, and the management services needed for delivery of those management actions. In each Annual Operational Plan the key focus areas for that given year are identified, along with business as usual tasks that are continual or repeated over the full five year period of the overarching National Fisheries Plan. The services required for achieving the tasks are also outlined, including services required of Government and stakeholders.

Part 3 of the National Fisheries Plan is the Annual Review Report, which assesses the progress towards meeting the Operational Objectives, Management Objectives and five year priorities described in Part 1 through reviewing delivery of the Annual Operational Plan.

Conceptual framework for EU management plans

The development of management plans for sharks should consider the following general issues:

- Management plans should be developed by individual EU Member States with respect to their fisheries that catch sharks, skates, rays and chimaeras;
- Applicable fisheries are not limited to those that target sharks, but also those that retain or discard sharks as bycatch in non-negligible numbers. A threshold level of catches and/or discards may be defined by the European Commission, above which fisheries must implement shark management plans;
- Management plans should be focused on the fishery, and as such may include multiple elasmobranch species and/or stocks that persist in the fishery area. There is need for coordination and harmonisation between management plans developed by different EU Member States that cover that same species/stocks;
- The conceptual objectives of management plans should refer to biological, economic and social sustainability, i.e. consistent with Article 2 of the CFP. For these objectives to be considered, the social and economic components (i.e., artisanal or coastal communities' dependencies) of the fleets affected by the plan should be described. Furthermore, the European Commission may consider requiring separate management plans for certain coastal fleets that are highly dependent on elasmobranchs; and
- Management plans must fit within the legal framework of any relevant RFMOs and be consistent with Article 10 of the CFP and the objectives of the EUPOA.

Recommendations on minimum requirements for management plans

Proposed minimum requirements for EU management plans are:

- Species and ecosystem
  - Species and stocks/populations covered by the plan shall be listed
  - Ecosystem services provided by these species in the trophic web and likely ecosystems impacts of overharvesting shall be described
- Overview of the fishery
  - Location of the fishery, including map of boundary coordinates and a description of seasonality in fishing grounds

- Describe the fleet(s) covered by the plan, including social and economic dependencies associated with catches of elasmobranchs
    - Quantify fishing effort in the last five years
    - Quantify retained and discarded catches of sharks in last five years
- Management objectives
    - Objectives referring to biological, social and economic sustainability of the fishery (ecological and human components), which are consistent with Article 2 of the CFP
    - Objectives shall be specific to the species/stocks and fleets involved; objectives for biological sustainability shall be coherent with existing objectives set by the relevant RFMO
- Conservation reference points
    - Appropriate reference points shall be defined for each species/stock
    - These shall mirror existing reference points set by the relevant RFMO, if they are already defined
- Catch and discard limits
    - Describe catch and discard limits and provide rational (with reference to the latest stock assessments and reference points, if available)
    - Describe mechanisms for limiting the catch and/or discards of sharks (by species if applicable)
    - Describe mechanisms for the monitoring, verification and enforcement of catch and discards limits
- By-catch mitigation
    - Describe measures for non-retention and safe release of applicable sharks, including safe release guidelines
    - Identify any other technical management measures designed to reduce catch or interaction with sharks
- Indicators
    - A suite of indicators that allow monitoring and evaluation of the plan against its implementation and stated objectives (biological, social, economic) shall be defined
- Timeframe
    - A realistic timeframe for achieving management objectives shall be elaborated
- Monitoring and evaluation

- Details shall be provided for when, how often and by what means monitoring will be undertaken
- Roles and responsibilities shall be defined for each of the monitoring tasks, including details of responsibilities of the relevant RFMO where necessary
- Criteria for the evaluation of the management plan shall be described, including a description of the conceptual approach and indicators

Recommendations on evaluation and adaptation of plans

In general terms, the process for evaluation and adaptation of management plans involves:

- Defining expected management outcomes;
- Establishing management performance indicators;
- Identifying data collection methods and ensuring that statistical data for the selected stock assessment tools are available;
- Analysing the data; and
- Reporting the findings of the reviewed management plan and adapting management strategies if necessary.

Monitoring provides feedback on the fishery situation, management inputs, and the selected performance indicators to evaluate if targets are being met. Further, it allows tactical adjustments to management according to any decision control rules that have been defined in the plan. If the situation changes, for example a new RFMO CMM or a new market opportunity; if inputs (e.g. budget, staff) change or do not materialize; or if performance indicators suggest targets are not being met, then adjustments to the management plan may be necessary.

Monitoring provides the data to evaluate a plan. However, in light of the analysis of that data, a critical review looking back over the plan is required. Typically this review would occur after 3 to 5 years whilst monitoring could occur more frequently depending on the data in question. The review process should lead to a new management plan updating and changing elements of the plan.

11. TASK 8 – ORGANISE A WORKSHOP

11.1. *Key findings and recommendations*

- A workshop was held at IPMA-Olhão, Portugal between 6th and8th November 2017.
- The workshop included participants from all Institutes in the Consortium, DG-MARE and EASME.
- The revision work provided in the Project was presented and discussed, and the final case studies (Task 9) were agreed upon.

11.2. *Objectives*

The objective of this task was to organise a workshop between DG MARE, EASME and scientists of the consortium to analyse outcomes of tasks 1-7, and discuss the approaches and methodologies to address the selected case studies in task 9. During the workshop, the final decision of the selected case studies was taken based on the results of previous tasks 1-7. This workshop had the participation of all scientists from all institutes participating in the project (IPMA, AZTI, CEFAS, IEO, IMARES, IRD and MRAG).

11.3. *Methodology*

A workshop was held at IPMA – Olhão, Portugal between 6th and 8th November 2017.

11.4. *Results and discussion*

The main outcomes of the workshop was a discussion and subsequent revision of the work carried in tasks 1 to 7, and a decision on the case study species/regions to be analysed, and the planning and allocation of work to be developed under these case studies.

12. TASK 9 – CASE STUDIES

The following case studies were developed during this Project.

- Case Study 1: Silky shark - ICCAT
- Case Study 2: Silky shark - IOTC
- Case Study 3: Blue shark - IOTC
- Case Study 4: Shortfin mako - IOTC

The case studies are intended mainly for providing advancements to the Scientific Working Groups of the tuna-RFMOs; in this case particularly to the ICCAT Sharks Working Group (case study 1) and to the IOTC WPEB (case studies 2, 3 and 4).

12.1. *CASE STUDY 1 - SILKY SHARK – ICCAT*

a. Background

Current knowledge and stock status

In the Atlantic Ocean, silky shark (*Carcharhinus falciformis*) is caught mainly as a bycatch species by several tuna fleets and fishing gears (e.g. longline, artisanal gillnet, purse seine and recreational fisheries).

Silky shark has been reported to grow larger and mature at later sizes in the northwest Atlantic than in the Eastern Pacific and Western Central Pacific (Bonfil, 2008). In general, females reach maturity between 6-13 years and give birth to an average of 5-7 live young (Clarke et al., 2105). Their life-history characteristics and pattern of movement, covering both oceanic and coastal waters, makes them particularly vulnerable bycatch species in global tuna purse seine fisheries, in addition to tuna and swordfish longline fisheries as well as other coastal fleets.

Silky shark has a circumglobal distribution, inhabiting coastal and oceanic tropical waters. It has been found a high overlap between the distribution of pelagic sharks and the longline fisheries in the Atlantic Ocean (Queiroz et al., 2016). In contrast, the European tuna purse seine fishery catches significantly less sharks in the Atlantic Ocean than elsewhere. Despite the comparatively low number of silky sharks reported as bycatch in the Atlantic, the post-release mortality rates of sharks remain high, ranging from 52% to over 80% (Eddy et al., 2016). The post-release mortiality in the Indian, Eastern, Central and Western Pacific Ocean, has been reported as higher than the Atlantic ranging from 80% to over 90% (Poisson et al., 2014b; Hutchindson et al., 2015). In addition, Task I data (nominal catch) submitted to ICCAT illustrates reporting for silky shark has only recently appeared in the statistics for purse seiners, with a low reporting for other gears. However, there is an ICCAT requirement to report all catches of shark species since 2011 (Rec. 11-08). The reason for that partial submission of data is that, until recently, the observer coverage in the Atlantic was relatively low (i.e. around 10%) and, thus, the estimation was not precise due to the extrapolation process and assumptions applied. This has been improved since 2014 when the observer coverage has increased to be close to 100%.

The silky shark stock in the Atlantic Ocean is considered a separate stock to others occurring in the rest of the oceans. There is no stock assessment or any reliable fishery-dependent indicators of current stock status for silky shark in the Atlantic Ocean and no timeframe has been established by the ICCAT Working Group on Sharks (WGS) to develop a stock assessment. The International Union for Conservation of Nature (IUCN) classifies the silky shark in both the Atlantic Ocean and globally, as vulnerable (Rigby et al., 2017) and has recently been included in the Annex II[28] of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), as it is considered as one of the three most traded shark species in the global shark fin trade. Analysis of relative abundance indices based on longline research surveys and observer data from the Gulf of Mexico, suggest a 91% decline of silky shark in this region between 1950 and 1990 (Baum and Myers, 2004). Additionally, Cramer (2000) estimated a 75% decline in relative abundance of silky shark between 1992 and 1997 in the Atlantic, Caribbean and Gulf of Mexico, using catch information on mandatory reports from the longline and bottom longline vessels. Moreover, following the results of an ecological risk assessment for shark species caught in the Atlantic pelagic longline fisheries (Cortés et al., 2007), silky shark was classified as highly vulnerable to the risk of over-exploitation by the Atlantic longline fishery. This was due to the combination of low productivity of the stock and high susceptibility to the fisheries. The analysis also highlighted that little information exists on the vertical distribution and habitat preferences of the species, and associated observer data in the Atlantic is highly variable. Later in 2010, silky shark was ranked first in the vulnerability to the Atlantic pelagic longline fishery in the Ecological Risk Assessment by Cortés et al. (2010).

Silky shark is a high-level predator and their removal by fisheries can have

[28] CITES, in its Appendix I lists species that are not necessarily now threatened with extinction but that may become so unless trade is closely controlled.

significant impacts on the marine food web and the ecosystem. This may include the replacement of sharks by other high tropic level species, or if no predators fill this gap, a top-down trophic cascade may occur (Gilman et al., 2016). Ecosystem-level trophic effects of fishing on shark populations are difficult to monitor due to the lack of long-term data and an understanding of the complex ecosystem dynamics of the pelagic habitats (Grubbs et al., 2016).

Obstacles preventing quantitative scientific advice

The general poor quality and reliability of the recorded catch statistics (grossly underestimated), the lack of reliable and detailed information regarding fishing effort and mortality (with the consequent impossibility of estimating standardized catch-per-unit-effort series), and the total absence of information on the composition of the catches, are at present the key obstacles preventing the quantitative scientific advice of the silky shark stock status in the Atlantic Ocean.

b. Objectives

As there is no enough data available on silky shark to carry out a full stock assessment, this case study focused on investigating the habitat preference of the species by modelling its occurrence with a set of biotic and abiotic oceanographic factors (e.g. SST, salinity, oxygen, kinetic energy, etc.) and spatio-temporal information on the fleets' activity using one of the most complete observer data in the region (i.e. from the EU purse seine fleet). These results provide information on the spatio-temporal dynamics of the species, inform about possible hotspots occurrences and identify habitat preferences, which can be used to develop alternative conservation and management measures for the ICCAT convention area.

A second objective of this case study was to investigate the efficiency of the no-retention measure currently in place in ICCAT and discuss the impacts the implementation of the best handling and releasing practices may have on species conservation.

Thirdly, a draft of an operational management plan for silky shark in the Atlantic Ocean was prepared, which is provided in Annex I.

c. Material and Methods

Investiganting the habitat preference of the species

Fisheries data

Spanish tropical tuna purse seine observer data collected by AZTI and IEO research organizations under the European program of data acquisition 'Data Collection Regulation' (DCR) were used for the analysis. The data were spatially confined to the eastern and central tropical Atlantic Ocean (20°S–23°N and 45°W-12°E; Figure 2.3.1) and temporally limited from 2003 to 2015, which is considered the period of the best quality observer data. The information was collected by trained fishery-observers aboard 33 Spanish tropical tuna purse-seiners during 336 fishing trips. A total of 7296 fishing sets were observed, corresponding to 5253 fishing days. These data consist of set-recorded locations of target and non-target fish captures, along with other associated information on the operational characteristics of the fleet and details of the fishing operation (e.g. set time, duration of each fishing phase, net characteristics, and technology onboard). For each fishing set, the observer records the quantity in weight or number and the average weight or length estimate of the bycatch for each species. Additionally, observers collect data on the amount and the species-composition of the tuna catch. The number of silky sharks caught per set during the fishing trips was not always available because observers sometimes only recorded a total and an average length/weight of sharks caught. In such cases, data were converted into numbers using published Length-Weight relationship $W = 2.10^{3} * L^{3.23}$ (Froese and Pauly, 2008). The term bycatch will be used herein in place of 'catch' to refer to the incidental mortalities of any non-target species.

A total of 12705 silky sharks were recorded as bycatch in the 7296 fishing sets considered between 2003 and 2015. Silky shark appeared in ~30% of the total sets (Figure 2.3.2). The average numbers of silky shark per set were 1.74 and 6.38, for total sets and positive sets, respectively. The length frequency of the silky sharks ranged from 30 to 250 cm, but was dominated by the 80-140 cm individuals (Figure 2.3.3) corresponding to immature individuals (Bonfil, 2008). A very negligible part of the measured silky sharks (n=1; <0.001%) were above 240 cm (Fig 2.3.3), which is the total length for first maturation in the eastern Atlantic Ocean (Bonfil, 2008). Thus, this study considers almost exclusively juveniles and pre-adults of silky sharks.

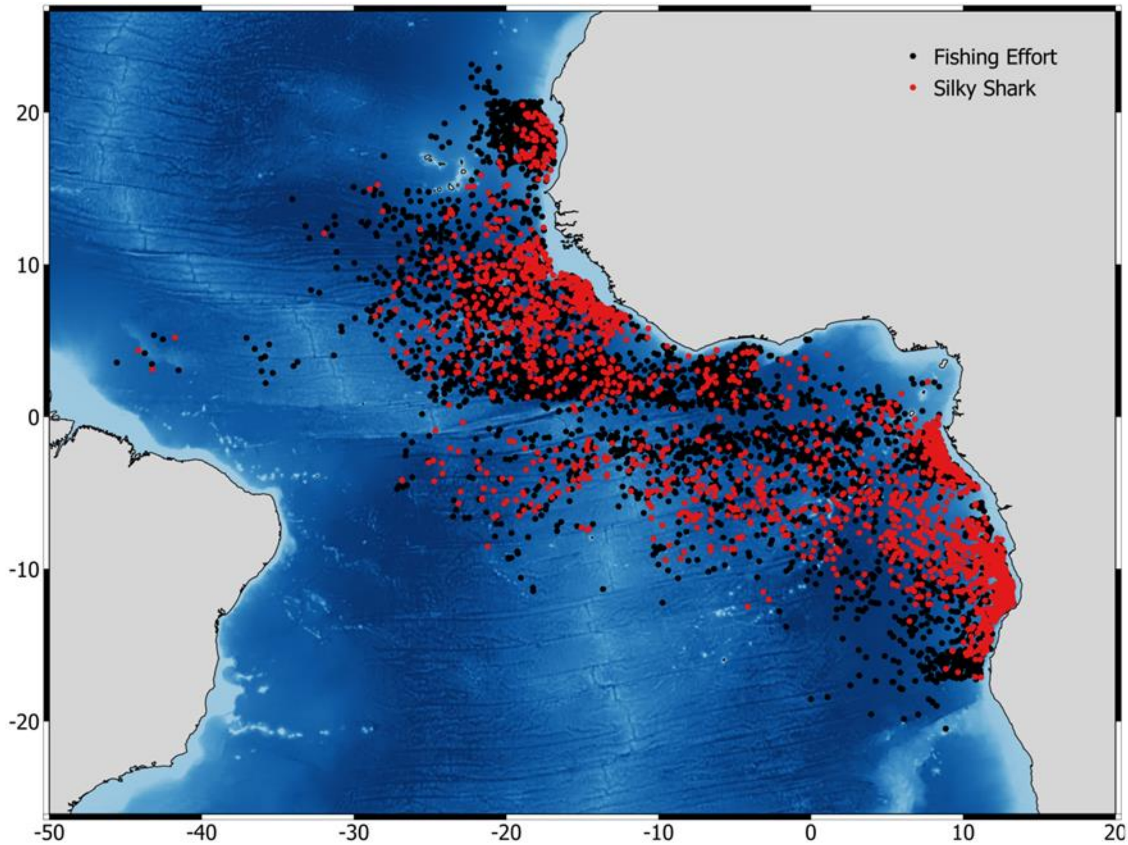


Figure 2.3.1. Spatial distribution of fishing effort (fishing sets, in black) as well as locations for sets were silky shark presence was detected (in red).

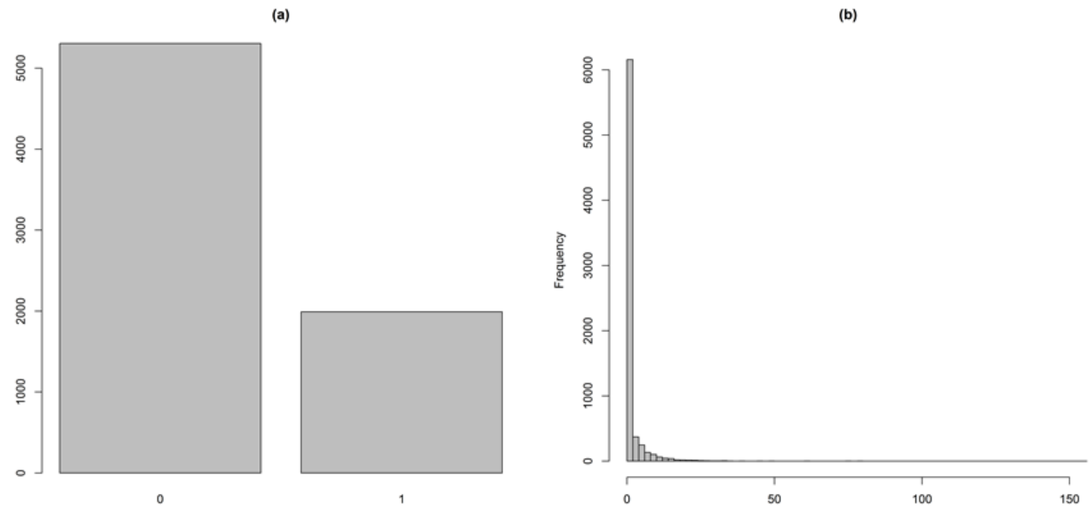


Figure 2.3.2. (a) Fishing set histogram of null and positive values of silky shark bycatch (b) Frequency histogram (in number) of silky shark bycatch.

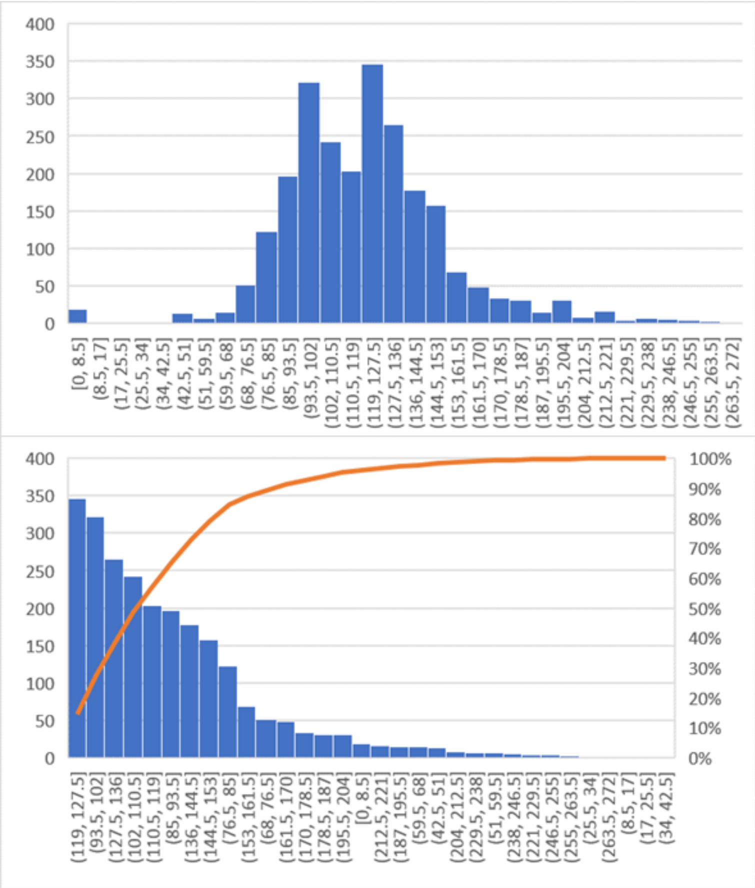


Figure 2.3.3. Histogram of size frequency (top) with size class (e.g. 0 – 8.5 cm) and accumulative histogram of size frequency (bottom) of the sharks investigated in this study.

Environmental data

Physical and biological environmental covariates were collated for each fishing set location, sourced and extracted using python routines and motu-client from the MyOcean-Copernicus EU consortium (http://marine.copernicus.eu/) and are: (i) daily sea surface temperature (SST; °C; 1/4° spatial resolution); (ii) the SST gradient derived from daily SST analysis as the increase/decrease of temperature in each pixel over an 7-day period (SST grad; °C; 1/4° spatial resolution); (iii) daily sea level anomaly (SSH; m; 1/4° spatial resolution); (iv) daily eddy kinetic energy derived from altimetry (EKE; m^2 s^{-2}; 1/4° spatial resolution); (v) daily salinity (Sal; g/kg; 1/4° spatial resolution); (vi) daily u and v vectors of current (UV; m/s; 1/4° spatial resolution); (vii) daily heading and speed of current derived from UV (Head; °; Speed; m/s; 1/4° spatial resolution); (viii) monthly chlorophyll concentration (CHL; mg m^{-3}; 1/4° spatial resolution); (ix) the CHL gradient derived from monthly CHL analysis as the increase/decrease of CHL amount in each pixel over an 31-day period (CHL grad; mg m^{-3}; 1/4° spatial resolution); and (x) monthly oxygen concentration (O_2; mg/l; 1/4° spatial resolution). To account for the potential effect of the community size (i.e. silky sharks may show traits of social behavior when juveniles (Springer, 1967; Jacoby et al., 2012), total by-catch of each fishing set, excluding sharks (TotalBC; in tons), were included in the analysis.

Certain spatial-temporal variables were also considered as potential explanatory covariates for the model, such as latitude, longitude, year, quarter, month, natural day (i.e. calendar day from 1 to 366), and time of the day when the set was conducted. Although most of these variables are not directly related to the environment, they may help identifying hidden ecological mechanisms or processes occurring at different time and spatial scales in our study.

Regime shifts identification

A first exploratory analysis of the spatial-temporal distribution of silky shark showed that species occurrences appear to be variable in time and space (Figure 2.3.4). Because natural quarters (i.e. January-March, April-June, July-September and October-December) do not necessarily represent the more ecologically meaningful scenarios, we develop a methodology to detect different environmental regimes in the Atlantic Ocean, based on statistical changes of the most common oceanography variables (i.e. SST, SST grad, CHL, CHL grad, SSH, Sal, O2). First, oceanographic variables were averaged, and the variance was extracted, for each calendar day of the study period (i.e. 2003-2015). Second, potential statistical time series change points were identified for each oceanographic variable (i.e. precandidates), using the *cpt.mean* and *cpt.var* functions of the changepoint package (Killick and Eckley, 2014). These functions calculate the optimal positioning and (potentially) number of changepoints for mean and variance data, respectively, using the user specified method ("PELT" in this case (Killick et al., 2012)). Third, precandidates that were shared by most of the oceanographic variables were kept and identified as candidates. Fourth, these candidates were confirmed or rejected as definitive change points using the function *CausalImpact* of the package CausalImpact (Brodersen et al., 2015), a function using Bayesian structural time-series model to investigate whether the origin of statistical changes is due to random effects or not.

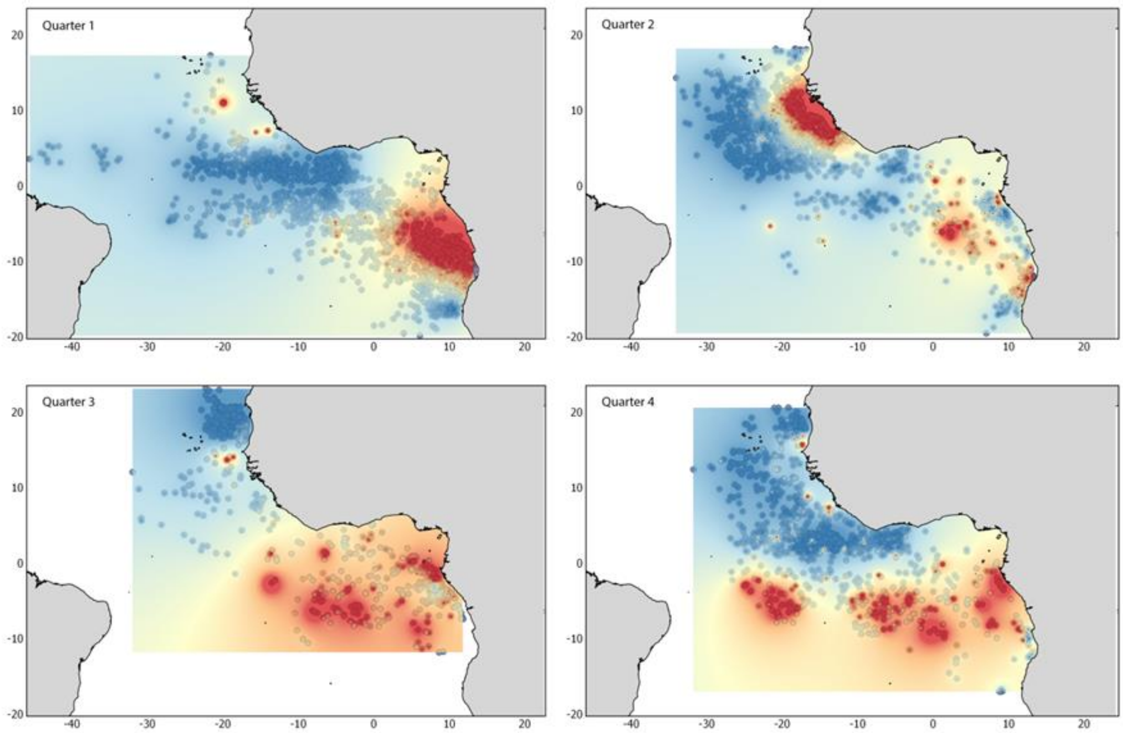


Figure 2.3.4. Heatmaps of the spatio-temporal distribution of silky sharks in the central and eastern tropical Atlantic Ocean (red). The fishing effort distribution of the fleet by quarter and the data used in the present study is also shown (blue dots).

Based on the mentioned statistical procedure, the current study identified three different environmental regimes throughout the year, separated by calendar days 155, 240, 290 (Figure 2.3.5). The annual environmental cycle seems to be primarily dominated by a stable and not very productive warm season, going from mid-October (i.e. day 290) to early June (i.e. day 155) (hereinafter referred to as stable season). From early June to the late August (i.e. day 240), however, the environmental system appears to suffer a significant change, increasing productivity and dissolved oxygen concentration while significantly decreasing SST (hereinafter the cool season). A third period starting in late August (i.e. day 240) and going until mid-October (i.e. day 290) completes the annual cycle and provides the system the opportunity to return to the predominant environmental situation, warming the sea surface and reducing the exceptional summer productivity (hereinafter the warming season). The three identified oceanographic regimes (i.e. the stable, cool and warming seasons) will provide the best spatial-temporal windows to be used in the later prediction part of the study.

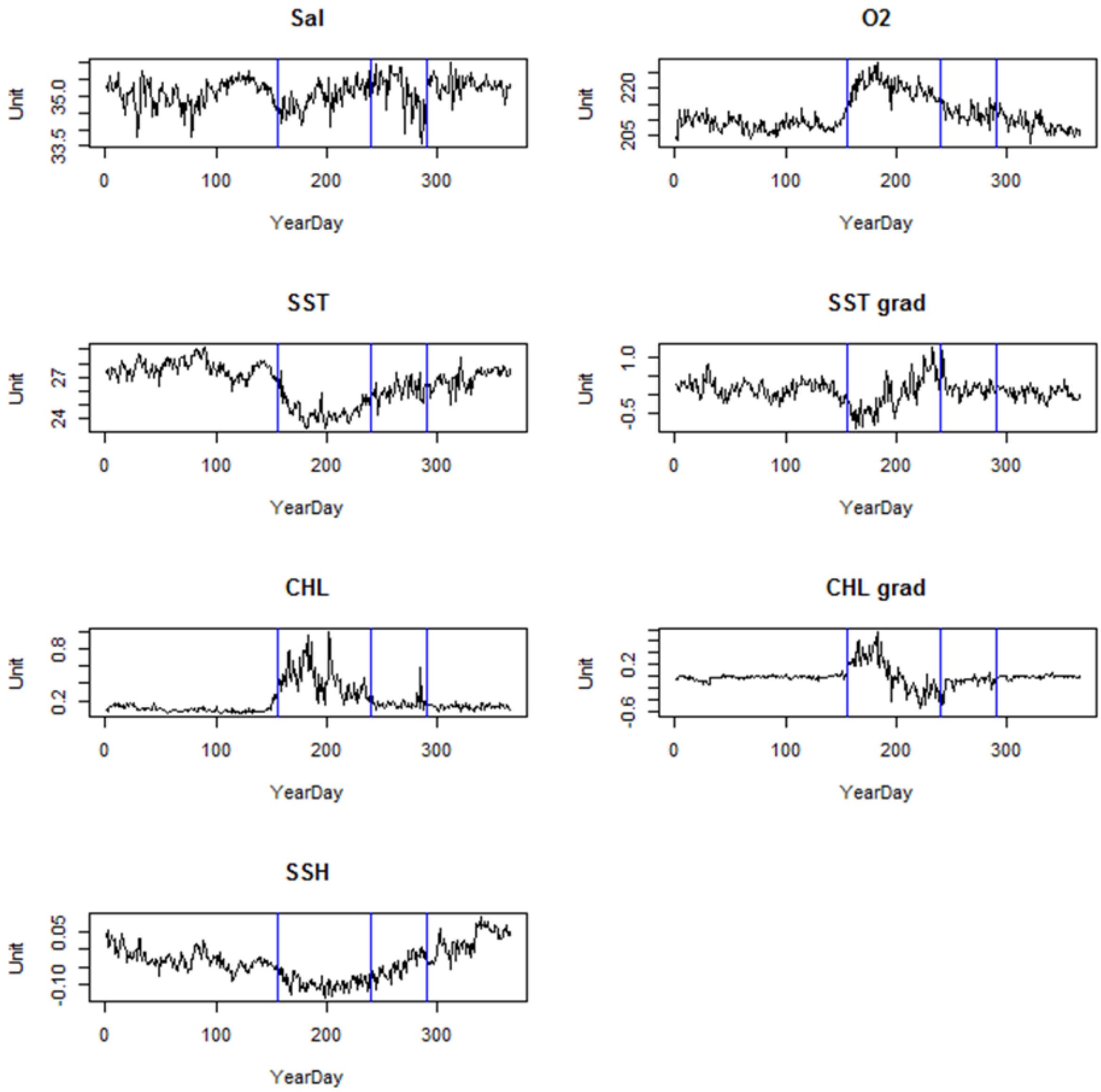


Figure 2.3.5. Annual averages for each of the oceanographic variables used in the regime shift identification analysis and their corresponding statistical change points (vertical blue lines).

Statistical model

As a preliminary exploration of the relative effect of covariates on the dependent variable (Dell et al., 2011), we used a recursive partitioning product, called Random Forest, available in the package party as the *cforest* function (Hothorn et al., 2015). This function implements random forest and bagging ensemble algorithms utilizing conditional inference trees as base learners and is safe even for variables of different types (i.e. continuous, discrete, factors) (Strobl et al., 2009). Also, predictor covariates were examined for correlation using pair plots and Pearson's rank correlations (Figure 2.3.6). To avoid correlation, and based on the previous relative importance information, one covariate from covariate pairs with a correlation > 0.7 and < -0.7 was removed from the variable selection process (Dormann et al., 2013; Hassrick et al., 2016). As an additional measure to avoid collinearity, as it may cause instability in parameter estimation in regression-type models (Dormann et al., 2013), a variance inflation factor analysis (VIF), function *vifstep* from the package usdm (Naimi et al., 2014; Naimi, 2015), was conducted using a cut-off value of 3 (Zuur et al., 2009). This function deals with multicollinearity problems by excluding highly collinear variables from a set through a stepwise procedure. Based on these tests, the variables Quarter, Month, O_2 and speed were removed owing to correlation/collinearity with more ecologically important variables. All other covariates available for model selection had low cross-correlation and cross-collinearity scores.

As an additional exploratory measure, univariate binomial GAMs (Generalized Additive Models; Hastie and Tibshirani (1986)) were established for each covariate considered in the study. These models were purely informative and provided information on both the expected functional shape of each covariate and their raw likely contribution to the deviance explained with regards species presence-absence.

Although preliminary analyses and models were conducted using count data and the negative binomial distribution (Lopez et al., 2016), the difficulties experienced to validate the final model led us to consider alternative distribution families. Thus, the present study uses the binomial distribution, a family that models the presence and absence of the species and provides probability indices of occurrence, irrespective of their amount (Dobson, 1983).

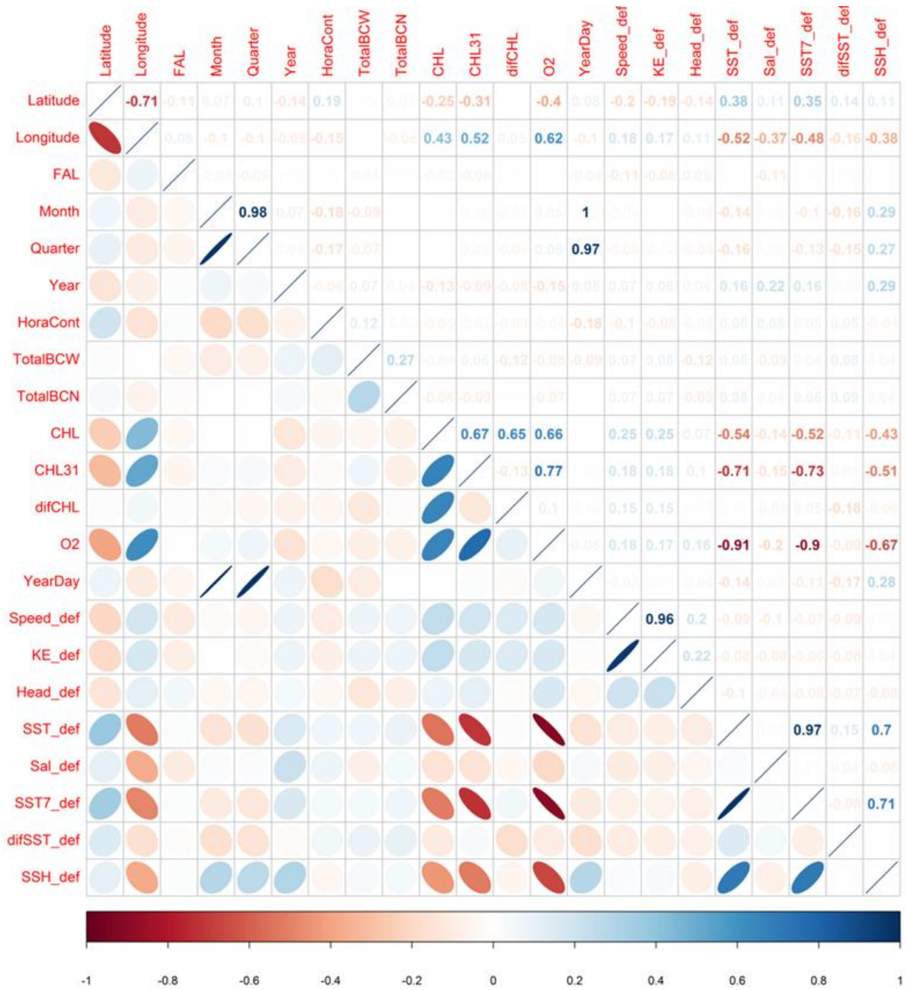


Figure 2.3.6. Pearson correlation figures and scores among all the covariates considered in the present study (latidude, longitude, silky shark -FAL-, month, quarter, year, hour –HoraCont-, total Bycatch (in weight) –TotalBCW-, total bycatch (in numbers) –TotalBCN-, chlorophyll a -CHL-, chlorophyll a 31 days before –CHL31, chlorophyll diference –difCHL-, oxygen -O2-, calendar day –yearDay-, speed of the current –Speed_def-, Eddy Kinetic Energy –KE_def-, heading of the current, sea surface temperature –SST_def-, salinity –Sal_def-, sea surface temperature 7 days before –SST7_def-, sea surface temperature diference –difSST_def-, sea surface height –SSH_def-).

Final model covariates were selected using a manual backward stepwise procedure (Wood, 2006). To avoid model overfitting and to simplify the interpretation of the results, the maximum degrees of freedom (measured as number of knots k) allowed to the smoothing functions were limited to the main effects at k = 4 and, for the first-order interaction effects, at k = 20 (Giannoulaki et al., 2013; Jones et al., 2014). The model with the lowest Akaike information criterion (AIC, Akaike (1974)) was chosen as the final model. Calendar year (Year) was included in the model as a random effect to account for inter-annual variability in shark occurrence and fishing effort (Wood, 2006; Brodie et al., 2015).

The final notation for the GAM model was:

$$PA \sim s(Longitude, Latitude, k=20) + s(CalendarDay, k=4) + s(TotalBC, k=4) + s(SSH, k=4) + s(SST, SST\ grad, k=20) + s(CHL, CHL\ grad, k=20) + Year_{random}$$

Where PA is the presence or absence of silky shark in each fishing set, and *s* represents a penalized regression spline type smoother based on generalized cross-validation (GCV).

The term *s(Latitude, Longitude)* measures the nonparametric spatial component of the silky shark occurrence (Cortés-Avizanda et al., 2011). Although a preliminary analysis with a non-parametric spline correlogram (Bjørnstad and Falck, 2001) suggested that the occurrence data for silky shark lack spatial autocorrelation, we included the spatial term in the model to check whether some spatial residual variation can be detected after estimating the covariate effects (Cortés-Avizanda et al., 2011).

The shapes of the functional forms for the selected covariates were plotted. When the slopes of the functional forms are positive, the covariates are related positively to the dependent variables, or vice versa. All the models, analysis and tests were conducted through the statistical language R (R Core Team, 2013).

Model validation and evaluation

A k-fold cross-validation method was used to evaluate the reliability and the predictive performance of the final model. This method consists of using independent data sets for model building (i.e. the training data) and model validation (i.e. the testing data), where data is partitioned into k equally sized segments or folds through random resampling. Model performance is assessed by successively removing each subset, re-establishing the model on the retained data, and predicting on the omitted data (Elith and Leathwick, 2009). In this study, a k = 5 partitioning method was used, meaning that 80% of the observations were used for model building, and the other 20% for model validation in an iterative procedure that was repeated 5 times. Hold-out validation avoids the overlap between training data and test data, yielding a more accurate estimate for the generalization performance of the algorithm (Villarino et al., 2015).

The predictive power of the model was assessed by computing a confusion matrix for each training and testing combination and their accuracy assessment indices, using the *cmx*, *presence.absence.summary*, *auc*, *optimal.thresholds*, *Kappa*, *sensitivity* and *specificity* functions in the PresenceAbsence package (Freeman and Moisen, 2008). The mean Area Under the receiver-operating Curve (AUC) (Hanley and McNeil, 1982) and the mean True Skill Statistic (TSS) (Allouche et al., 2006) were calculated for each iteration from each confusion matrix. Likewise, sensitivity (proportion of observed occurrences correctly predicted), specificity (proportion of absences correctly predicted), accuracy (proportion of the presence and absence records correctly assigned), and omission error (proportion of observed occurrences incorrectly predicted) were calculated given the defined threshold value. The AUC provides a single measure of overall model accuracy that is threshold independent, with an AUC value of 0.5 indicating the prediction is as good as random, whereas 1 indicates perfect prediction (Fielding and Bell, 1997). AUC has been extensively used in Species Distribution Models (SDM) and measures the ability of the model to correctly predict where a species is present or absent (Elith et al., 2006). An AUC value of >0.75 is considered to have a good predictive power and is acceptable for conservation planning (Pearce and Ferrier, 2000). TSS is an alternative measure of model accuracy that is threshold dependent and not affected by the size of the validation set (Allouche et al., 2006). It is an appropriate evaluative tool in cases where model predictions are formulated as presence–absence maps (Allouche et al., 2006). TSS is on a scale from -1 to +1, with 0 representing no predictive skill and is calculated from the confusion matrix outputs as sensitivity plus specificity minus 1 (i.e. TSS = sensitivity + specificity - 1). Threshold dependent and independent statistics, such as AUC and TSS, are used in combination when evaluating the predictive power of a SDM (Pearson et al., 2006).

The modelled probability of species presence was converted to either presence or absence using probability thresholds obtained using two criteria: sensitivity is equal to specificity, and maximization of sensitivity plus specificity, as reported in Jiménez-Valverde and Lobo (2007) and Lezama-Ochoa et al. (2016). Thus, the cases above this threshold are assigned to presences, and below to absences.

Predictions of distributions

The final model was used to predict and map the daily distribution and habitat preferences of the species, including standard error estimates, using the *predict.gam* function of the mgcv package (Wood, 2014). For predictions, the selected environmental variables (SST, SST grad, CHL, CHL grad, SSH) were averaged across the whole period (2003–2015) for each calendar day and position at a 1×1° resolution, and the 'TotalBC' covariate was set to mean levels.

The distributions of the species, as well as the standard error estimates, were then averaged for each seasonal regime identified in the previous section (i.e. stable, cool, and warming seasons). The predicted distributions of silky shark were plotted as spatial maps for each season (see results). The prediction methods described here were then repeated to obtain the presence-absence distribution of the species, applying the probability threshold estimated previously.

Efficiency of the no-retention measure

Silky sharks are mainly captured by longlines in tropical waters as well as coastal fleets such as gillnets. Purse seiners also capture sharks as bycatch, representing less than 0.5% in weight of the total catch (Restrepo et al., 2016). However, the great majority of this bycatch (>90%) consist of silky sharks. These are captured with all set types, being the highest proportions on sets on natural and man-made logs.

ICCAT Recommendation 11-08 in place does not allow the retention of silky sharks onboard fishing vessels. Consequently, all silky sharks shall be released, dead or alive. The prohibition to retain silky shark onboard is also in place in the Eastern (IATTC Res C-16-06) and Western and Central Pacific Ocean (WCPFC CMM 2013-08). ICCAT Rec. 11-08 also requests purse seine vessels engaged in ICCAT fisheries to take additional measures to increase the survival rate of silky sharks incidentally caught. For this reason, the conditions of how the animals are handled and released during the fishing operation can be determinant for their survivorship. For example, the Spanish and other associated flag vessels associated under ANABAC and OPAGAC has agreed a Code of Conduct for purse seiners including, among others, (i) best practices for handling and safe release of elasmobranchs and turtles, (ii) the use of non-entangling FAD, and (iii) 100% of observer coverage (Lopez et al., 2017[29]).

To monitor and assess the level of compliance of these good practices, a voluntary monitoring and verification system was implemented in 2014-2015, and is continuously evaluated, in all the vessels of the ANABAC and OPAGAC fleets,

[29] see: https://www.azti.es/atuneroscongeladores/wp-content/uploads/2017/05/Buenas-Prácticas-OPAGAC-ANABAC-feb-2017-FIRMADO_English.pdf

including Spanish and other flags, operating globally in 4 tuna RFMOs areas (ICCAT, IOTC, WCPFC and IATTC). The monitoring is based on specifically designed forms and in-situ data recorded by trained scientific observers, and more recently, also by electronic monitoring systems with a 100% observer coverage in both the purse seiners and support vessels. Fishing practices are assessed by the independent research body AZTI for each vessel every semester and results are used to provide scientific advice and identify correction mechanisms (i.e., when no-compliance is observed corrective actions are suggested to vessel owners/captains).

For sensitive fauna release, the code developed appropriate species-specific handling procedures that always preserve the crew's safety while discouraging other practices that are less favourable. These releasing procedures are based in the outputs of the EU project MADE (Poisson et al., 2014a), which have been used as standard best practice for safe release operations in tRFMOs. The data is collected using specific forms in English, French and Spanish on fauna release operations through scientific observers (Annex II). The level of conformity (i.e. conform or non-conform) and the reason of non-conformity during fauna release operations (inevitable residual mortality; lack of specific material for liberation; real non-conform procedure), as well as the time used to release animals are computed for each species, fishing trip and vessel, which allows to see in detail vessel-specific behaviour and evolution for each animal group. Information on biological parameters such as the size and sex of the specimens is also recorded. The level of conformity is the percentage of the sum of cases classified as conform and those classified as inevitable residual mortality to the total of records by species or species group. Those classified as inevitable residual mortality correspond to cases in which the specimens were already dead or could not be handled with security and are reclassified as conform in the assessment of best practices. This is because they correspond to cases in which the crew did efforts to apply the best practices but could not release safely the specimens.

As the overall impact is considerable, in addition to the best practices currently in force in PS vessels of ANABAC and OPAGAC, this work reviews the potential impact on the shark survival of the defined good practices in purse seining (Restrepo et al., 2016), which should be also extended to other gears.

d. <u>Results</u>

Investigating the habitat preference of the species

The habitat suitability model achieved a 19% of overall deviance explained, which is generally considered a reasonably good score for fisheries-based studies (Murase et al., 2009) (Table 2.4.1). The results of the GAM model are shown as plots of the best-fitting smooths for the conditional effect of the covariates on the parameter of interest (i.e. silky shark presence) (Figure 2.4.1). The y-axis reflects the influence of each covariate on species presence, given that the other variables are included in the model. The influence of the two-dimensional splines, (i.e. *s(latitude and longitude), s(SST, SST grad), s(CHL, CHL grad)*) are represented in surface plots. Approximate confidence curves have been obtained and as well as a plot for each univariate function (i.e. *s(Calendar Day), s(TotalBC), s(SSH)*) (Figure 2.4.1).

Table 2.4.2. Multi variable-based GAM for silky shark and its AUC, mean and standard deviation accuracy indexes values after k = 5 k-fold cross-validation, and TSS score.

Covariates	edf	p-value	% Dev.	AUC	Accuracy	Sensitivity	Specificity	Omission	Threshold	TSS
s(Long, Lat)	18.18	<0.001								
s(Calendar Day)	1.95	<0.001								
s(TotalBC)	2.83	<0.01								
s(SSH)	2.95	<0.001								
s(SST, SST grad)	15.94	<0.001								
s(CHL, CHL grad)	14.07	<0.001								
Yearrandom		<0.001								
Full model			19	0.78±0.01	0.74±0.01	0.64±0.03	0.77±0.002	0.12±0.02	0.37±0.03	0.42±0.03

The retained environmental covariates in the final model suggested complex relationships between species presence and certain oceanographic conditions, particularly those related to productivity processes. The model highlighted three main areas with higher silky shark presence probability, off Gabon, off Guinea and the southern and central tropical Atlantic Ocean (Figure 2.4.1 top-left). Calendar day had a strong influence on silky shark presence too, with probability peaking around day 250 (Figure 2.4.1 top-middlet). A general positive pattern between silky shark presence and total bycatch in the set was also detected by the model, although a slight decrease was observed between 5-10 tons (Figure 2.4.1 top-right). The optimum SSH values for silky shark presence ranged between 0 and -0.1 m (Figure 2.4.1 bottom-left). The two-dimensional splines surface plot of SST and ST grad showed that silky shark presence probability was higher at relatively fast cooling waters of ~24-30 ºC (waters that has decreased their temperature in about 3-4 ºC in a week; Figure 2.4.1 bottom-middle). Likewise, the surface plot representing the CHL and CHL grad interaction showed an overall increase in silky shark presence probability in waters significantly and quickly increasing their CHL concentration (1-3 mg m-3 in a week) (Figure 2.4.1 bottom-right).

AUC values, accuracy indexes and TSS scores for cross-validated models are shown in Table 2.4.1. The model showed good ability to predict silky shark presence, with AUC and accuracy values of 0.78±0.01 and 0.74±0.01, respectively, for cross-validated models. Sensitivity and specificity values for cross-validated models showed good performance scores too, 0.64±0.03 and 0.77±0.002, respectively. The omission error was low in general (0.12±0.02), also indicating that the model performed well. Low-intermediate threshold values were obtained in all cases (0.37±0.03), showing good proportion of predicted area suitability (Pearson, 2007; Lezama Ochoa et al., 2016). The TSS indicated a correlation between the predicted shark presence probability and the observed presence, with a TSS value of 0.42±0.03 (Brodie et al., 2015).

The predicted spatial patterns of silky shark presence across each environmental regime (i.e. stable, cool, warming) demonstrated the complexity of species responses to environmental conditions (Figure 2.4.2 and 2.4.3). The predictions highlighted both persistent and temporary areas of higher silky shark presence probability. The silky shark presence probability along the entire Gabonese coast was high across each season, with marked presence of the species in the adjacent Cape Lopez area during cool and warming periods. Silky shark presence probability increased off Guinea and south and central tropical Atlantic Ocean during cool and warming seasons. These areas appear to be very dynamic, with two small presence probability locations during the stable period that increases and extends the probability of presence of the species along Senegal and Liberia and in the southern and central tropical Atlantic Ocean during transitional seasons. The species distribution plots also indicated a pattern of offshore movement during the cool season (Figure 2.4.2). The high probability presence of the species located in the Gabonese area during the stable season slightly decreases during the cool season, where the species probability of presence moved further west (Figure 2.4.2 top). It is interesting to note that the predicted maps of standard deviation of the species presence probability showed little variability in general (mean = 0.04; max = 0.17; Figure 2.4.2 bottom) with the highest probabilities located at the most southern and western part of the study area, where few observations were available for the model (Figure 2.4.3).

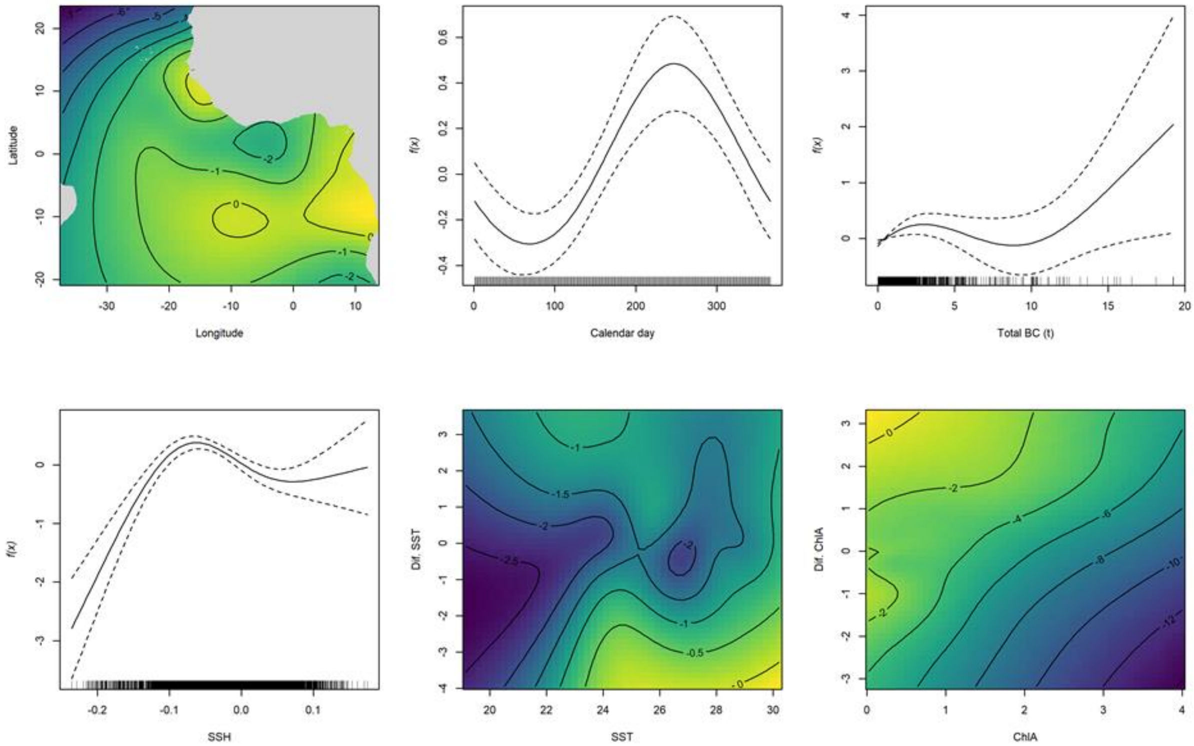


Figure 2.4.1. The partial effects of each individual covariate (Calendar Day, Total BC -total bycactch in tons-, SSH –sea surface height-) are plotted as smoothed fits, b-d, respectively. Broken lines correspond to 2 standard errors, above and below the estimate of the smooth being plotted. Short vertical lines located on the x-axes of each plot indicate the values at which observations were made. The partial effect of the two-dimensional terms (latitude and longitude; SST gradient and SST -sea surface temperature-; CHL gradient and CHL -chlorophyll a-) are represented in surface plots, a and e-f, respectively.

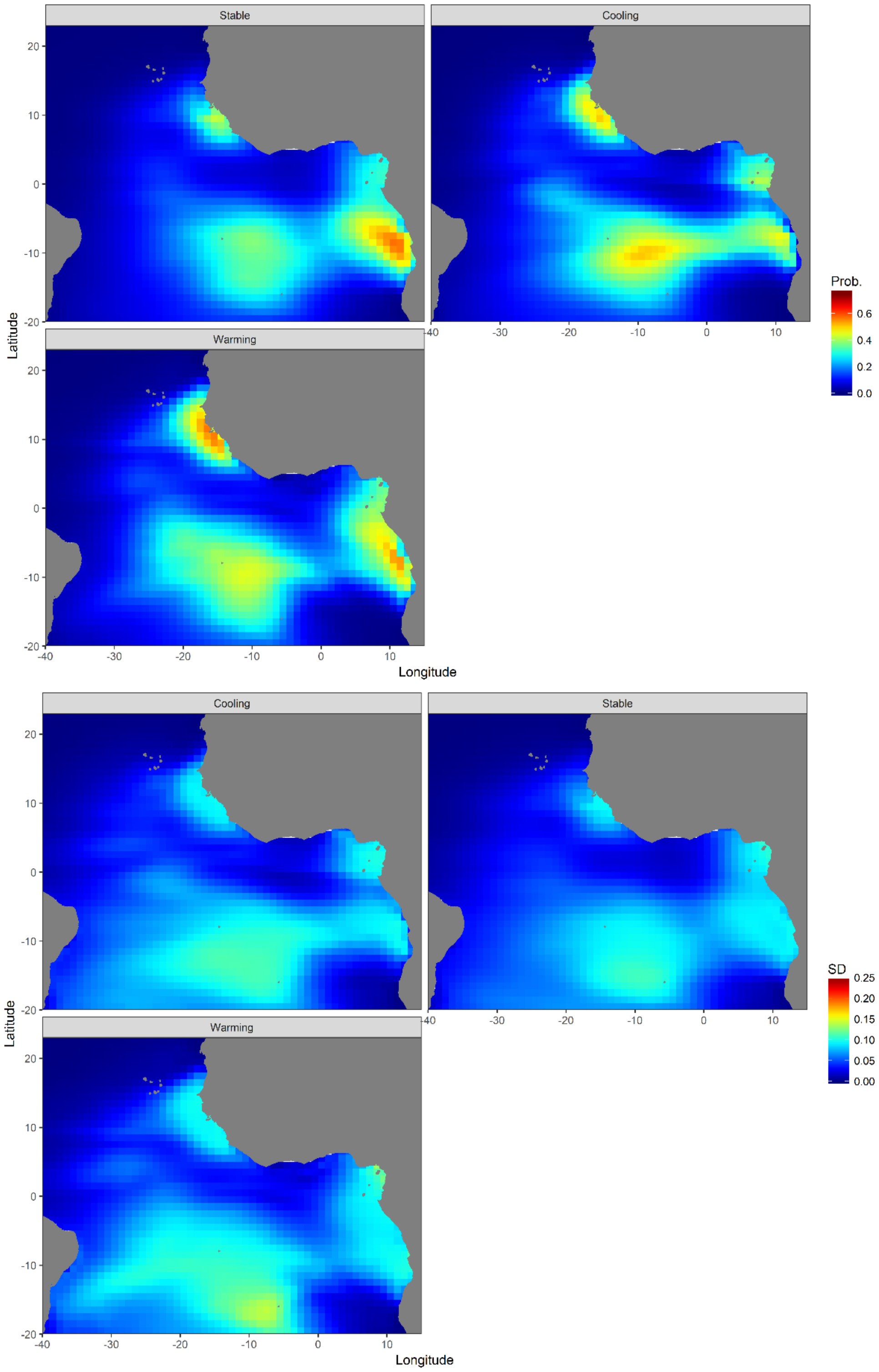


Figure 2.4.2. Averaged predictions of silky shark probability (top) and standard error (bottom) for the three environmental regimes identified in this study: stable, cool and warming season.

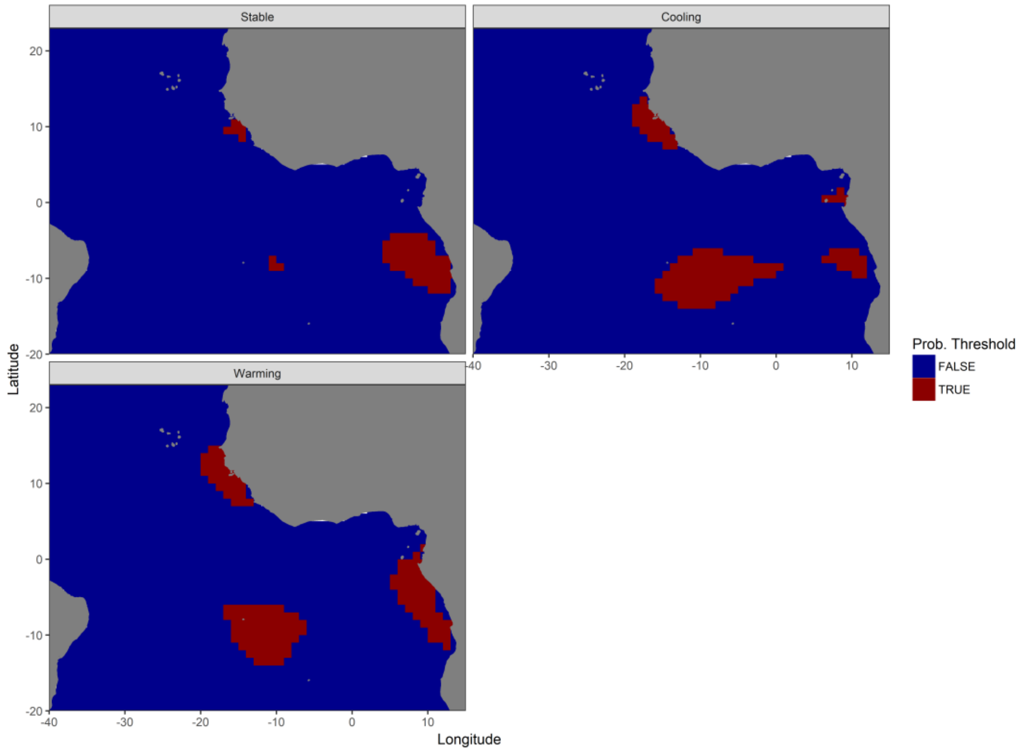


Figure 2.4.3. Averaged predictions of silky shark presence-absence, after applying the probability threshold (i.e. areas where probability of presence is above the established threshold), for the three environmental regimes identified in this study: stable, cool and warming seasons.

<u>Efficiency of the no-retention measure</u>

The work of Restrepo et al. (2016, 2017) analyses the different mitigation options ordered by the time when the measure takes place within the fishing operations, focusing on sets on floating objects, and estimates the potential reduction of mortality (Table 2.4.2). When combining all the measures listed in Table 2.4.2, the survival of silky sharks would be expected to increase by ≈71% for the purse seiners (this is the sum of the expected mortality reduction from each of the mitigation measures). Considering that silky sharks composed over the 90% of the shark bycatch and due to the vulnerability of this species, many studies are taking place in collaboration with the fishing sector to find viable a mitigation measures for the reduction of the non-intentional mortality.

RFMOs now encourage the use of non-entangling FADs, and the t-RFMOs have adopted bycatch mitigation measures for the use of non-entangling FADs. In 2006, IATTC did the first recommendation focused on non-entangling FAD designs (C-04-05), particularly to prevent sea turtle entanglements. Later, species-specific guidelines were gradually introduced in t-RFMOs worldwide: IATTC (C-13-04, C-16-

01), ICCAT (14-01, superseded by 15-01, 16-01), IOTC (Res. 12-04; Res 13-08 superseded by Res. 15/08 and Res. 17/08), WCPFO (CMM-17-01). The designs of non-entangling raft and subsurface structures were set to reduce the entanglement of sharks, sea turtles or any other species. In line with the guidelines, ICCAT required the replacement of existing FADs with non-entangling FADs by 2016 (Rec. 16-01) and in the IATTC area by 2019, including the use of biodegradable materials (C-17-02). These measures have been implemented as sustainable fishing standards also by the fishing companies in the frame of the Best Practices Program of ANABAC and OPAGAC as well as by the tuna processors and retailers. For example, ISSF (International Seafood Sustainability Foundation) recently adopted a conservation measure for the use of non-entangling FADs (i.e. measure 3.5: Transactions with Vessels that Use Only Non-entangling FADs). In addition, other standards such as the UNE 195006:2016 for Tuna from Responsible Fishing include the use of non-entangling FADs as a must. With these measures the probability of the entangling rate on the FAD is eliminated. The full implementation of this measure would eliminate the entanglement risk Restrepo et al. (2016, 2017).

The highest mortality rates are registered when sharks are loaded on board. Therefore, some mitigation measures could be directed to avoid the catch of sharks. One of this option is to reduce the number of sets to floating objects or FOB (man made or natural) where the catch rate of shark is higher, being negligible in set to free swimming schools. A 20% effort shift towards sets on free schools could decrease mortality by 16% (Peatman and Pilling, 2016). It has been also observed that the shark catch rate is higher in small aggregations. As such, setting on schools of tuna bigger than 10 tons and avoiding smaller schools would reduce the number of silky sharks by 21%-41% depending on the ocean (Dagorn et al., 2012). If adapting the fishing strategy to these two measures to avoid the shark fishing, a minimum reduction of the 41% on the shark mortality would be obtained in the Atlantic Ocean.

Other mitigation options are directed to the release during the setting of the nets. To avoid brailing, the most aggressive process for shark during the set, some actions to attract the sharks out of the net have been tested with not consistent results. One of the most promising is fishing the sharks on the net with high post-releasing survival rates, i.e. 100% (Sancristobal et al., 2016), but a partial catching rate, i.e. 21%.

Once the sharks are on board, the use of best handling and release practices are being applied to enhance the shark survival rate (Poisson et al., 2014a). Recently, different works have been directed to explore the post release survival and the contribution of the best fishing practices to the reduction of post release mortality. Results show that the post release survival depends on the landing stage from which is released (e.g. entangled in the net, 1st brail, posterior brails) and the state of the specimen when releasing (Poisson et al. 2014b, Hutchinson et al., 2015, Filmalter et al., 2015b, Eddy et al., 2016). As such, the post-release survival can go from 69% to 81% when releasing an animal entangled in the net, and from 6.7% to 52% if the release is occurring during brailing. Overall it could contribute to the total survival ranged from 8.5 to 19% (Filmalter et al., 2015b).

Table 2.4.2. Mitigation measures and their potential reduction in mortality.

Mitigation options	Measure	Mortality reduction	References
Passive mitigation	Use non-entangling FADs	No mortality due to entanglement	Filmalter et al. (2013) Filmalter et al. (2015a) ISSF, 2015 Murua et al. (2016)
Avoid catching before setting	Shift 20% effort to free schools	+16%	Peatman and Pilling (2016)
	Set only on FADs with > 10 t tunas	+25%	Dagorn et al. (2012)
	Set at a pre-determined time of the day when tunas are present, and sharks are away	not effective [1]	Restrepo et al. (2017) [4]
	Attract the sharks away before setting	NA	Restrepo et al. (2017) [5]
Release bycatch from the net	Fish sharks from the net	+21%	Sancristobal et al. (2016)
	Attract sharks out of the net	not effective [2]	Restrepo et al. (2017) [6]
	Make a shark escape panel in the net	not effective [3]	Restrepo et al. (2017) [7]
Release bycatch from the deck	Release from the deck by using best handling and release practices	+9%	Poisson et al., 2014b Filmalter et al. (2015b) Hutchinson et al.(2015)
All together		**≈71%**	

[1] As both, tunas and sharks, apparently make excursions away from FADs at similar times (usually during night time).
[2] As the sharks did not follow the FAD when it got towed by the tender out of the net.
[3] Measure apparently not widely applicable to purse seine fleets due to several factors.
[4] See cruises 4, 8, 12 and 13.
[5] See cruise 2.
[6] See cruises 4 and 5.
[7] See cruises 5, 6, 7, 9 and 14.

To decrease potential impacts by purse seiners fishing on dFADs and improve the long-term sustainability of the tropical tuna fishery, the two Spanish tuna purse seiner associations, ANABAC and OPAGAC, established in 2012 a voluntary agreement known as the "Code of Good Practices" for responsible tuna fishing activities. Since the establishment of the evaluation and verification system information on 718 fishing trips of the two Spanish tuna purse seiner associations, ANABAC and OPAGAC, has been collected and evaluated in the Atlantic Ocean. A total of 38964 interactions with sensitive fauna have been recorded (i.e. sharks, whale sharks, mantas, rays and turtles) from which 62,4% correspond to silky sharks (24298 records). The level of conformity in the handling and releasing practices for this species is of 85,2% of the total interactions (including those classified as conform by observers, i.e., 17229, and those classified as inevitable residual mortality, i.e., 3482). To estimate the contribution of the Best Practices program to the reduction of mortality, if those in which best practices could be successfully applied are considered (conform cases classified by observes, i.e., 17229) and a conservative post-release survival rate of 20% is applied, 2087 silky sharks or 12% of the individuals caught could survive. There is no information on other gears. However, further work should be developed to improve the best practices on handling and safe release for purse seiners but also other gears. In the case of purse seiners, additional measures would be necessary to reduce the impact of the gear in this species.

e. Final remarks

The habitat model developed in the present work shows the strong relationship between silky shark distributions and the oceanography of the area, which suggest strong seasonal changes in their distribution in response to the environmental changes, likely driven by productivity processes. Understanding the habitats and ecology of pelagic species can assist for both single species and ecosystem-based management and to develop both spatial and time-specific conservation measures. For example, silky shark spatial/time distributions could be used to reduce unwanted bycatch of this species when seeking other target species (Hobday et al., 2010), reducing the interaction rates with silky shark while maintaining tuna catches. Although further works should address similar models for target species to infer these ratios, this work provides seasonal distribution maps that can already be used for management and conservation planning of the silky shark. Indeed, the model highlighted the vital importance of the areas off Gabon and off Guinea, as well as the southern part of the central Atlantic Ocean for this species. These hotspots, both persistent and dynamic at different scales throughout the year, seem to be key for juveniles and pre-adults of silky sharks. The area off Gabon seem to be persistent and constant for silky shark presence within the year. However, the areas off Guinea and southern and central Atlanctic are more temporary and dynamic with higher presence during transitional periods (i.e. cool and warming periods) to be considered if encounter probability ratio-based conservation and mitigation measures are desirable to develop for this vulnerable species.

With regard to mitigation measures, when all the mitigation measures previously mentioned are used in combination, the silky shark survival is expected to increase by 71% (Restrepo et al., 2016) for the purse seiners. Also increasing the survival of other shark species. For longliners and gillnetters no information is available.

However, their implementation has different degrees of difficulty. Whereas the release of individuals from the deck is simple and implies negligible costs. Others can incur in costs, as for example such as shifting effort to free schools or not setting on small tuna aggregations, or would need crew available, as for fishing sharks from the net. In any case, all these measures are attainable and would contribute towards shark conservation (Restrepo et al., 2016). Currently, the best practices of handling and safe release in the purse seiners are being applied so it is expected that around a maximum of 10 % of survivorship of all silky shark caught is obtained with this measure. However, further work should be developed to improve the best practices on handling and safe release for purse seiners but also other gears. In the case of purse seiners, additional measures would be necessary to reduce the impact of the gear in this species as spatial/temporal adaptive management.

f. References

Akaike, H. 1974. A new look at the statistical model identification. Automatic Control. *IEEE Transactions* 19: 716-723.

Allouche, O., Tsoar, A., Kadmon, R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *J. Appl. Ecol.* 43: 1223-1232.

Bjørnstad, O.N., Falck, W. 2001. Nonparametric spatial covariance functions: Estimation and testing. *Environ. Ecol. Stat.* 8: 53-70.

Baum, J.K, Myers, R. 2004. Shifting Baselines and the Decline of Pelagic Sharks in the Gulf of Mexico. *Ecol. Lett.* 7:135–145.

Bonfil, R. 2008. "*The Biology and Ecology of the Silky Shark, Carcharhinus falciformis*". In Camhi, M., Pikitch, E.K. and Babcock, E.A. Sharks of the Open Ocean: Biology, Fisheries and Conservation. Blackwell Science. pp. 114–127.

Brodersen, K.H., Gallusser, F., Koehler, J., Remy, N., Scott, S.L. 2015. Inferring causal impact using Bayesian structural time-series models. *Ann. Appl. Stat.* 9: 247-274.

Brodie, S., Hobday, A.J., Smith, J.A., Everett, J.D., Taylor, M.D., Gray, C.A., Suthers, I.M. 2015. Modelling the oceanic habitats of two pelagic species using recreational fisheries data. *Fish. Oceanogr.* 24: 463-477.

Clarke, S., Coelho, R., Francis, M., Kai, M., Kohin, S., Liu, K.M., Simpfendorfer, C., Tovar-Avila, J., Rigby, C., Smart, J. 2015. Report of the Pacific Shark Life History Expert Panel Workshop, 28-30 April 2015. Western and Central Pacific Fisheries Commission.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heuperl, M., Holtzhausen, H., Santos, M.N., Ribera, M., Simpfendorfer, C. 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquat. Living Resour.* 23: 25-34.

Cortés, E., Brown, C.A., Beerkircher, L.R. 2007. Relative Abundance of Pelagic Sharks in the Western North Atlantic Ocean, Including the Gulf of Mexico and Caribbean Sea. *Gulf and Caribb. Res.* 19 (2): 37-52.

Cortés-Avizanda, A., Almaraz, P., Carrete, M., Sánchez-Zapata, J.A., Delgado, A., Hiraldo, F., Donázar, J.A. 2011. Spatial Heterogeneity in Resource Distribution Promotes Facultative Sociality in Two Trans-Saharan Migratory Birds. *PLoS ONE* 6: e21016 doi 10.1371/journal.pone.0021016

Cramer, J. 2000. Large Pelagic Logbook Catch Rates for Sharks. International Commission for the Conservation of Atlantic Tunas Scientific Committee, SCRS/1999/047 51, no. 6: 1842–18.

Dagorn, L., Filmalter, J.D., Forget, F., Amandè, M.J., Hall, M.A., Williams, P., Murua, H., Ariz, J., Chavance, P., Bez, N. 2012. Targeting bigger schools can reduce ecosystem impacts of fisheries. *Can. J. Fish. Aquat. Sci.* 69: 1463-1467.

Dell, J., Wilcox, C., Hobday, A.J. 2011. Estimation of yellowfin tuna (*Thunnus albacares*) habitat in waters adjacent to Australia’s East Coast: making the most of commercial catch data. *Fish. Oceanogr.* 20: 383-396.

Dobson, A.J. 1983. Introduction to statistical modelling. London: Chapman and Hall.

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J.R.G., Gruber, B., Lafourcade, B., Leitão, P.J., Münkemüller, T., McClean, C., Osborne, P.E., Reineking, B., Schröder, B., Skidmore, A.K., Zurell, D., Lautenbach, S. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36: 27-46.

Eddy, F., Brill, R., Bernal, D. 2016. Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. *Fish. Res.* 174: 109–117.

Elith, J., Graham, C.H., Anderson, R.P., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick J. R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.McC.M., Townsend Peterson, A., Phillips, S.J., Richardson, K., Scachetti-Pereira, R., Schapire, R.E., Soberón, J., Williams, S., Wisz, M.S., Zimmermann, N.E. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: 129-151.

Elith, J., Leathwick, J.R. 2009. Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. *Annu. Rev. Ecol. Evol. Syst.* 40: 677-697.

Fielding, A.H., Bell, J.F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environ. Conserv.* 24: 38-49.

Filmalter, J.D., Capello, M., Deneubourg, J.L., Cowley, P.D., Dagorn, L. 2013. Looking behind the curtain: quantifying massive shark mortality in fish aggregating devices. *Front. Ecol. Environ.* 11(6): 291–296.

Filmalter, J.D., Cowley, P.D., Forget, F., Dagorn, L. 2015a. Fine-scale 3-dimensional movement behaviour of silky sharks *Carcharhinus falciformis* associated with fish aggregating devices (FADs). *Mar. Ecol. Porg. Ser.* 539: 207–223.

Filmalter, J., Hutchinson, M., Poisson, F., Eddy, W., Brill, R., Bernal, D., Itano, D., Muir, J., Vernet, A.L., Holland, K., Dagorn, L. 2015b. Global comparison of post release survival of silky sharks caught by tropical tuna purse seine vessels. ISSF Technical Report 2015-10. International Seafood Sustainability Foundation, Washington, D.C., USA.

Freeman, E.A., Moisen, G. 2008. PresenceAbsence: An R Package for Presence Absence Analysis. 2008 23: 31 doi 10.18637/jss.v023.i11

Froese, R., Pauly, D. 2008. Fishbase 2008. Available from http://www.fishbase.org

Giannoulaki, M., Iglesias, M., Tugores, M.P., Bonanno, A., Patti, B., De Felice, A., Leonori, I., Bigot, J.L., TiČIna, V., Pyrounaki, M.M., Tsagarakis, K., Machias, A., Somarakis, S., Schismenou, E., Quinci, E., Basilone, G., Cuttitta, A., Campanella, F., Miquel, J., Oñate, D., Roos, D., Valavanis, V. 2013. Characterizing the potential habitat of European anchovy *Engraulis encrasicolus* in the Mediterranean Sea, at different life stages. *Fish. Oceanogr.* 22: 69-89.

Gilman, E., Chaloupka, M., Swimmer, Y. Piovano, S. 2016. A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. *Fish Fish.* 17: 748-784.

Grubbs, R., Carlson, J., Romine, J., Curtis, T., McElroy, W., McCandless, C., Cotton, C., Musick, J. 2016. Critical assessment and ramifications of a purported marine trophic cascade. *Sci. Rep.* 6: 20970. DOI: 10.1038/srep20970.

Hanley, J.A., McNeil, B.J. 1982. The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology* 143: 29-36.

Hassrick, J.L., Henderson, M.J., Huff, D.D., Sydeman, W.J., Sabal, M.C., Harding, J.A., Ammann, A.J., Crandall, E.D., Bjorkstedt, E.P., Garza, J.C., Hayes, S.A. 2016. Early ocean distribution of juvenile Chinook salmon in an upwelling ecosystem. *Fish. Oceanogr.* 25: 133-146.

Hastie, T., Tibshirani, R. 1986. Generalized additive models. *Stat. Sci.* 1: 297-310.

Hobday, A.J. 2010. Ensemble analysis of the future distribution of large pelagic fishes off Australia. *Prog. Oceanog.* 86(1–2): 291-301.

Hothorn, T., Hornik, K., Strobl, C., Zeileis, A. 2015. Party: a laboratory for recursive partitioning. R package version 10-23.

Hutchinson, M., Itano, D., Muir, J., Leroy, B., Holland, K. 2012. The post-release condition of FAD associated silky sharks (*Carcharhinus falciformis*) caught in tuna purse seine gear. WCPFC-SC8-2012/ EB-WP-12 Rev 1. Western and Central Pacific Fisheries Commission.ISSF 2015. ISSF Guide to Non-Entangling FADs.

ISSF 2018. ISSF Skippers' Guidebook. http://www.issfguidebooks.org/downloadable-guides/

Jacoby, D.M.P., Croft, D.P., Sims, D.W. 2012. Social behaviour in sharks and rays: analysis, patterns and implications for conservation. *Fish Fish.* 13: 399-417.

Jiménez-Valverde, A., Lobo, J. M., 2007. Threshold criteria for conversion of probability of species presence to either–or presence–absence. *Acta Oecologica*, 31: 361-369.

Jones, A.R., Hosegood, P., Wynn, R.B., De Boer, M.N., Butler-Cowdry, S., Embling, C.B. 2014. Fine-scale hydrodynamics influence the spatio-temporal distribution of harbour porpoises at a coastal hotspot. *Prog. Oceanogr.* 128: 30-48.

Killick, R., Eckley, I.A. 2014. changepoint: An R Package for Changepoint Analysis. *J. Stat. Soft.* 58: 19. doi 10.18637/jss.v058.i03

Killick, R., Fearnhead, P., Eckley, I.A. 2012. Optimal detection of changepoints with a linear computational cost. *J. Amer. Stat. Assoc.* 107: 1590-1598.

Lezama Ochoa, N., Murua, H., Chust, G., Van Loon, E., Ruiz, J., Hall, M., Chavance, P., Delgado de Molina, A., Villarino, E. 2016. Present and future potential habitat distribution of *Carcharhinus falciformis* and *Canthidermis maculata* by-catch species in the tropical tuna purse-seine fishery under climate change. *Front. Mar. Sci.* 3. doi 10.3389/fmars.2016.00034

Lopez J, Alvarez-Berastegi D., Soto M., Murua H. 2016. Modelling the oceanic habitats of Silky shark (Carcharhinus falciformis), implications for conservation and management. ICCAT–SCRS -2016–175.

Lopez, J., Goñi, N., Arregi, I., Ruiz, J., Krug, I., Murua, H., Murua, J., Santiago, J. 2017. Taking another step forward: system of verification of the code of good practices in the Spanish tropical tuna purse seiner fleet operating in the Atlantic, Indian and Pacific Oceans. IOTC–2017–WGFAD01–12.

Murase, H., Nagashima, H., Yonezaki, S., Matsukura, R., Kitakado, T. 2009. Application of a generalized additive model (GAM) to reveal relationships between environmental factors and distributions of pelagic fish and krill: a case study in Sendai Bay, Japan. *ICES J. Mar. Sci.* 66: 1417-1424.

Murua, J., Itano, D., Hall, M., Dagorn, L., Moreno, G., Restrepo, V. 2016. Advances in the use of entanglement-reducing drifting fish aggregating devices (dFADs) in tuna purse seine fleets. ISSF Technical Report 2016-08. International Seafood Sustainability Foundation, Washington, D.C., USA.

Naimi, B. 2015. usdm: Uncertainty analysis for species distribution models, R package version 1.1-12.

Naimi, B., Hamm, N.A.S., Groen, T.A., Skidmore, A.K., Toxopeus, A.G. 2014. Where is positional uncertainty a problem for species distribution modelling? *Ecography* 37: 191-203.

Pearce, J., Ferrier, S. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. *Ecol. Model.* 133: 225-245.

Pearson, R.G. 2007. Species' distribution modeling for conservation educators and practitioners. American Museum of Natural History 50.

Pearson, R.G., Thuiller, W., Araújo, M.B., Martinez-Meyer, E., Brotons, L., McClean, C., Miles, L., Segurado, P., Dawson, T.P., Lees, D.C. 2006. Model-based uncertainty in species range prediction. *J. Biogeogr.* 33: 1704-1711.

Peatman, T., Pilling, G. 2016. Monte Carlo simulation modelling of purse seine catches of silky and oceanic whitetip sharks. Twelfth Regular Session of the WCPFC Scientific Committee. WCPFC-SC12-2016/ EB-WP-03.

Poisson, F., Séret, B., Vernet, A.L., Goujon, M., Dagorn, L. (2014a). Collaborative research: development of a manual on elasmobranch handling and release best practices in tropical tuna purse-seine fisheries. *Marine Policy*, 44: 312–320.

Poisson, F., Filmalter, J.D., Vernet, A.L., Dagorn, L. (2014b). Mortality rate of silky sharks (*Carcharhinus falciformis*) caught in the tropical tuna purse seine fishery in the Indian Ocean. *Canadian Journal of Fisheries and Aquatic Sciences*, 71: 795–798.

Queiroz, N., Humphries, N.E., Mucientes, G., Hammerschlag, N., Lima, F.P., Scales, K.L., Miller, P.I., Sousa, L.L., Seabra, R., Sims, D.W. 2016. Ocean-wide tracking of pelagic sharks reveals extent of overlap with longline fishing hotspots. *Proc. Natl. Acad. Sci.* 6pp.

R Core Team 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria ISBN 3-900051-07-0.

Restrepo, V., Dagorn, L., Moreno, G. 2016. Mitigation of Silky Shark Bycatch in Tropical Tuna Purse Seine Fisheries. ISSF Technical Report 2016-17. International Seafood Sustainability Foundation, Washington, D.C., USA.

Restrepo, V., Dagorn, L., Moreno, G., Forget, F., Schaefer, K., Sancristobal, I., Muir, J., Itano, D. 2016. Compendium of ISSF At-Sea Bycatch Mitigation Research Activities as of July, 2016. ISSF Technical Report 2016-13. International Seafood Sustainability Foundation, McLean, Virginia, USA.

Restrepo, V., Dagorn, L., Itano D., Justel-Rubio and A., Forget F. and G. Moreno 2017. A Summary of Bycatch Issues and ISSF Mitigation Initiatives To-Date in Purse Seine Fisheries, with emphasis on FADs. lSSF Technical Report 2017-06. International Seafood Sustainability Foundation, Washington, D.C., USA.

Rigby, C.L., Sherman, C.S., Chin, A., Simpfendorfer, C. 2017. *Carcharhinus falciformis*. IUCN Red List of Threatened Species 2017: e.T39370A117721799.

Sancristobal, I., Martinez, U., Boyra, G., Muir, J., Moreno, G., Restrepo, V. 2016. ISSF bycatch reduction research cruse on the F/V MAR DE SERGIO in 2016. ICCAT SCRS/2016/156.

Springer, S. 1967. Social organization of shark population. Sharks, skate and rays: 149-174.

Strobl, C., Hothorn, T., Zeileis, A. 2009. Party on! A New, Conditional Variable-Importance Measure for Random Forests Available in the party Package. *J. Anim. Ecol.* 1/2: 14-17.

Villarino, E., Chust, G., Licandro, P., Butenschön, M., Ibaibarriaga, L., Larrañaga, A., Irigoien, X. 2015. Modelling the future biogeography of North Atlantic zooplankton communities in response to climate change. *Mar. Ecol. Prog. Ser.* 531: 121-142.

Wood, S. 2006. Generalized additive models: an introduction with R. Chapman & Hall/CRC.

Wood, S. 2014. Package ‘mgcv’. R package version17-29.

Zuur, A.F., Mira, A., Carvalho, F., Ieno, E.N., Saveliev, A.A., Smith, G.M., Walker, N.J. 2009. Negative Binomial GAM and GAMM to Analyse Amphibian Roadkills Mixed effects models and extensions in ecology with R. Springer New York, New York, NY, pp 383-397.

g. Annex I. Atlantic Ocean silky shark management plan

Silky Shark: Management Plan Summary of Information Available

Silky shark (*Carcharhinus falciformis*) ICCAT

The silky shark is a circumtropical oceanic and coastal-pelagic species (Last and Stevens, 2009). It is most often found near the edge of continental and insular shelves at depth of around 200 m, or within the epipelagic zone further offshore where it has been caught in depths of over 4000 m (Figure I.2).

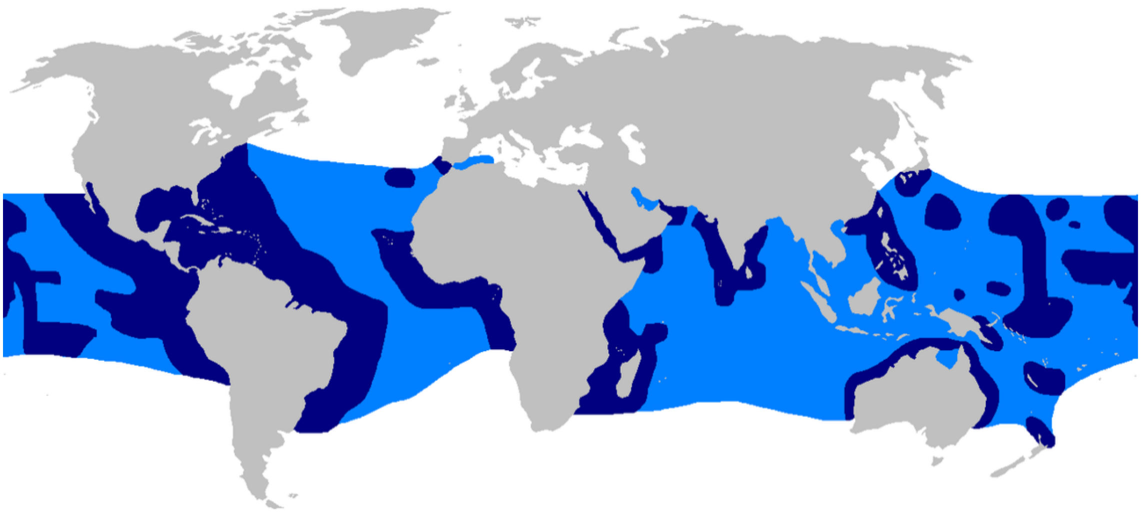


Figure I.2. Geographic distribution of silky shark. Confirmed (dark blue); suspected (light blue). Source: Bonfil (2008).

Despite its broad distribution, the population structure remains relatively unknown. Genetic studies indicate there are overall at least five mitochondrial DNA populations globally (Clarke et al., 2015a). Within the Pacific, there is one stock in the western Pacific and two stocks in the eastern Pacific (north and south), separated by the equator (Aires da Silva et al., 2014). It is noted that the degree of genetic separation is slight in these regions and may not be sufficient to be considered as separate sub-populations for management purposes. In addition to the Pacific, separate stocks occur in the Indian Ocean and Atlantic Ocean.

Sub-adult animals move from nearshore nursery areas further offshore to oceanic waters where they show a gregarious behaviour and are often associated with drifting objects at the surface and tuna schools (Filmalter et al., 2013). Silky sharks have been reported to grow larger and mature at later sizes in the northwest Atlantic than in the Eastern Pacific and Western Central Pacific (Bonfil, 2008). In general, females reach maturity between 6-13 years and give birth to an average of 5-7 live young (Clarke et al., 2105b). Being a relatively long-lived, slow growing species coupled with their gregarious behaviour and pattern of movement covering both oceanic and coastal waters makes them particularly vulnerable bycatch species in global tuna purse seine fisheries in addition to tuna and swordfish longline fisheries.

Within the ecosystem, silky shark is a high-level predator and their removal by fisheries can have significant impacts on the marine food web. This may include the replacement of sharks by other high tropic level species, or if no predators fill this gap a top-down trophic cascade may occur (Gilman et al., 2016). Ecosystem-level trophic effects of fishing on shark populations are difficult to monitor due to the lack of long-term data sets and an understanding of the complex ecosystem dynamics and pelagic habitats (Grubbs et al., 2016).

Overview of the fishery

Historically, silky sharks were first taken in western Atlantic equatorial waters when the Japanese longline fleet first started in 1956 (Uozumi and Nakano, 1996). This fishery continued to expand rapidly during the 1960s and extended across the majority of the Atlantic by the end of the decade.

Silky sharks have been targeted by the United States commercial shark bottom longline and pelagic longline fishery, as well as recreational fishing. It is reported that up to 75% of individuals caught in the US shark bottom longline fishery in the Gulf of Mexico and Southern Atlantic are retained, which mainly comprises small animals less than 110 cm total length (Enzenauer et al., 2015). Silky sharks are also taken as bycatch in the US Atlantic pelagic longline fishery targeting tuna and swordfish. Here, estimates of survival were approximately 50% and 65% in the swordfish and tuna-directed sets respectively (Gallagher et al., 2014). Elsewhere in the region, it was reported that silky shark are one of five species most commonly caught in the Cuban longline fishery (Espinosa, 2004).

Longline fisheries in southwest Atlantic also take silky shark, including southern Brazil (Amorim et al., 1998), north eastern Brazil (Hazin et al., 1990) and Uruguay (Marín et al., 1998). Catches are reported in the artisanal gillnet fleet off Paraná State (Costa and Chaves, 2006). Within the European Union (EU), both Portuguese and Spanish longline fleets operate in the Atlantic. The distribution of Spanish longline fishing effort (number of hooks) between 1950 and 2005 is shown in Figure I.3 below.

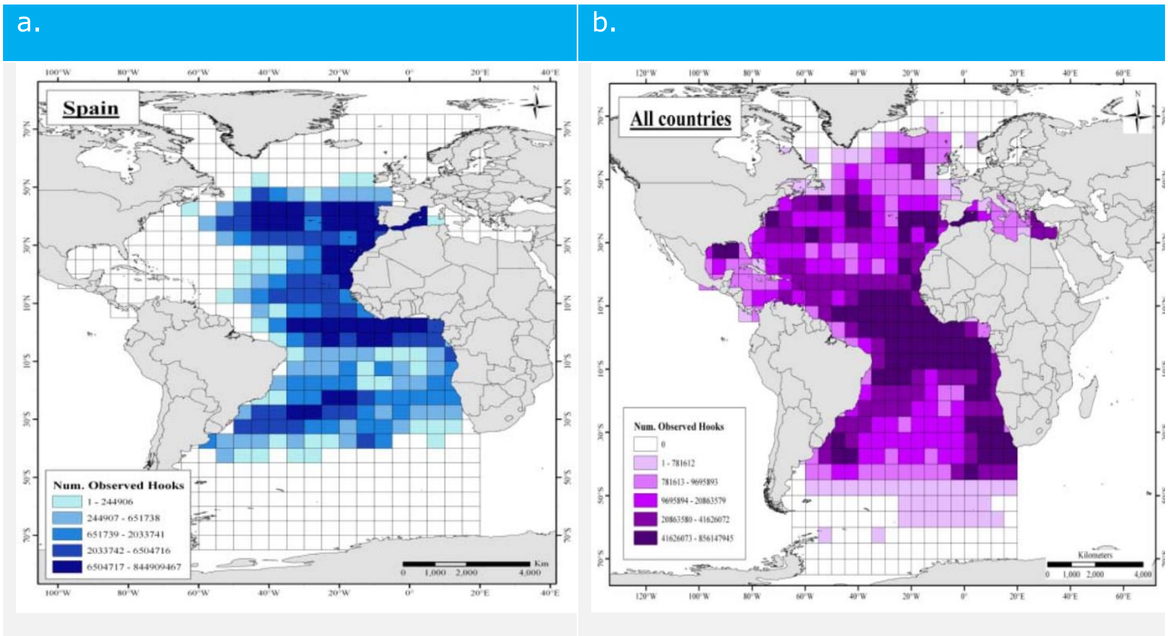


Figure I.3. Distribution of total effort in longline fleets (number of observed hooks) for EU (Spain) and all fleets combined (including USA, Venezuela, Brazil and Namibia) between 1950 and 2005 (source: Cortés et al., 2008).

More recently, a study by Queiroz et al. (2016) showed that the entire Spanish and Portuguese longline-vessel fishing fleets show an 80% overlap of fished areas with pelagic shark hotspots, potentially increasing shark susceptibility to fishing exploitation. The pattern of fishing behaviour showed that the deployment of longlines from the EU fleet was concentrated in three main areas in the North Atlantic: (i) a central area bounded by the Gulf Stream (Gulf Stream and North Atlantic Current/Labrador Current convergence zone -NLCZ-), and the Azores Islands in the north and down to 30°N in the south, (ii) a smaller area west of the Iberian Peninsula, and (iii) several smaller, more dispersed areas off northwest Africa. In addition, seasonal patterns showed that more southerly areas of the central North Atlantic were exploited during winter months (December to February) with progressive northerly movements through spring into summer, when fishing was concentrated in the NLCZ region, followed by a general southeast shift during autumn (September to November). In contrast to the NLCZ region, the West African upwelling area was exploited year-round, whereas the west Iberian area was most heavily fished in autumn and winter.

Given the high overlap between the distribution of pelagic sharks and the longline fisheries in the Atlantic Ocean, the geographic distribution of total cumulative catches of swordfish (*Xiphias gladius*) between 1980 and 2015 can be used to illustrate the likely spatial distribution of fishing pressure on silky sharks (Figure I.4); which could be valuable to identify and infer the likely interaction of the longline fleet targeting swordfish with silky shark catch (which is prohibited to retain onboard ICCAT vessels as per Recommendation 11-08).

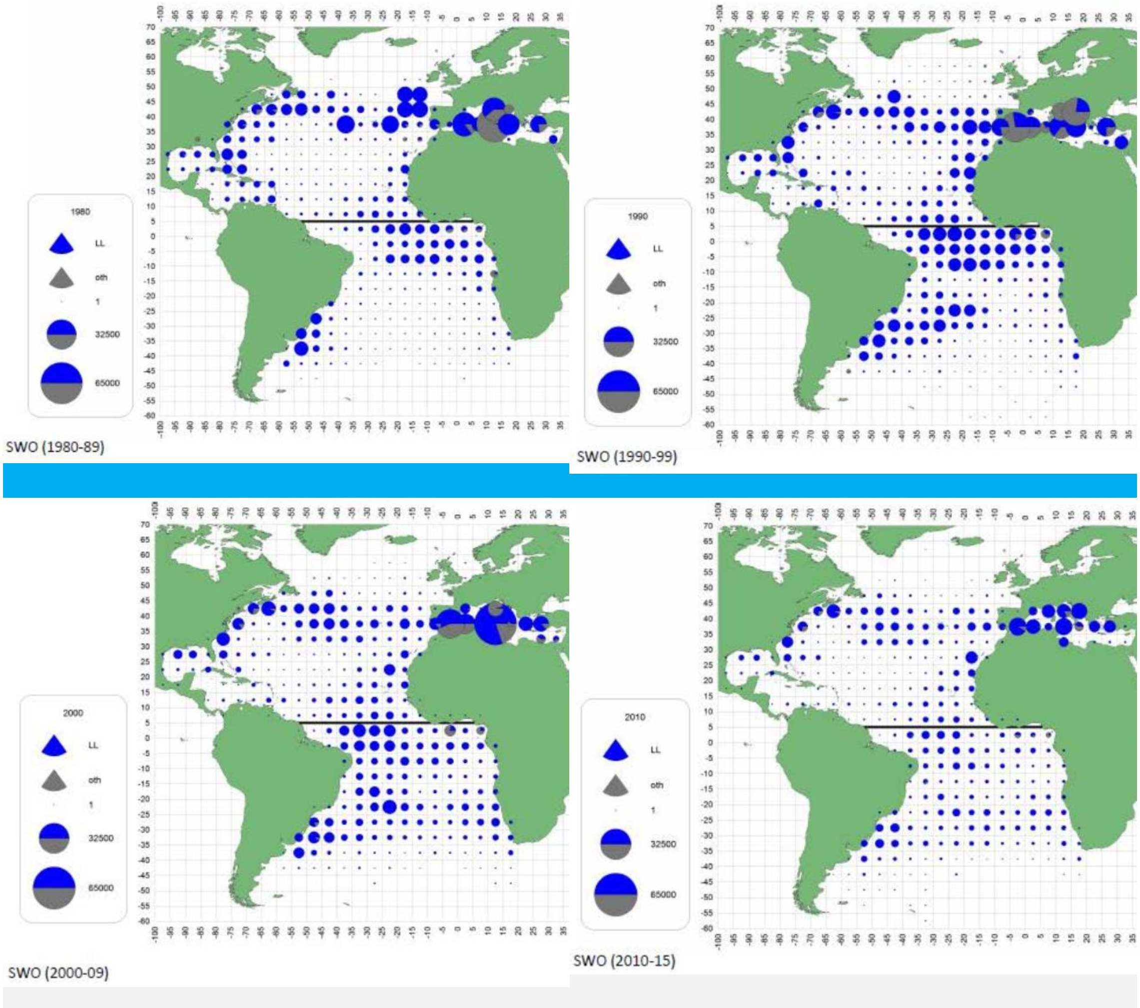


Figure I.4. Distribution of swordfish cumulative catch (tonnes) by major gears, shown on a decadal scale for the period 1980 – 2015 (source: ICCAT, 2017).

In contrast, the European tuna purse seine fishery is considered to catch significantly less sharks, and silky shark, in the Atlantic Ocean than both elsewhere and other gears (Murua et al., 2013). For example, reports indicate that only 244 silky sharks were taken as bycatch in the Atlantic Ocean between 2003 and 2007, which correspond to 1 ton of silky shark for 1000 tones of target species (skipjack, yellowfin and bigeye) (Amandé et al., 2010). In the case of Indian Ocean, the catch of silky shark was around 3 tones for 1000 tons of target species, considerable higher than in the Atlantic (Amande et al., 2008). Moreover, in the Indian and Pacific Ocean silky shark comprises around 90 % (Chavance et al., 2012) and 75-

85% (Hall and Roman, 2013) of the total shark bycatch, while in the Atlantic Ocean this percentage is reduced to around 50-60% (Amande et al., 2010).

Despite the comparatively low number of silky sharks bycaught by target catch in the Atlantic by purse seiners, the mortality rates of sharks remain high, ranging from 52% to over 80% (Eddy et al., 2016).); which in conjunction with the large catch and effort of purse seiners in the area (Figure I.4), makes necessary to develop silky shark mitigation measures for purse seiners.

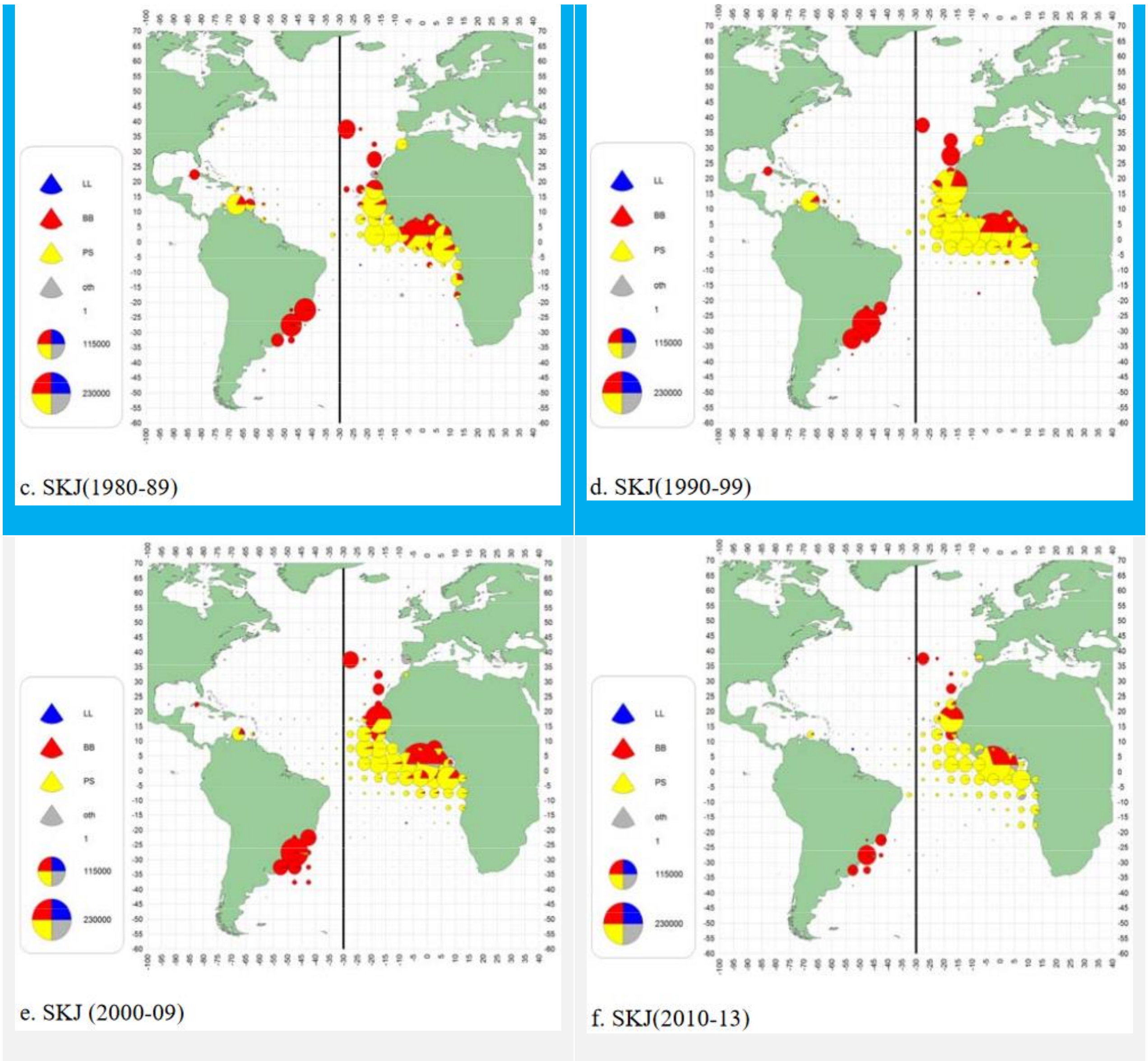


Figure I.5. Geographical distribution of the skipjack tuna catches by major gears, showing purse seine gear in yellow between 1980 and 2013.

In addition, Task I data (nominal catch) submitted to ICCAT illustrates reporting for silky shark has only recently appeared in the statistics for purse seiners (Figure I**.6**). Although this has been an ICCAT requirement to report all catches of shark species since 2011 (Rec. 11-08), it would appear that this has only recently started to occur for this species.

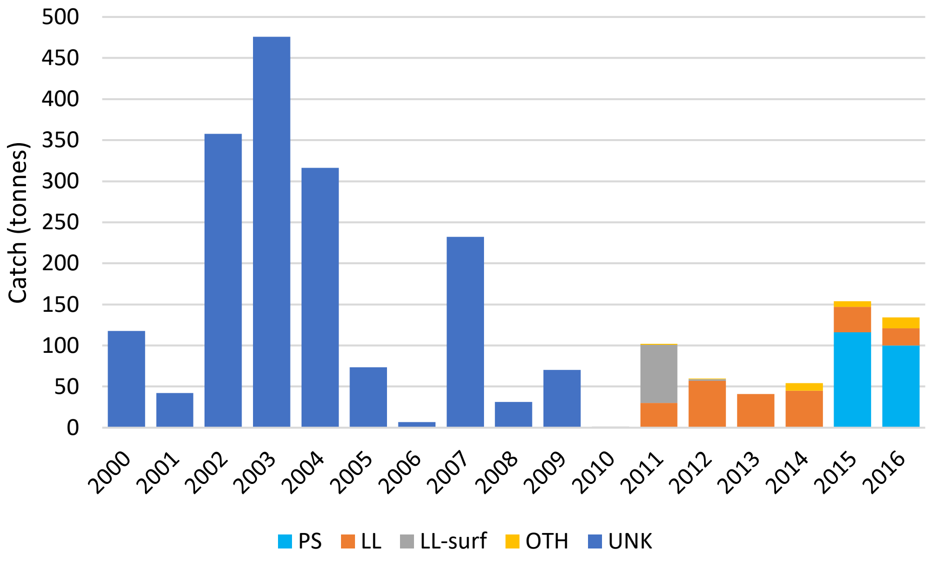


Figure I.6. Nominal catches (tonnes) of silky shark by gear type between 2000 and 2016 (source: ICCAT, 2018 Task I dataset). PS – purse sine; LL – deep-set longline; LL-surf – surface longline; OTH – other gear types; UNK – unkown gear type.

The main EU fleets to be considered in the plan would be:

- Spanish longline targeting swordfish;
- Portuguese longline targeting swordfish;
- Spanish purse seine; and,
- French purse seine.

Management objectives

ICCAT adopts Recommendations and Resolutions on the basis of scientific evidence, which is provided by the Standing Committee on Research and Statistics (SCRS). ICCAT Rec. 11-08 is specific to management of the silky shark (ICCAT, 2011). This recognises silky sharks as being "ranked as the species with the highest degree of vulnerability in the 2010 ecological risk assessment for Atlantic sharks".

No specific management objectives have been defined for silky shark. A number of management recommendations have been made for shark species overall. These include:

- "Precautionary management measures should be considered particularly for stocks where there is the greatest biological vulnerability and conservation concern, and for which there are very few data and/or great uncertainty in assessment results. Management measures should ideally be species-specific whenever possible" (ICCAT Rec. 14-06). This would necessarily include silky sharks as they have been identified as one of the most vulnerable.

- "Considering the need to improve stock assessments of pelagic shark species impacted by ICCAT fisheries and bearing in mind Rec. 12-05 adopted in 2012 as well as the various previous recommendations which made the submission of shark data mandatory, the Committee strongly urges the CPCs to provide the corresponding statistics, including discards (dead or alive), of all ICCAT fisheries, including recreational and artisanal fisheries, and to the extent possible non-ICCAT fisheries capturing these species. The Committee considers that a basic premise for correctly evaluating the status of any stock is to have a solid basis to estimate total removals."
- "The Committee reiterates that the CPCs provide estimates of shark catches in purse seines, gillnets, and artisanal fisheries. Estimates of shark entanglements in FADs are also important. Management measures should be applied to these sectors where catches of shark species are determined to be significant. Methods for mitigating shark by-catch by these fisheries also need to be investigated and applied."

Conservation reference points

No stock assessment has been conducted for silky shark and no biological reference points have been defined to prevent the stock reaching the point of recruitment impairment or to maintain the stock at levels equivalent to B_{MSY}.

Cortes et al. (2015) conducted an ecological risk assessment for eleven species of shark in the Atlantic Ocean including silky shark. The results showed that silky shark had variable levels of intermediate productivity and high susceptibility and are therefore regarded as "highly vulnerable". In addition, International Union for Conservation of Nature (IUCN) has defined the conservation status of silky shark across all three ocean regions as "vulnerable" (Rigby et al., 2017).

Catch and discard limits

Conservation measures that apply to the silky shark are related to the prohibition of retained catches and recording of interactions, outlined in the table below (Table I.3).

Table I.3. ICCAT recommendations and resolutions applicable to silky shark.

Rec.	Description
11-08	**On the conservation of silky sharks caught in association with ICCAT fisheries.**
1	CPCs shall require fishing vessels flying their flag and operating in ICCAT managed fisheries to **release all silky sharks whether dead or alive**, and prohibit retaining on board, transshipping, or landing any part or whole carcass of silky shark.
2	CPCs shall require vessels flying their flag to **promptly release silky sharks unharmed**, at the latest before putting the catch into the fish holds, giving due consideration to the safety of crew members. Purse seine vessels engaged in ICCAT fisheries shall endeavour to take additional measures to increase the survival rate of silky sharks incidentally caught.
3	CPCs shall record through their **observer programs** the number of discards and releases of silky sharks with indication of status (dead or alive) and report it to ICCAT.
4	Silky sharks that are caught by **developing coastal CPCs for local consumption are exempted** from the measures established in paragraphs 1 and 2, provided these CPCs submit Task I and, if possible, Task II data according to the reporting procedures established by the SCRS.

Bycatch mitigation

ICCAT fisheries do not have any binding bycatch mitigation for silky shark above those outlined in Rec. 11-08, described in the table below (Table I.4).

Table I.4. ICCAT recommendations encouraging live release of silky sharks.

Rec	Description
11-08	**On the conservation of silky sharks caught in association with ICCAT fisheries.** CPCs shall require fishing vessels flying their flag and operating in ICCAT managed fisheries to **release all silky sharks whether dead or alive**, and prohibit retaining on board, transshipping, or landing any part or whole carcass of silky shark.

Research into the post-capture mortality rate of silky sharks caught in the tropical purse seine fishery in the Indian Ocean Research shows an overall high mortality rate of 81% (Poisson et al., 2014). In addition, Hutchinson et al. (2015) reported that the total mortality rates of silky sharks captured in purse seine drifting fish aggregating devices (FADs) was found to exceed 84%. These high mortality values suggest methods to prevent sharks being brought on board should be a priority for future management mitigations. However, good handling practices could reduce incidental mortality of silky sharks released from the deck by up to 19% (Filmalter et al., 2015).

Mitigation measures adopted by industry independently for pelagic shark species in tropical purse seine fisheries (over 90% of which are silky sharks), summarised by International Seafood Sustainability Foundation (ISSF) at Indian Ocean Tuna Commission (IOTC) in 2016, noted that gillnet and longline fisheries have significantly higher impacts on silky sharks. The majority of purse seine operators are ISSF members and adhere to these mitigation measures. Mitigation by purse seiners that have been shown to work include:

- Use of non-entangling FADs;
- Reduction in number of FAD related sets;
- Reduction in setting on FADs with low tuna abundance;
- Release of live sharks (100% survival should be possible); and
- Use of best handling and release practices as developed by ISSF.

Estimates from the Pacific Ocean suggest that if sets were only made on free-swimming schools of tuna, this could reduce silky shark capture in the western and central Pacific by 83% (Peatman and Pilling, 2016).

Best practice guidelines for the release of sharks can be found in a report produced by the Conservation of Migratory Sharks (CMS, 2016). To mitigate the impacts of purse seiners and longliners on shark species it advocated three main methods.

i) Indirect mitigation

This should be done primarily through the identification and protection of critical habitats such as nursery grounds. Within these habitats best practice could include:

- Spatial closures – permanent or seasonal;
- Prohibition of fishing with steel leaders; and,
- Permanent or seasonal gear restrictions in other fisheries that exploit these areas.

ii) Capture avoidance

For purse seine vessels the recommendations relate to improving FAD management, specifically:

- Avoid FADs set on free swimming schools;
- Use chum to attract sharks away from FADs before the set is made;
- Remove entangling FADs;
- Avoid setting on FADs if > 10 tonnes of tuna are present;
- Improve FAD design;
- Minimise the use of non-biodegradable materials in FAD construction;

- Vessels to report all interactions with FADs to the relevant Regional Fisheries Management Organisation (RFMO);
- All FADs used by CPC vessels to be clearly identified with alpha-numeric codes;
- Regulate the total number of FADs deployed;
- Spatial closures, where FAD deployment is prohibited; and,
- Develop national and fishery-wide FAD Management Plans.

Longline recommendations give a number of operational and gear type options:

- Set tuna longlines deeper than 100m; do not use shallow shark lines;
- Avoid setting lines on the bottom; use floats to raise demersal lines;
- If shallow lines are needed (e.g. for swordfish), set longlines overnight; and,
- Monofilament lines and large circle hooks maximize escape and post-release survival.

(iii) Improved release and post release survival

For purse seine vessels best practice release is split between releasing from the purse seine itself and from the seiner decks.

Best practice for releasing bycatch from purse seines:

- Whenever possible, release shark bycatch before it reaches the deck;
- Use a brailer to lift sharks <3m long out of the bunt, over the float line, and into the sea;
- Release sharks entangled in the walls of the bunt back into the sea as the net is being hauled, by reducing the haul rate to reduce tension and if necessary cutting the net;
- Use hooks and lines to fish sharks out of the bunt and release them into the sea; and,
- Test the use of an escape hatch to allow sharks to swim out of the bunt.

Best practice for releasing bycatch from purse seiner decks:

- Return bycatch to the water as quickly as possible;
- Use hoppers to facilitate the rapid sorting and release of sharks and rays landed on deck from the brailers;

- Ensure that crews are trained to handle bycatch carefully; it must not be lifted by the head, gill slits, spiracles or tail, be thrown or dropped onto the deck, or trodden on;
- Do not use gaffs, hooks or wire to punch holes in, handle, or move sharks and rays;
- Provide ramps or escape hatches from the deck to openings on the side of the vessel to allow sharks and rays to be returned rapidly and safely to the sea. Small animals can be dropped headfirst into the water;
- Use a crane with a sling or cargo net to lower large sharks and rays into the sea, if no ramp or escape hatch is available; and,
- Shark bycatch may be released alive from the lower deck if there is a bycatch conveyor belt and a waste chute with a sufficient water flow to carry the shark through the drain.

Release from longlines:

- Use large circle hooks and monofilament lines;
- Use as short a soak time as practical;
- If possible, release sharks without removing them from the water;
- If hooks cannot be removed, use a line cutter to cut the line as close to the hook as possible;
- If sharks must be brought on deck, minimise the time they spend out of the water;
- Train crew to handle sharks carefully on deck (see best practice handling technique for purse seine catches);
- Exclude longlining from critical habitats, or mandate best practice in these areas; and,
- Undertake research with industry to identify other longline mitigation measures and best practices for particular species, fisheries, and regions.

Indicators

There is no stock assessment or any reliable fishery-dependent indicators of current stock status for silky shark in the Atlantic Ocean. To date, only three shark species judged to be the most vulnerable have been assessed under ICCAT; blue shark, shortfin mako shark and the porbeagle shark. Silky shark is currently classified as vulnerable by IUCN (Rigby et al., 2017).

Rather than estimates of absolute abundance, a number of ad-hoc analyses of relative abundance has been calculated using longline research surveys and observer data from the Gulf of Mexico. The results suggest that the abundance of silky shark in this region has declined by 91% between 1950 and 1990 (Baum and Myers, 2004). Further to this, Cramer (2000) calculated a 75% decline in relative abundance of silky shark between 1992 and 1997 in the Atlantic, Caribbean and Gulf of Mexico, using mandatory reports from the longline and bottom longline vessels.

Cortés et al. (2007) conducted an ecological risk assessment of silky shark as part of an analysis of pelagic sharks caught in the Atlantic pelagic longline fisheries. The results categorised the relative risk to over-exploitation by pelagic longline fleets and showed that the combination of low productivity and high susceptibility places silky shark as highly vulnerable (Figure I.7). The analysis also highlighted that little information exists on the vertical distribution and habitat preferences, and associated observer data in the Atlantic is variable. Later in 2010, silky shark was ranked first in the vulnerability to the Atlantic pelagic longline fishery (Cortés et al., 2010).

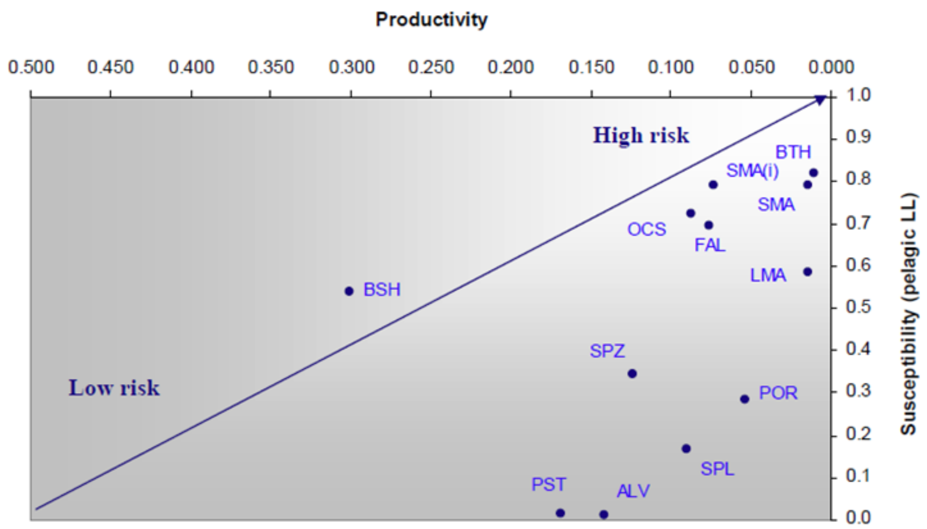


Figure I.7. Productivity-susceptibility plot for 11 species of Atlantic pelagic sharks. Productivity is expressed as r (intrinsic rate of increase of the population) and susceptibility as the product of availability, encounterability, selectivity and post-capture mortality. Silky shark denoted by "FAL".

Timeframe

No stock assessments of silky shark have been performed and no timeframe has been established by the ICCAT Working Group on Sharks (WGS) to develop a timeframe to develop a management plan.

Monitoring and evaluation

Monitoring and evaluation should be conducted through the ICCAT Working Group on Sharks. Management recommendations are to release all silky sharks whether dead or alive, and prohibit retaining on board, transshipping, or landing any part or whole carcass of silky shark. Compliance of the recommendation is achieved by monitoring through fisheries observers.

Increase in silky shark data quality - To enable sufficient data to be collected to conduct a stock assessment, high quality data is required. It is recommended that EU fleets (longline and purse seine) should ensure that all incidental bycatch of silky shark are correctly reported, including whether the shark was released dead or alive. This could include where possible size frequency data on released sharks. Detailed biometric data on silky sharks should be collected and there is a potential for a tag-release programme to be initiated for silky sharks where observers are present on longline vessels and the potential for shark survival is higher.

Confirmation of stock distribution - Genetic samples should be collected from silky sharks across the Atlantic Ocean, to verify the stock distribution. This should be implemented for EU vessels and recommended as part of an updated ICCAT recommendation for all fisheries that catch silky shark.

Evaluation should be done through the development of a stock assessment of silky shark through the ICCAT Working Groups. Currently, ad-hoc research of historical CPUE trends suggests significant large decline in population size. However, without a full stock assessment and associated biological reference points, the current status of the stock and the performance of current management measures remain unknown.

References

Aires-da-Silva, A., Lennert-Cody, C., Maunder, M.N., Román-Verdesoto, M. 2014. Stock status indicators for silky sharks in the eastern Pacific Ocean. Document SAC-05-11a. Inter-American Tropical Tuna Commission Scientific Advisory Committee Fifth Meeting. 12-16 May 2014, La Jolla, California, USA.

Amande, J.M., Ariz, J., Chassot, E., Chavance, P., Delgado de Molina, A., Gaertner, D., Murua, H., Pianet, R., Ruiz, J. 2008. By-catch and discards of the european purse seine tuna fishery in the indian ocean: Estimation and characteristics for the 2003-2007 period. IOTC-2008-WPEB-12. Indian Ocean Tuna Commission, Mahe, Seychelles.

Amande, M. J., J. Ariz, E. Chassot, A. Delgado de Molina, D. Gaertner, H. Murua, R. Pianet, J. Ruiz, P. Chavance. 2010. Bycatch of the European purse seine tuna fishery in the Atlantic ocean for the 2003-2007 period. *Aquat. Living Resour.* 23: 353-362.

Amorim, A.F., Arfelli, C.A., Fagundes, L. 1998. Pelagic elasmobranchs caught by longliners off southern Brazil during 1974-97: an overview. *Mar. & Freshw. Res*. 49: 621-632.

Baum, J.K, Myers, R. 2004. Shifting Baselines and the Decline of Pelagic Sharks in the Gulf of Mexico. *Ecol. Lett.* 7:135–145.

Bonfil, R. 2008. "*The Biology and Ecology of the Silky Shark, Carcharhinus falciformis*". In Camhi, M., Pikitch, E.K. and Babcock, E.A. Sharks of the Open Ocean: Biology, Fisheries and Conservation. Blackwell Science. pp. 114–127.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Santos, M.N., Ribera, M., Simpfendorfer, C. 2008. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. ICCAT. SCRS/2008/138.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heuperl, M., Holtzhausen, H., Santos, M.N., Ribera, M., Simpfendorfer, C. 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquat. Living Resour.* 23: 25-34.

Cortés, E., Brown, C.A., Beerkircher, L.R. 2007. Relative Abundance of Pelagic Sharks in the Western North Atlantic Ocean, Including the Gulf of Mexico and Caribbean Sea. *Gulf and Caribb. Res.* 19 (2): 37-52.

Cortés, E., Domingo, A., Miller, P., Forselledo, R., Mas, F., Arocha, F., Campana, S., Coelho, R., Da Silva, C., Hazin, F.H.V., Holtzhausen, H., Keene, K., Lucena, F., Ramirez, K., Santos, M.N., Semba-Murakami, Y., Yokawa, K. 2015. Expanded ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Collect. Vol. Sci. Pap. ICCAT* 71(6): 2637-2688.

Costa, L., Chaves, P.T.C. 2006. Elasmobranchs caught by artisanal fishing in the south cost of Parana State and north cost of Santa Catarina State, Brazil. *Biota Neotrop.* 6(3): http://dx.doi.org/10.1590/S1676-06032006000300007.

Clarke, C.R., Karl, S.A., Horn, R.L., Bernard, A.M., Lea, J.S., Hazin, F.H., Prodohl, P.A., Shivji, M.S. 2015a. Global mitochondrial DNA phylogeography and population structure of the silky shark, *Carcharhinus falciformis. Mar. Biol.* 162(5): 945-955.

Clarke, S., Coelho, R., Francis, M., Kai, M., Kohin, S., Liu, K.M., Simpfendorfer, C., Tovar-Avila, J., Rigby, C., Smart, J. 2015b. Report of the Pacific Shark Life History Expert Panel Workshop, 28-30 April 2015. Western and Central Pacific Fisheries Commission.

CMS. 2016. Draft best practice guidelines for sharks and rays taken in purse seine and longline fisheries. Prepared by S. L. Fowler. First Workshop of the Conservation Working Group of the Memorandum of Understanding on the Conservation of Migratory Sharks, Bristol, United Kingdom, 31 October – 01 November 2016.

Cramer, J. 2000. Large Pelagic Logbook Catch Rates for Sharks. International Commission for the Conservation of Atlantic Tunas Scientific Committee, SCRS/1999/047 51, no. 6: 1842–18.

Eddy, F., Brill, R., Bernal, D. 2016. Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. *Fish. Res.* 174: 109–117.

Enzenauer, M.P., Deacy, B.M., Carlson, J.K. 2015. Characterization of the shark bottom longline fishery: 2014. NOAA Technical Memorandum NMFS-SEFSC-677. NOAA, Florida, USA.

Espinosa, L. 2004. Situación actual de los tiburones en Cuba. Centro de Investigaciones Pesqueros. Havana, Cuba.

Filmalter, J., Hutchinson, M., Poisson, F., Eddy, W., Brill, R., Bernal, D., Itano, D., Muir, J., Vernet, A.L., Holland, K., Dagorn, L. 2015. Global comparison of post release survival of silky sharks caught by tropical tuna purse seine vessels. ISSF Technical Report 2015-10. International Seafood Sustainability Foundation, Washington, D.C., USA.

Gallagher, A.J., Serafy, J.E., Cooke, S.J., Hammerschlag, N. 2014. Physiological stress response, reflex impairment, and survival of five sympatric shark species following experimental capture and release. *Mar. Ecol. Prog. Ser.* 496: 207–218.

Gilman, E., Chaloupka, M., Swimmer, Y. Piovano, S. 2016. A cross-taxa assessment of pelagic longline by-catch mitigation measures: conflicts and mutual benefits to elasmobranchs. *Fish Fish.* 17: 748-784.

Grubbs, R., Carlson, J., Romine, J., Curtis, T., McElroy, W., McCandless, C., Cotton, C., Musick, J. 2016. Critical assessment and ramifications of a purported marine trophic cascade. *Sci. Rep.* 6: 20970.

Hall, M., Roman, M. 2013. Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. *FAO Fish. Tech. Pap*. 568. Rome, FAO. 249 pp.

Hazin, F.H.V., Couto, A.A., Kihara, K., Otsuka, K., Ishino, M. 1990. Distribution and abundance of pelagic sharks in the south-western equatorial Atlantic. *J. Tokyo Univ. Fish.* 77(1): 51-64.

Hutchinson, M.R., Itano, D.G., Muir, J.A., Holland, K.N. 2015. Post-release survival of juvenile silky sharks captured in a tropical tuna purse seine fishery. *Mar. Ecol. Prog. Ser.* 521: 143- 154.

ICCAT. 2011. Recommendation 2011-08. On the Conservation of Silky Sharks Caught in Association with ICCAT Fisheries.

ICCAT. 2017. Report of the 2017 ICCAT Atlantic Swordfish Stock Assessment Session. Madrid. Spain, 3-7 July, 2017. 85 pp.

ICCAT. 2018. Report of the 2018 ICCAT Standing Committee on Research and Statistics. Madrid. Spain, 1-5 October, 2018. 469 pp.

Last, P.R. and Stevens, J.D. 2009. Sharks and Rays of Australia. CSIRO Division of Fisheries, Hobart.

Marín, Y.H., Brum, F., Barea, L.C., Chocca, J.F. 1998. Incidental catch associated with swordfish longline fisheries in the south-west Atlantic Ocean. *Mar. & Freshw. Res*. 49(7): 633-639.

Murua, H., F. J. Abascal, J. Amande, J. Ariz, P. Bach, P. Chavance, R. Coelho, M. Korta, F. Poisson, M. N. Santos, and B. Seret. 2013. Provision of scientific advice for the purpose of the implementation of the EUPOA sharks. Final Report. European Commission, Studies for Carrying out the Common Fisheries Policy (MARE/2010/11 - LOT 2)

Queiroz, N., Humphries, N.E., Mucientes, G., Hammerschlag, N., Lima, F.P., Scales, K.L., Miller, P.I., Sousa, L.L., Seabra, R., Sims, D.W. 2016. Ocean-wide tracking of pelagic sharks reveals extent of overlap with longline fishing hotspots. *Proc. Natl. Acad. Sci.* 6pp.

Peatman, T., Pilling, G. 2016. Monte Carlo simulation modelling of purse seine catches of silky and oceanic whitetip sharks. WCPFC-SC12-2016/ EB-WP-03. Western and Central Pacific Fisheries Commission.

Poisson, F., Filmalter, J., Vernet, A., Dragorn, L. 2014. Mortality rate of silky sharks (*Carcharhinus falciformis*) caught in tropical tuna purse seine fishery in the Indian Ocean. *Can. J. Fish. Aquat. Sci.* 71: 795–798.

Rigby, C.L., Sherman, C.S., Chin, A., Simpfendorfer, C. 2017. *Carcharhinus falciformis*. IUCN Red List of Threatened Species 2017: e.T39370A117721799.

Uozumi, Y., Nakano, H. 1996. A historical review of Japanese longline fishery and billfish catches in the Atlantic Ocean. Collective volume of scientific papers. Report of the second ICCAT Billfish Workshop. ICCAT, Madrid.

h. Annex II. Best Practices forms for evaluating the sensitive fauna release

Verification of Good Practices ANABAC/OPAGAC

RELEASE OF ASSOCIATED FAUNA

Form **B2**

version 2017

fishing set nº:

Date:

fishing trip code

route form nº:

route line nº:

fauna liberation form nº:

purse shaping start time

h	h	m	m

Released fauna - sharks (1 line by individual, see example)

	individual			release mode							time		(4) state of the animal				
	(1) species	(2) size	(3) sex	using brailer	by stretcher, fabric, sarria, cargo net	with specific equipment	manual from deck	after disentangling	non conform	reason of non conformity (6)	animal detected	animal released	Excellent	Good	Fair	Poor	Unacceptable
0	FAL	140	2					1			7:35	7:47		X			
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	
29																	
30																	

Notes (5):

(1) put species code - see usual observers handbook. **(2)** in centímeters

Data verified

(3) sex: 1 male; 2 female; 3 undetermined **(4)** score as shown in the manual: Excellent, Good, Fair, Poor, Unacceptable;

(5) if photos of the individuals were taken, mention code of the corresponding photos **(6)** RI (residual unavoidable mortality: the animal comes dead, or is not detected and is kept on board, o is detected in lower deck and cannot be handled safely); M (lack of material); NC (not complying: good practices are not applied although the conditions allow their application

If more than 30 individuals are released, continue on a new form azti tecnalia

Verification of Good Practices ANABAC/OPAGAC

RELEASE OF ASSOCIATED FAUNA

Form **B3**

version 2017

fishing set nº:

Date:

fishing trip code

route form nº:

route line nº:

fauna release form nº:

purse shaping start time			
h	h	m	m

Released fauna - whale sharks, rays (1 line/individual, see example)

	individual			release mode									time		(4) state of the animal				
	(1) species	(2) size	(3) sex	drowning the corks	notch in the net	using the brailer (small shark)	using the brailer	by stretcher, fabric, sarria, cargo net	with specific equipment	manual from deck	non conform	reason of non conformity (6)	animal detected	animal released	Excellent	Good	Fair	Poor	Unacceptable
0	RHN	520	3	1									7:49	8:36	X				
1																			
2																			
3																			
0	RMB	120	2							1			8:44	8:49		X			
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			

Released fauna - turtles (1 line/individual, see example)

	individual			release mode						time		(4) state of the animal				
	(1) species	(2) size	(3) sex	after disentang.	manual from deck	through removing net/plastic remains or hook	non conform	reason n.c.	onboard 1d	animal detected	animal released	Excellent	Good	Fair	Poor	Unacceptable
0	TTL	90	1		1					9:04	9:21	X				
1																
2																
3																
4																
5																
6																
7																

Notes (5):

(1) put species code - see usual observers handbook. (2) in centimeters

Data verified

(3) sex: 1 male; 2 female; 3 undetermined **(4)** score as shown in the manual: Excellent, Good, Fair, Poor, Unacceptable;

(5) if photos of the individuals were taken, mention code of the corresponding photos **(6)** RI (residual unavoidable mortality: the animal comes dead, or is not detected and is kept on board, o is detected in lower deck and cannot be handled safely); M (lack of material); NC (not complying: good practices are not applied although the conditions allow their application

12.2. *CASE STUDY 2 – SILKY SHARK - IOTC*

a. *Background*

In the Indian Ocean, silky shark is targeted by some semi-industrial, artisanal and recreational fisheries and are a bycatch of industrial fisheries such as pelagic longline tuna and swordfish fisheries, and the purse seine fishery.

Current knowledge and stock status

Catch and effort statistics

Prior to the early 1970s the information on the fisheries is scarce. Unrecording shark catches, recording but not reporting shark catches, and lack of species-specific statistics are common for most of the fleets in the region. Significant catches of sharks have gone unrecorded in several countries and many of the available records probably severely under-represent the actual level of catches, since they do not account for discards (unrecording catches of sharks for which only the fins were traditionally kept, or of sharks discarded because of their size or condition) or reflect dressed weight instead of live weight. In addition, shark finning was considered to be regularly occurring for this species. The bycatch/release injury rate is unknown, but in all likelihood, high. As regards to length composition of the catches, the available information remains anecdotal and grossly fragmented. Additionally, there is also currently limited information on fishing effort, preventing the estimation of nominal and standardized CPUE trends.

Life history

Life history traits are reasonably well-known for this species in the Indian Ocean. There is information on age and growth, including estimates on von Bertalanffy growth parameters and longevity, and on reproductive biology. In addition, there are several conversion factors available (length-weight relationships, fins/carcass ratios).

Stock assessments and stock status

Following the results of a Productivity and Susceptibility Analysis (PSA, a semi quantitative Ecological Risk Assessment) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC), silky shark was qualified as potentially being at high risk of overexploitation. Those types of analysis, like the

PSA, provide a rank of relative vulnerability of the species but do not provide stock status. Up until now, no quantitative stock assessment has been conducted by the IOTC Working Party on Ecosystems and Bycatch (WPEB); consequently, the stock status for this species remains unknown. Notwithstanding the foregoing, current outlooks would suggest that maintaining or increasing fishing would be likely to lead to declines in biomass, productivity and CPUE. A stock assessment is envisaged and in the WPEB workplan to take place in 2019.

Obstacles preventing quantitative scientific advice

The poor quality and reliability of the recorded catch statistics (grossly underestimated), the lack of reliable and detailed information regarding exerted fishing effort and mortality (with the consequent impossibility of estimating standardized catch-per-unit-effort series) and the total absence of information as regards to the composition of the catches are at present the key obstacles preventing the quantitative scientific advice of the silky shark stock status in the Indian Ocean.

b. *Objectives*

The specific objectives of this case study are the following:

- Reconstruct silky shark catch time series for the period 1971-2015.
- Explore the possibility of estimating catch-per-unit-effort time series based on the longline fisheries with bycatch of silky sharks.
- Estimate a probability density distribution for silky shark intrinsic population growth rate (r) based on biological parameters, for later use as a prior in assessment models.
- Test the implementation of feasible stock assessment models for Indian Ocean silky shark, specifically models based on catch, resilience and qualitative stock status information.

c. *Material and Methods*

Catch time series reconstruction

Catches were reconstructed between 1971 and 2015 using Task 1 (EUPOA) method based on ratios (see Coelho et al., 2018, the main report of this Project).

CPUE series

The available information on silky shark catches by Portuguese, Spanish and French longliners fishing in the Indian Ocean was compiled. Following a preliminary analysis, it was concluded that the available data are very scarce and clearly insufficient to meet the needs for estimating standardized catch rates.

Demographic analysis

A stochastic population dynamics model (demographic analysis) using age-based Leslie Matrices was carried out to estimate the population intrinsic growth rate (r) (Caswell, 2001). Since only females produce off-spring, the demographic analysis was carried out exclusively for the female component of the population (Simpfendorfer, 2004). The age-structured model conceived was a pre-breeding survey model, where reproduction and natality take place first, followed by the probability of survivorship-at-age. Thus, the age-specific fecundity values of the Leslie matrix (Fx) were calculated as the products of the age-specific fertilities (mx) and the first-year survivorship (s0): Fx=s0.mx. In terms of survivorship, the age-specific survivorship was estimated based on several indirect life history equations, specifically on Pauly (1980), Hoenig (1983), Jensen (1996), Peterson and Wroblewski (1984), Chen and Watanabe (1989).

Two different scenarios were analysed and compared (Table 3.3.1). These scenarios accounted for different possible alternatives that can be used to estimate fecundity (either a 1 or 2-year reproductive cycle, still uncertain for the species).

Uncertainty in the analysis was introduced in the survivorship and fecundity parameters. Uncertainty in the survivorship parameters was introduced by generating age-specific random survivorship values from a uniform distribution with support defined between the minimum and maximum empirical age-specific estimates. For the fecundity parameters, uncertainty was considered by generating random age-specific fertilities based on a normal distribution, with the expected values and standard deviations based on the fertility-at-age values. Each scenario was simulated using 10,000 Monte Carlo replicates varying each input parameter (survivorship and fecundity) based on the previously assumed distributions. The resulting 10,000 Leslie matrices were analysed, and the distributions of the output parameters summarized as the mean *r* values and the corresponding 95% confidence intervals (0.025 and 0.975 quantiles).

Table 3.3.1 Biological data inputs for the demographic analysis for different scenarios.

Parameter	Scenario 1	Scenario 2	References
Theoretical maximum length (L_{inf})	320.4		Hall et al. (2012)
Growth coefficient (k)	0.057		
Theoretical age at length zero (t_0)	-5.12		
Median age for knife-edge maturity	15		
Litter size	7.2		
Sex ratio at birth	1:1		
Lifespan	35		Joung et al. (2008)
Scalar coefficient of weight on length	0.0000118		Romanov and Romanova (2009
Power coefficient of weight on length	2.97417		
Reproductive cycle	1	2	

Assessment model

Considering the information available, effort was focused on the implementation of the Monte Carlo method (CMSY) to estimate fisheries reference points from catch, resilience and qualitative stock status information on data-limited stocks, developed by Froese *et al*. (2017).

In essence, the model implements a stock reduction analysis using default priors for the intrinsic rate of population growth (r), based on resilience; for the carrying capacity or unexploited stock size k based on maximum observed catch and estimated priors for *r*; and start, intermediate, and final year depletion levels (B/K), based on a set of simple rules.

This model framework allows for the inclusion of priors for the input parameters (r, K and depletion) based on expert knowledge or estimated by any other feasible methods. The stock reduction analysis uses a Schaefer biomass dynamic model and an algorithm for identifying feasible r-k combinations to estimate biological and management quantities (r, K, MSY, B_{MSY}, F_{MSY}) as well as time series of biomass, fishing mortality, and stock status benchmarks (B/B_{MSY}, F/F_{MSY}).

It is worth noting that, in its current version, CMSY addresses the overestimation of productivity at very low stock sizes (general shortcoming of production models) by implementing a linear decline of surplus production when biomass falls below 1/4 K.

<u>Data and CMSY run configuration</u>

Input data

Estimated catches for the period 1971 to 2015 were used. No abundance index was available for this stock.

Range of parameters explored

Using a stochastic Leslie matrix model, a distribution of r values was computed with a mode at 0.064 and a 90% confidence interval in the range 0.050 – 0.077. By using this quite narrow range we assume a very precise idea about this parameter, which would strongly restrict the space of parameters r and K explored by the model. In order to explore a wider range of plausible r values, no range was specified, and the resilience value available on Fishbase was used (Froese & Pauly, 2015).

As a note, and comparing to the default used values, for silky shark resilience is estimated to be very low (Froese & Pauly, 2015), which for CMSY defaults corresponds to values of r in the range 0.015-0.100. The median estimate is very similar, and only the ranges modestly wider than the first implemented option described before.

As regards to the range of depletion rates (B/k), at the start of the time series (1971), the stock is believed to be already exploited, but at a light level. An initial depletion rate (B/k) of 0.7-0.9 was therefore used. In order not to constrain too much the estimated stock trajectory, a wider range, between 0.2 and 0.7, was used for the final year (2015) depletion rate.

By default, CMSY uses an intermediate depletion rate (10 years before the end of the available time series) with values in the range 0.2-0.6. Preliminary runs using this default option showed that the range is very restrictive. The estimated trajectory goes just under the upper limit of this intermediate range, which shows that this default value strongly constrains the model. In order to give the model more freedom, a larger range was set (0.1-0.9, for year 2000 in the available time series).

Further model configuration involved both the choice of variance for the catch data (observation error), and variance of the process error. For both the default value was 0.1, which seemed considerable low (especially given that the catches were estimated by using a model); hence, higher values (0.2) were tested. This was found to have no effect on the output of CMSY.

d. Results

Catch time series reconstruction

There are differences in the reported *versus* estimated silky shark catches along the entire time series. Before the mid 1980s there are very few reported catches of silky shark. From then on there is a rapid increase in both series. However, in the estimated time series the catches continued to increase until the mid-2000s, while in the reported catches there is a peak in catches in the 1990s followed by an abrupt decrease. Such abrupt increase and decrease in the reported catches in that period may be related with a Sri Lanka targeted fishery for silky shark that operated for the last 40 years (IOTC, 2016). Between 2005 and 2015 there are some oscillations in both series but at very different catch levels (Figure 3.4.1).

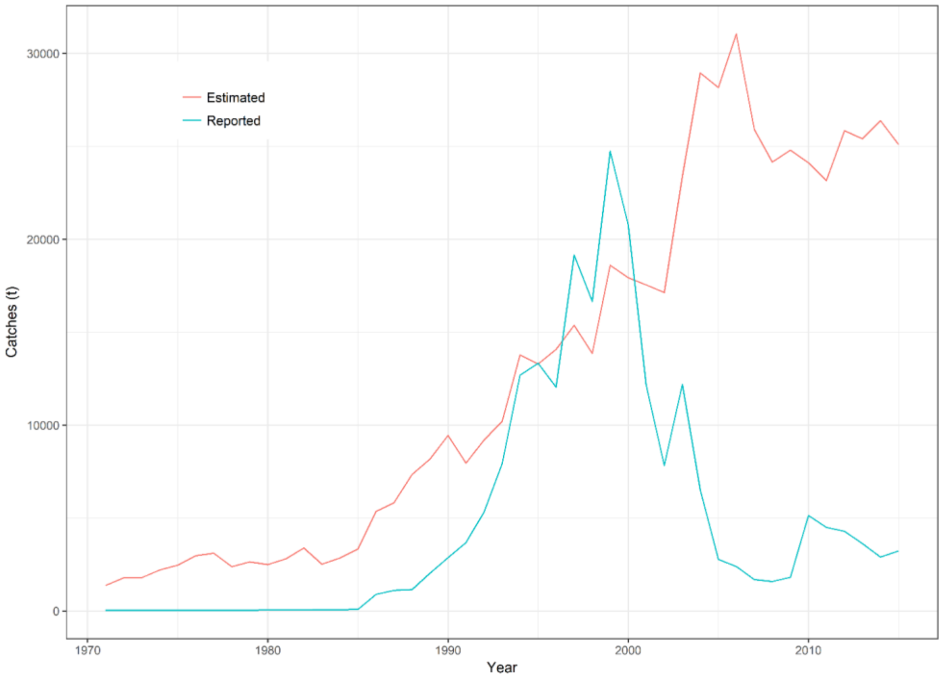


Figure 3.4.1. Time series of reported and estimated silky shark catches, between 1971 and 2015, for the Indian Ocean.

Standardized catch rates

After preliminary runs using Portuguese and Spanish observer data, the very limited interactions/catches with this species precluded any advancement on this issue. Therefore, at this point only catch based assessment models were tested.

Demographic analysis

Using different biological scenarios, either a 1 or 2-year reproductive cycle, had an effect on the estimated r (Figure 3.4.2). When assuming a 1-year reproductive cycle (Scenario 1) the estimates of r were higher than when assuming a 2-year reproductive cycle (Scenario 2). The estimates of r were 0.064 and 0.026 for Scenario 1 and 2, respectively.

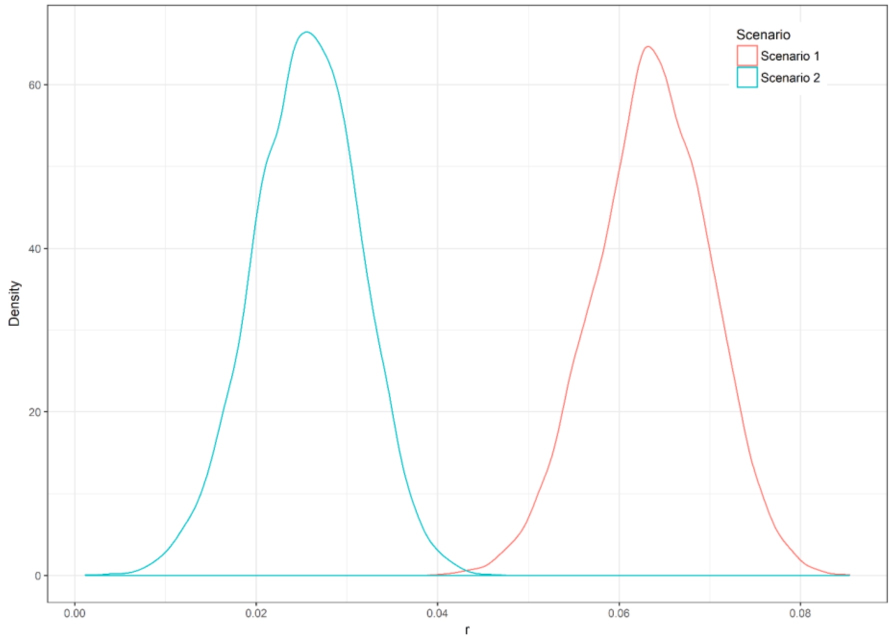


Figure 3.4.2. Plot of r estimates from stochastic demographic analysis for the different biological scenarios.

Assessment model

Influence of the choice of the prior on r:

The two options tested for the prior on r did not have a marked impact on the outcome of CMSY. This is probably due to the fact that, although the range based on the resilience (CMSY default value) is slightly wider than the one based on the Leslie matrix model, the central value for both ranges is similar. The estimated r and k are therefore very similar: Leslie scenario: r = 0.069, k = 727 (thousand tonnes); resilience scenario: r = 0.062, k = 765 (thousand tonnes) (Figure 3.4.3).

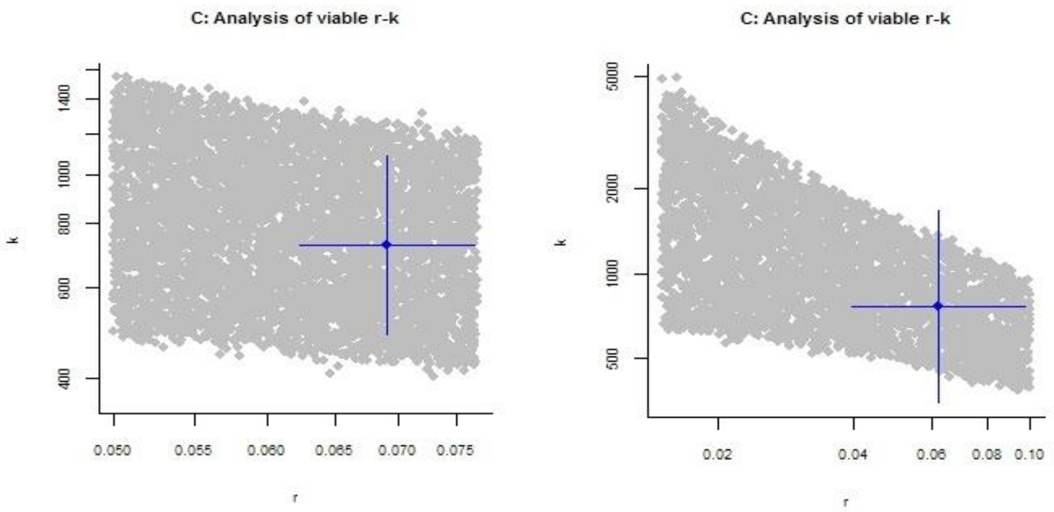


Figure 3.4.3. Viable r/k pairs (grey dots), and "best estimates" (and associated uncertainty), blue crosses, for the runs of CMSY using the Leslie based priors on r Leslie based (0.050 – 0.077; left panel) and the resilience based priors on r (0.015 – 0.1; right panel).

Run with default settings for depletion rate in intermediate year:

Using the default setting resulted in a trajectory strongly constrained by the depletion rate in the intermediate year (Figure 3.4.4). The trajectory goes close to the upper limit in the intermediate year, and close to the lower limit in the final year. This suggests that a less constraining range should be used for the intermediate depletion range.

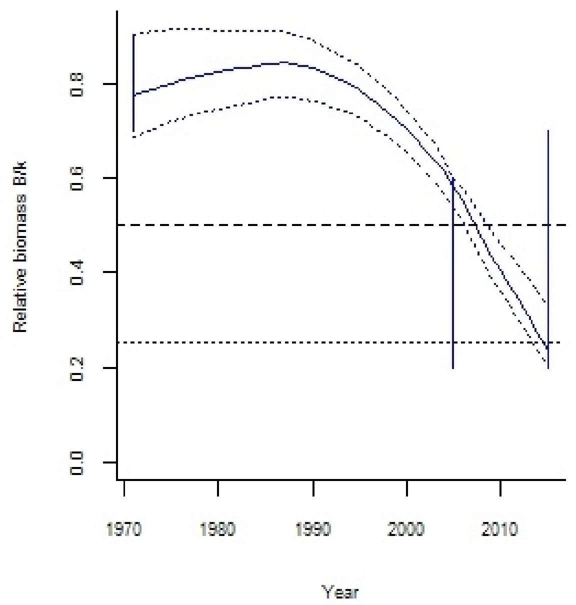


Figure 3.4.4. Estimated stock biomass using the expert knowledge on initial and final depletion rates, and the default setting for intermediate depletion rates.

Output of the final CMSY configuration:

The agreed final configuration of the model included the resilience based r prior (as the Leslie based estimate was considered excessively restrictive), the expert knowledge based initial and final depletion rates (with the assumptions of light depletion in the first year of the time series and a wide range, from light to strong depletion, in the last year of the time series), and a very broad range of depletion for the intermediate year (with a view to minimizing the impact in the CMSY results). Final model configuration estimates of r, k and related quantities are given in Table 3.4.1.

Table 3.4.1. Final model configuration estimates from CMSY.

Parameter	Estimate	95% CI
r	0.062	0.0397-0.0970
k	765 (1000 t)	351-1666 (1000 t)
MSY	11.9 (1000 t)	6.19-22.7 (1000 t)
Relative biomass on last year (2015)	0.528 k	0.215-0.695
Exploitation F/Fmsy on last year (2015)	2	1.54-4.90

The stock is believed to have been at almost pristine state in 1971 (B/k around 0.8), started declining in the 1990s to close to B_{MSY} in 2015. The exploitation rate was low in the early years, increasing strongly since the early 1990s to a value of 2 times F_{MSY} currently.

Therefore, the results give the perception that the stock biomass is still above B_{MSY} (stock is not overexploited), but the current fishing mortality is high, around 2 times higher than F_{MSY} (stock is currently under over-exploitation).

Stock status and management recommendations

Catches exceeded maximum sustainable yield from 1994 onwards, with an upward trend until the end of the reconstructed time series (2015) (Figure 3.4.5).

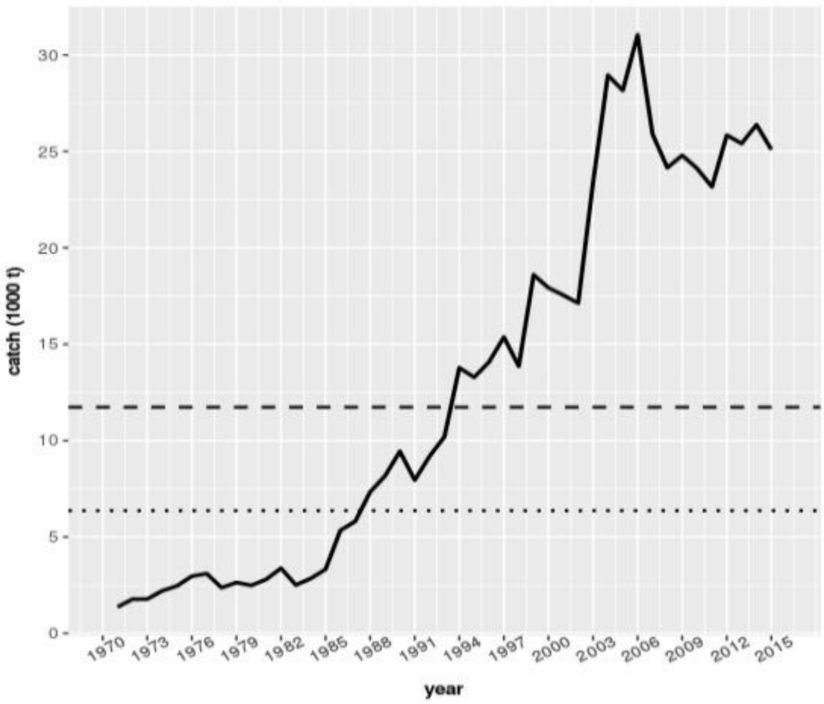


Figure 3.4.5. Reconstructed catch time series (1971-2015). Horizontal dashed line indicates MSY, and the dotted line indicates the lower confidence limit of MSY.

Exploitation was below the MSY-level in the years before 2003. From then onwards, the exploitation increased beyond the levels compatible with maximum sustainable yield. The exploitation rate for year 2015 (last in the available time series) was predicted to be well above the MSY-level (F_{2015}/F_{MSY} = 2.07), with a wide margin of uncertainty around that prediction (1.54-4.90) (Figure 3.4.6).

CMSY predicts biomass above B_{MSY} from the beginning of the time series up to year 2007; from then on, biomass would be between half B_{MSY} and B_{MSY}. The estimation of current biomass (2015) was 1.03, with a considerable margin of uncertainty in the prediction (0.44-1.39) (Figure 3.4.7).

According to the CMSY predictions, at present the silky shark stock would be subjected to overfishing but not overfished (Figure 3.4.8).

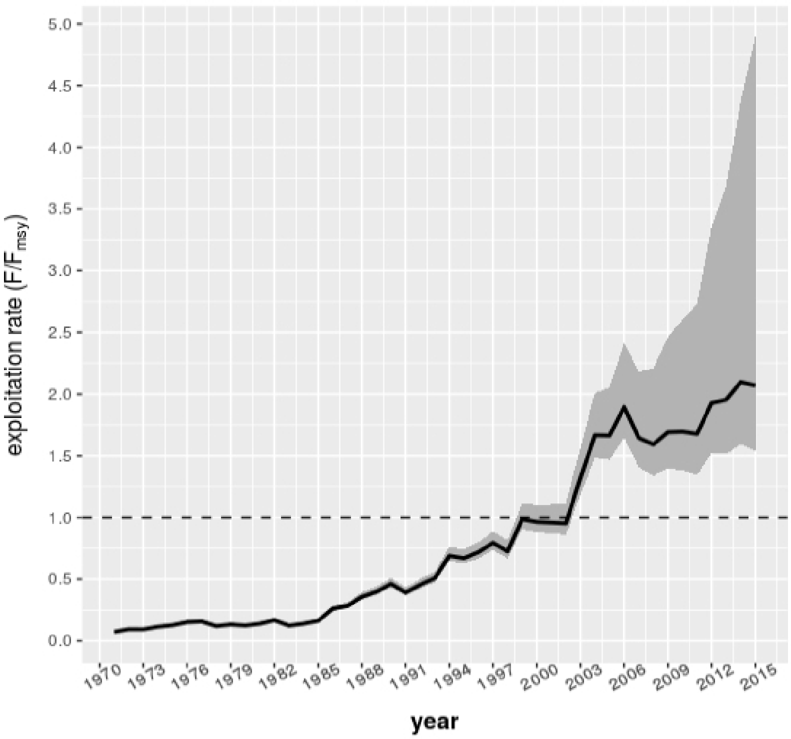


Figure 3.4.6. Exploitation rate (solid line) and associated uncertainty (grey shaded area). Dashed horizontal line indicates exploitation compatible with MSY.

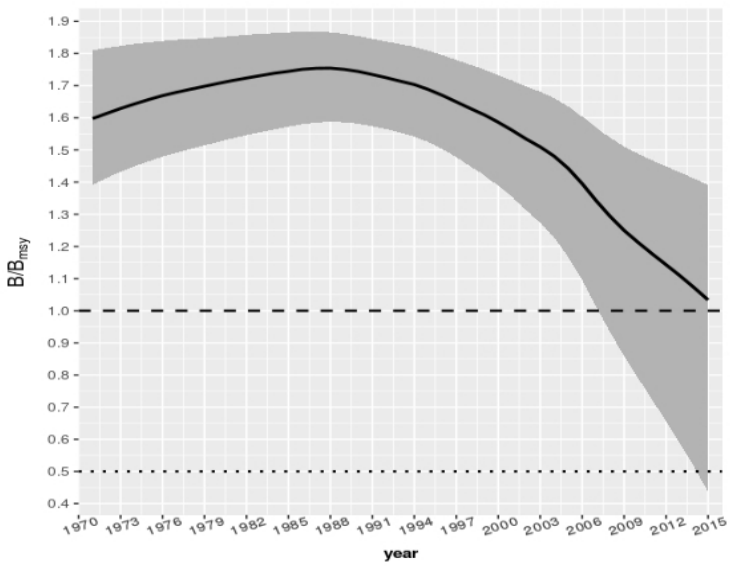


Figure 3.4.7. Biomass predicted by CMSY (solid line), with confidence limits (grey shaded area). Horizontal dashed line indicates B_{MSY} and the dotted line indicates half of B_{MSY}.

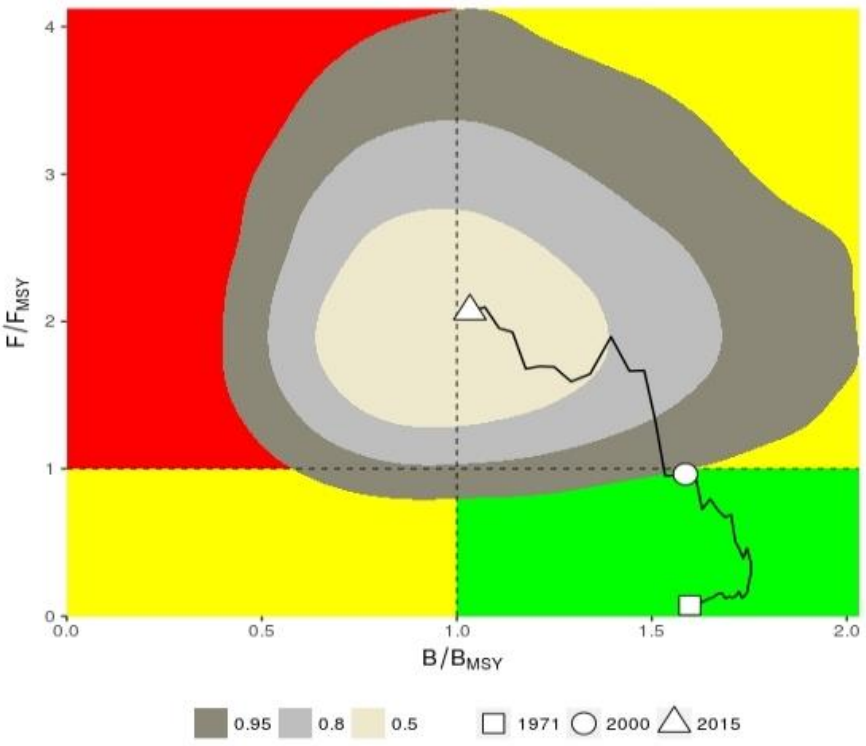


Figure 3.4.8. Temporal evolution of biomass and exploitation relative to B_{MSY} (vertical dashed line) and F_{MSY} (horizontal dashed line), respectively. Bivariate empirical confidence intervals correspond to the last year in the available time series (2015).

e. Final remarks

Due to the considerable amount of uncertainty in the estimates, management advice is not clear. Recent fishing mortality levels appear to be likely in excess of F_{MSY}. Fishing reduction to the levels observed during the last years in the 1990s and early years in the 2000s would likely be sustainable. Precautionary management may restrict catches at levels observed in late 1980s and early 1990s (9000 t) until additional information (for instance, CPUE data) allow for a more detailed analysis.

Given the current level of uncertainty on the estimated reference points, the estimated lower 95% confidence limit of maximum sustainable yield (6400 t) may serve as guidance for total allowed catches.

Management measures designed to reduce catch and effort directed at Indian Ocean silky shark should be implemented.

f. References

Caswell, H. 2001. Matrix Population Models: Construction, Analysis, and Interpretation, 2nd ed. Sinauer Associates, Sunderland, Massachusetts.

Chen, S., Watanabe, S. 1989. Age dependence of natural mortality coefficient in fish population dynamics. *Nippon Suisan Gakk*. 55: 205-208.

Coelho, R., Apostolaki, P., Bach, P., Brunel, T., Davies, T., Díez, G., Ellis, J., Escalle, L., Lopez, J., Macias, D., Merino, G., Mitchell, R., Murua, H., Overzee, H., Poos, J.J., Richardson, H., Rosa, D., Sánchez, S., Santos, C., Séret, B., Urbina, J.O., Walker, N. 2018. Improving scientific advice for the conservation and management of oceanic sharks and rays. Draft Final Report. European Commission. Specific Contract No. 1 under Framework Contract No. EASME/EMFF/2016/008.

Froese, R. and Pauly, D. eds. 2015. FishBase. World Wide Web electronic publication. www.fishbase.org.

Froese, R., Demirel, N., Coro, G., Kleisner, K.M., Winker, H. 2017. Estimating fisheries reference points from catch and resilience. *Fish. Fish*. 18:506-26.

Hall, N., Bartron, C., White, W., Dharmadi, Potter, I. 2012. Biology of the silky shark *Carcharhinus falciformis* (Carcharhinidae) in the eastern Indian Ocean, including an approach to estimating age when timing of parturition is not well defined. *J. Fish Biol*. 80: 1320–1341.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. *Fish. Bull.* 82:898-903.

IOTC, 2016. Silky Shark supporting information. Information collated from reports of the Working Party on Ecosystems and Bycatch and other sources as cited. Available from iotc.org.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Can. J. Fish. Aquat. Sci.* 53: 820-822.

Joung, S.J., Chen, C.T., Lee, H.H., Liu, K.M. 2008. Age, growth, and reproduction of silky sharks, *Carcharhinus falciformis*, in northeastern Taiwan waters. *Fish. Res*. 90: 78–85.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperatures in 175 fish stocks. *J. Cons. Int. Explor. Mer*. 39: 175-192.

Peterson, I., Wroblewski, J.S. 1984. Mortality rates of fishes in the pelagic ecosystem. *Can. J. Fish. Aquat. Sci*. 41: 1117-1120.

Romanov E., Romanova N., 2009. Size distribution and length-weight relationships for some large pelagic sharks in the Indian Ocean. Working Party on Ecosystems and Bycatch, IOTC Document IOTC-2009-WPEB-06: 12 p.

Simpfendorfer, C.A., Bonfil, R., Latour, R.J. 2004. Mortality estimation. In: Musick, J.A., Bonfil, R. (Eds.) Elasmobranch Fisheries Management Techniques, APEC Secretariat, Singapore, pp. 165–186.

12.3. *CASE STUDY 3 – BLUE SHARK - IOTC*

a. Background

Current knowledge and stock status

Blue shark (*Prionace glauca*) is one of the pelagic shark species most frequently caught as bycatch of pelagic fisheries all over the world, sometimes as targeted species. It is considered as one of the main shark species in tuna-RFMOs worldwide. In the Atlantic and Indian Oceans, from the previously conducted Ecological Risk Assessments (ERAs), blue shark received a high vulnerability ranking as, although one of the most productive shark species, it was also characterised by a high susceptibility to longline gear (Cortés et al., 2015; Murua et al., 2012). In the Pacific it was found to be one of the most vulnerable species to pelagic longliners.

Blue shark is most likely the pelagic elasmobranch species for which more data is currently available, including biological data, recent reported catch, discard data and length composition data. Particularly, an extensive review of the Atlantic and Indian Ocean size composition was performed using detailed observer data (Coelho et al., 2017). However, there are still considerable uncertainties in the reported historical catch data and discard rates for this species. For further details on this see Task 1 of the main report from this Project (see Coelho et al., 2018).

In tuna-RFMOs there has been an effort to move to quantitative stock assessments for pelagic sharks, especially in the most recent years and for the main shark species. *P. glauca* is the only species with quantitative stock assessments in the three oceans, carried out in recent years.

In the Pacific Ocean, the North stock was last assessed using both a production model and an integrated age-structured model (using SS3, the Stock Synthesis model platform), of which the latter was adopted for management advice. For that stock it was estimated that spawning biomass is above MSY, and relative fishing mortality is below fishing mortality at MSY (ISC, 2017).

In the South stock of the Atlantic Ocean, Bayesian production models were applied. Some predicted that the stock was not overfished and that overfishing was not occurring while others predicted that the stock was overfished and that overfishing was occurring (Anon., 2015). For the North Atlantic stock, all scenarios considered with the Bayesian surplus production model and also an integrated model (Stock Synthesis) indicated that the stock was not overfished and that overfishing was not occurring. However, it was acknowledged that there still remained a high level of uncertainty in data inputs and model structural assumptions, by virtue of which the possibility of the stock being overfished and overfishing occurring could not be ruled out (Anon., 2015). ICCAT is the only tuna-RFMO that has adopted a regulation measure regarding blue shark[30], which aims to maintain the catches of blue shark to levels not higher than during the period 2011-2015.

In the Indian Ocean, a first stock assessment was attempted in 2015, however due to uncertainties in the input data it was not possible to provide stock status. A new assessment was performed in 2017 by the IOTC Working Party on Ecosystems and Bycatch (WPEB) with improved data. Four stock assessment models were applied in 2017, specifically a data-limited catch only model (SRA), two Bayesian biomass dynamic models (JABBA with process error and a Pella-Tomlinson production model without process error), and an integrated age-structured model (SS3). All models produced similar results suggesting the stock is currently not overfished nor subject to overfishing. But with the trajectories showing consistent trends towards the overfished and subject to overfishing quadrant of the Kobe plot. The major sources of uncertainties identified were catches and CPUE indices of abundance (IOTC, 2017).

Obstacles preventing quantitative scientific advice

As noted above, blue shark has recently been assessed using quantitative methods on all oceans, using mostly integrated age-structure models. However, some models remain highly uncertain due to uncertainties and conflicts in the input parameters.

Therefore, since a considerable amount of information is already available (mainly catch series, relative indices of abundance and size distributions), the next step in the short/medium term for the assessment of the species could be to improve the information that could lead to more robust implementation of the models currently used in assessment and a reduction of the uncertainty of the results.

b. *Objectives*

Given that blue shark is one of the pelagic elasmobranchs for which more data is available, here we focused on the development of a preliminary exercise with data-

[30] ICCAT Recommendation 16-12 – Recommendation by ICCAT on Management for the Conservation of Atlantic Blue Shark caught in association with ICCAT fisheries.

limited Management Strategy Evaluation (MSE) to test options for different management procedures (MPs).

A second objective was to develop length-based indicators, from length-frequency distribution, and compare those to reference points derived from life-history parameters and ecological theory or empirical observation, providing a snapshot of the status.

Thirdly, a draft of an operational management plan for blue shark in the Indian Ocean was prepared, which is provided in Annex III.

c. *Material and Methods*

Management Strategy Evaluation (MSE)

Operating model

Using DLMTools an age-structured spatial operating model (OM; Carruthers et al., 2014) was constructed based on the last IOTC 2017 Stock Synthesis base case assessment (Rice, 2017). In DLMtools, an OM contains four separate components, each containing a set of parameter values for different aspects of the simulation:

- Stock - parameters describing the stock dynamics
- Fleet - parameters describing the fishing fleet dynamics
- Obs (Observation) - parameters describing the observation processes (how the observed fishery data is generated from the simulated data)
- Imp (Implementation) - parameters describing the management implementation (how well the management regulations are implemented)

The Indian Ocean blue shark OM is extensively documented in the Data Limited toolkit Case Studies[31] and is also a data object in the "DLMtool" package in R (R Core Team, 2018).

Management procedure evaluation

Eighty-nine Management Procedures (MPs) were evaluated in the Indian Ocean blue shark MSE, including four reference methods (FMSYref[32], FMSYref50[33], FMSYref75[34], and NFref[35]), which relate to fishing under conditions of perfect

[31] http://www.datalimitedtoolkit.org/Case_Studies_Table/Blue_Shark_IO_IOTC/Blue_Shark_IO_IOTC.html

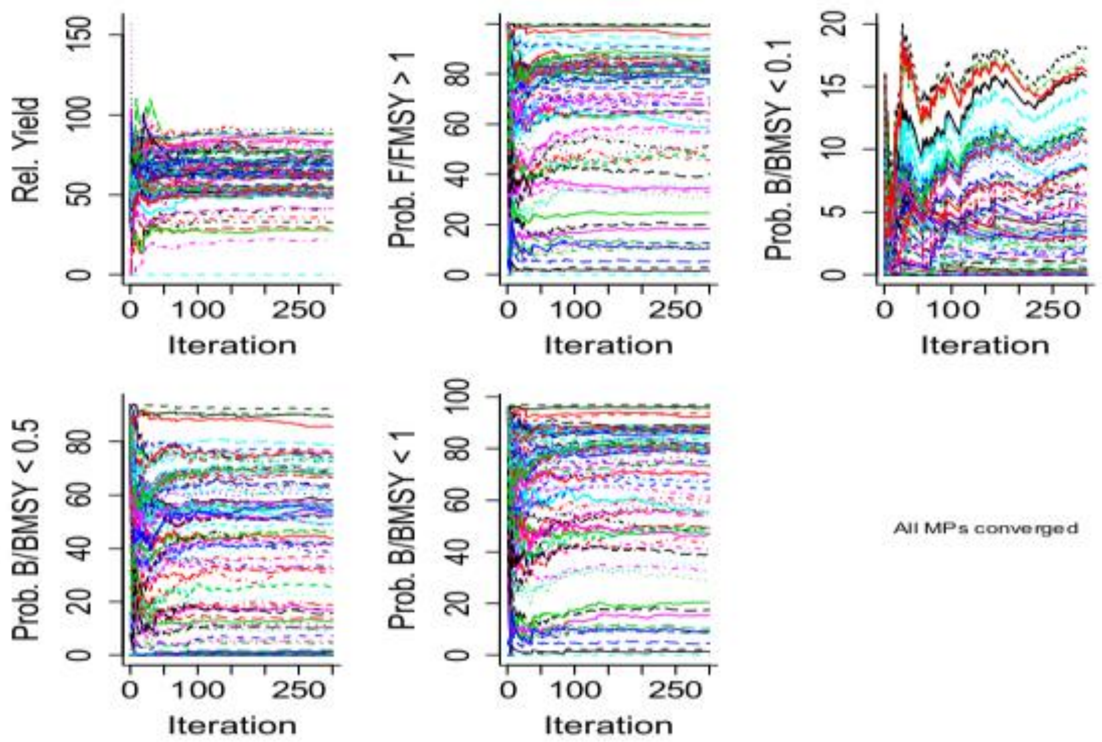
[32] A reference F_{MSY} method
[33] A reference F_{MSY} method that fishes at half of F_{MSY}
[34] A reference F_{MSY} method that fishes at three quarters of F_{MSY}

knowledge. At this stage, no additional custom MPs (complementary to the existing ones in DLMtool) were developed to be tested by this preliminary management strategy evaluation.

A check for MSE convergence was performed based on if the relative position of the tested management procedures was stable with respect to the following performance metrics (Figure 4.3.1):

- AAVY: Average Annual Variability in Yield.
- LTY: Average Long-Term Yield relative to Reference Yield (yield at F_{MSY}).
- P10: Probability Spawning Biomass above 10% B_{MSY}.
- P100: Probability Spawning Biomass > B_{MSY}.
- P50: Probability Spawning Biomass above 50% B_{MSY}.
- POF: Probability F < F_{MSY}.
- STY: Average Short-Term Yield relative to Reference Yield (yield at F_{MSY}).
- Yield: Yield relative to Reference Yield (yield at F_{MSY}).

The number of simulations (300) was sufficient and it is assumed that the MSE model has converged (Figure 4.3.1).



---

35 No Fishing Reference MP

Figure 4.3.1. Convergence diagnostic plot (continuous change in relative position of a particular management procedure is an indication that more iterations are required for the model to converge. All tested management procedures converged).

After checking for MSE convergence, acceptable management procedures (from all that were tested) were identified on the basis of compliance with previously agreed minimum performance limits and management performance targets. Management procedures that fulfil both the minimum performance limits and the management targets are considered to be acceptable options for managing the fishery concerned. As a first step, the minimum performance limits and management performance targets considered were aimed at selecting acceptable methods with a low likelihood of the stock being depleted to low levels and a high probability that the stock biomass is maintained close to the management target.

The defined minimum performance limits and management performance targets were:

1. <u>Minimum performance limits used to eliminate management procedures considered too risky for management:</u>
   80% probability biomass in years 11-50 (last 40 years of projection time) and years 41-50 (last 10 years of projection time) of the projected years (50) above 0.2 B_0. The underlying reason for using both time periods was to warrant that management procedures had a high probability of not falling below the biomass limit for the entire period of the projection, while accounting for simulations where biomass may start below the limit and need a reasonable time to rebuild. The second argument for assessing biomass levels over the last 10 years of the fifty-year projection was to avoid an instance where the biomass is well above the minimum limit for most the projection period, but declining and eventually crashing during the end of the projection period.

2. <u>Removing management procedures that are unlikely to accomplish the management targets for the stock:</u>
   50% probability that the biomass in the last 10 years of the projection period (years 41-50) is above 0.25 B_0 (assumed target level).

The acceptable management procedures were then inspected in relation to current conditions, trends in B/BMSY and F/FMSY and analysis of trade-offs of several performance metrics (e.g. yield vs probability of overfishing and/or being overfished). The value of information was analyzed through the sensitivity of the performance of the MPs with respect to the assumed parameters in the OM and the observation error model (OEM). This analysis was performed for the four management procedures with the greatest sensitivity.

Length based indicators

There has been increasing interest in the application of length-based indicators (LBI) for data-limited stocks. Size-frequency data are often available for both exploited species and common bycatch species. Size-frequency data can be used for screening methods and potentially developing reference points and indicators that reflect size-selective fishing pressure (ICES, 2015a). Indicators of status are calculated from length-frequency distributions and compared to Reference Points (RP) derived from life-history parameters and ecological theory or empirical observation, providing a snapshot assessment of status under steady state assumptions.

The ICES workshop on the 'Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks' (WKLIFE V) selected a set of LBIs characterising conservation of large and small individuals, yield optimisation and maximum sustainable yield (ICES, 2015a). A traffic light approach was used to compare ratios of indicators and reference points to expected values where conservation, yield or MSY properties were considered as achieved. This suite of LBI outputs is considered to provide an overall perception of stock status.

The underlying data requirements are:

- Length at 50% maturity $L_{50\%}$
- von Bertalanffy growth parameter L_∞
- Maximum length L_{max} (whilst this parameter is not used *per se*, this parameter can be used to estimate L_∞, if otherwise unavailable, or to help evaluate what may be a sensible value of L_∞ in published growth studies)
- Life history invariant M/k or individual estimates of natural mortality *M* and von Bertalanffy *k*
- Length-weight conversion factors *a* and *b*
- Catch at length (by sex where appropriate)

The LBI considered by ICES (Table 4.3.1), arranged by property, are:

Conservation of large individuals: Comparing indicators characterising the upper portion of the length frequency distribution to the RP L_∞ provides an indication of the degree of truncation of the population size structure that may be caused by fishing. Indicators chosen to characterise the upper portion are the mean length of the largest 5% ($L_{max5\%}$) and the 95th percentile ($L_{95\%}$) of the length frequency distribution, both of which are considered more stable than the maximum length in the catch (ICES, 2014; Probst *et al.*, 2013). The ratio of indicator to RP L_∞ is expected to be above 0.8, based on a simulation study (Miethe and Dobby, 2015).

The proportion of mega-spawners (fish larger than the optimum length, L_{opt}, plus 10%) in the stock (P_{mega}) follows the principle of '*Let the mega-spawners live*' (Froese, 2004). Old, large fish play several important roles in the long-term survival of a population, as they may produce more eggs (increased fecundity), larger eggs or young (which may have better survival) and may have a greater spawning success. Consequently, P_{mega} can be viewed as a simple proxy for the resilience of a stock. The principle is to implement a fishing strategy where no mega-spawners are caught. However, if the catch reflects the size structure of the population, values above 0.3 are considered healthy (Froese, 2004; Miethe & Dobby, 2015).

Conservation of immatures: LBI relating to small individuals follow the principle '*Let them spawn*' (Froese, 2004). Overfishing is theoretically impossible if every spawner produces at least one replacement spawner (Myers and Mertz, 1998). Therefore, if the indicator length at first capture (L_c; estimated as the length at 50% of the first mode) is above the RP L_{mat}, biomass is likely to be above that which produces MSY (ICES, 2014). A simulation study found the 25th percentile ($L_{25\%}$) of the length frequency distribution to be a suitable proxy when L_c is difficult to estimate (Miethe & Dobby, 2015). Based on theory, the ratio of indicator to RP L_{mat} is expected to be greater than 1.

Optimal yield: LBI relating to optimal yield follow the principle '*Let them grow*' (Froese, 2004) which states that all fish caught should be within 10% of the RP optimum harvest length (L_{opt}). L_{opt} represents the length where cohort biomass and egg production are maximal in an unexploited state and where catch is maximal for a given fishing mortality (*F*), or *F* minimal for a given catch (Cope & Punt, 2009). L_{opt} is calculated:

$$L_{opt} = \frac{3}{3 + M/_k} L_\infty$$

Where *M* is natural mortality, *k* is the von Bertalanffy rate coefficient and *M*/*k* is a life history invariant. If the central indicators mean length of individuals larger than L_c (L_{mean}) or length class with maximal biomass (L_{maxy}) are close to the RP L_{opt} then either the stock is lightly exploited or the fishery is operating with a target length that is sustainable and close to MSY (ICES, 2014). Given the requirement that fish caught are within 10% of L_{opt}, the ratio of indicator to RP should be 0.9–1.1.

MSY: *F=M* is a proxy for MSY. The length at which *F=M* ($L_{F=M}$) is rearranged from Beverton and Holts equation for mean length in the catch as a function of the von Bertalanffy growth parameters, length at first capture and natural and fishing mortality:

$$L_{F=M} = (1-a)L_c + aL_\infty$$

$$a = \frac{1}{2\left({}^{M}/_{k}\right) + 1}$$

This RP gives the mean length in the catch expected from fishing at F=M in the long term; hence a suitable indicator is L_{mean}. If L_{mean} is less than $L_{F=M}$ then fishing mortality is likely to be larger than *M* and hence F_{MSY} (ICES, 2014). The ratio of indicator to RP should therefore be greater than or equal to 1.

Table 4.3.1: Summary of length-based indicators (LBI) with corresponding reference points and indicator ratio.

Indicator	Calculation	Reference point	Indicator ratio	Expected value
$L_{max5\%}$	Mean length of largest 5%	L_{inf}	$L_{max5\%}/L_{inf}$	> 0.8
$L_{95\%}$	95th percentile of the length frequency distribution	L_{inf}	$L_{95\%}/L_{inf}$	> 0.8
P_{mega}	Proportion of individuals above Lopt + 10%	0.3-0.4	P_{mega}	> 0.3
$L_{25\%}$	25th percentile of the length frequency distribution	L_{mat}	$L_{25\%}/L_{mat}$	> 1
L_c	Length at first catch (length at 50% of mode)	L_{mat}	L_c/L_{mat}	> 1
L_{mean}	Mean length of individuals > Lc	$L_{opt}=2/3L_{inf}$ *	L_{mean}/L_{opt}	≈ 1
L_{maxy}	Length class with maximum biomass in catch	$L_{opt}=2/3L_{inf}$ *	L_{maxy}/L_{opt}	≈ 1
L_{mean}	Mean length of individuals > L_c	$LF=M=(0.75Lc+0.25L_{inf})$ *	L_{mean}/LF=M	≥ 1

* simplified equations resulting from substituting M/k = 1.5; an assumption based on the life history of teleost fish

Whilst such length-based approaches have been used for various stocks of teleost and shellfish (ICES, 2015b), they have not been applied extensively to elasmobranchs. Potential obstacles for using LBI for elasmobranchs include:

a. Sample size: Are the underlying sample sizes sufficiently large, given that there can be a broad length range and limited availability of data?

b. Variability in measurements: Elasmobranchs may be measured as total length (with caudal fin depressed), total length (with caudal fin in natural position), fork length, precaudal length or, for batoids, disc width. Furthermore, some measurements may be taken in a 'straight line' under the body or by tape measure over the body, the latter potentially including 'curvature' and thus exaggerating true length.

c. Sexual and ontogenetic segregation: The complex segregation of many shark species, whereby they can aggregate according to sex and/or size, may influence the catches that are measured, and so could confound any observations on temporal changes in LBI. This issue may also be more pronounced when sampling effort (e.g. numbers of trips) are limited.

d. Size selectivity: Some fisheries encountering sharks may not sample the full-length range, as smaller individuals may not get hooked, larger individuals may break through the snood. Hence, any spatio-temporal changes in fishing practices and gear configurations may result in a change in size selection, which may not be accounted for in underlying data.

Length-length conversion factors

As the various data considered in the present case study incorporated information on total length (L_T), fork length (L_F) and precaudal length (L_{PC}), attempts have been made to standardise all data to L_T, using the equations below:

$L_{PC} = 0.762.L_T - 0.2505$ Nakano et al. (1985), cited by Semba & Yokoi (2016)

$L_{PC} = 0.76.L_T - 1.95$ McKinnell & Seki (1998), cited by Nakano & Seki (2003)

$L_{PC} = 0.74.L_T + 3.92$ Hazin et al. (1991), cited by Nakano & Seki (2003)

$L_F = 1.3908 + 0.8313.L_T$ Kohler et al. (1996)

Conversions of L_{PC} to L_T were based on the mean values obtained from equations 1–3. Only a single equation was used for L_F to L_T (Kohler et al., 1996), as this study was based on a much larger sample size than other published studies.

Maximum length L_{max}

The maximum length reported for *P. glauca* is at least 383 cm L_T (Bigelow and Schroeder, 1948; Ebert & Stehmann, 2013).

Interestingly, the largest length bin in the data set analysed was the 365–370 cm L_F (= 437.4–443.4 cm L_T), which would indicate that either the L_{max} in several sources is incorrect, there has been a measurement or input error, or some of the data ascribed as L_F were actually L_T.

Whilst L_{max} is not necessarily included within LBI, it is recommended that such information be collated, as L_{max} can be used to derive estimates of L_∞ (if robust growth studies are lacking). It can be informative as to gauging whether published growth parameters are biologically plausible, and it can help in the quality checking of input data.

Length at 50% maturity $L_{50\%}$

This was based on the reported lengths at 50% maturity ($L_{50\%}$) for female *P. glauca.* Published estimates of $L_{50\%}$ range from 193 cm L_T (Joung et al., 2011; cited by Rice & Semba, 2014) and 194.4 cm L_T (Jolly et al., 2013), to 159 cm L_{PC} (=210 cm L_T; Nakano et al. 1985) and 140–160 cm L_{PC} (= 186–212 cm L_T; Nakano & Seki, 2003).

For the purposes of the present study, two values of $L_{50\%}$ were considered. The first value (193.7 cm L_T) was based on the mean of the estimates of Joung et al. (2011) and Jolly et al. (2013) and includes one study from South African waters. This value was broadly comparable with the findings of Francis & Duffy (2005). The second value was 210 cm L_T, as this better reflected the findings of Nakano et al. (1985) and Nakano & Seki (2003), noting that these studies were from the north-western Pacific Ocean.

Growth parameters L_∞ and k

There have been several age and growth studies for blue shark in the Pacific Ocean and around South Africa (Cailliet & Bedford, 1983; Tanaka, 1984; Nakano, 1994; Hsu et al., 2011; Jolly et al., 2013; Fujinami et al., 2016), and so there are various estimates for both k and L_∞. The values considered in the present case study are given in Table 4.3.2. Given that the female L_∞ estimated by Cailliet & Bedford (1983) does not appear to be biologically plausible, and the estimate of k was much higher than other studies, this study was excluded.

From the remaining five studies, the mean value of k for females was 0.138 (range = 0.11–0.172), whilst the mean value of L_∞ for females was 330.4 cm L_T (range = 317.4–339.2).

Table 4.3.2. Summarised growth parameters considered in the exploratory analyses. F = Female; M = Male; C = Combined; L_T = Total length (cm); L_{PC} = Pre-caudal length (cm).

Area	**Sex**	**Length**	**L_∞**	**Conversion to L_T**	**K**	**Source**
California	F	L_T	241.9		0.251	Cailliet & Bedford (1983)
	M	L_T	295.3		0.175	
	C	L_T	265.5		0.223	
North Pacific	F	L_{PC}	243.3	(= 321.9 L_T)	0.144	Nakano (1994), cited by Semba & Yokoi (2016)
	M	L_{PC}	289.7	(= 383.5 L_T)	0.129	
North Pacific	F	L_T	317.4		0.172	Hsu et al. (2011), cited by Semba & Yokoi (2016)
	M	L_T	375.8		0.121	
North Pacific	F	L_{PC}	256.3	(= 339.2 L_T)	0.147	Fujinami et al. (2016), cited by Semba & Yokoi (2016)
	M	L_{PC}	284.8	(= 377.0 L_T)	0.117	
North Pacific	F	L_{PC}	256.1	(= 338.9 L_T)	0.116	Tanaka (1984), cited by Nakano & Seki (2003)
	M	L_{PC}	308.2	(= 408.0 L_T)	0.094	
South Africa	F	L_T	334.7		0.11	Jolly et al. (2013)
	M	L_T	294.6		0.14	
	C	L_T	311.6		0.12	

Natural mortality M

There have been several studies attempting to estimate M for *P. glauca.* Aires-da-Silva & Gallucci (2007) estimated annual survivorship (s), where $s = e^{-M}$, for the North Atlantic stock from various theoretical approaches. The mean and median survivorships for ages 2+ were estimated at 0.78 and 0.81, and the maximum estimated survivorship was 0.91. These three values equate with estimated values of M of 0.248, 0.211 and 0.094, respectively.

Biologically-speaking, *M* should be age/size dependent, with higher *M* for the smallest size classes. Semba & Yokoi (2016) provided age- and sex-specific estimates of *M* for *P. glauca* in the North Pacific. Depending on the estimator and growth parameters used, estimates of *M* ranged from 0.081–0.392 (males) and 0.083–0.365 (females). The means of these values were approximately 0.2.

For the purposes of the present study, two arbitrary values of *M* were considered: 0.1 (which is close to the minimal estimates of both Semba & Yokoi (2016) and Aires-da-Silva & Gallucci (2007)), and 0.2, which was the approximate mean value of Semba & Yokoi (2016) and close to the median value of Aires-da-Silva & Gallucci (2007).

The life history parameters used for the exploratory analyses of LBI for Indian Ocean blue shark are summarised in Table 4.3.3.

Table 4.3.3. Summary table of input parameters for LBI. L_T = Total length and L_F = fork length.

Parameter		Value (L_T)	Value (L_F)
L_∞ (female)	Mean	330.4 cm	276.05
	Min	317.4 cm	265.25
	Max	339.2 cm	283.37
$L_{50\%}$ (female)	Lower estimate	193.7 cm	162.41
	Upper estimate	210 cm	175.96
k (female)	Mean	0.138	
	Min	0.110	
	Max	0.172	
M	Lower estimate	0.1	
	Upper estimate	0.2	
a			3.18×10^{-6}
b			3.1313

Catch data available

Data used during the last stock assessment by IOTC were used for exploratory analyses of LBI. Sex-disaggregated size data were available for five 'fleets' operating, or that had operated, in the IOTC area (Table 4.3.4).

Data from the former Soviet Union were available for the years 1966–1989, but sample sizes could be small in many of these years. Consequently, data were aggregated into three 8-year time blocks (1966–1973, 1974–1981 and 1982–1989).

There were a few records (n = 11) of fish in or above the [335–340) length bins. If these values do reflect L_F then that would equate with specimens greater than 4 m L_T, and so further quality checks on whether these are coding errors, or whether the original data actually refer to L_T, could usefully be undertaken. For the exploratory studies presented here, all fish in or above the [340-345) length bins were excluded.

Table 4.3.4: Sample sizes and length ranges of Indian Ocean blue shark measured in Japanese, Portuguese, Taiwanese and South African fisheries, with earlier data from former Soviet Union exploratory fisheries.

Nation	Years	Females		Males	
		Sample size (by year)	Length range	Sample size (by year)	Length range
Japan	1992–2013	146–2571	[40–45) – [285–290)	69–2337	[40–45) – [365–370)
Portugal	2011–2014	83–358	[100–105) – [290–295)	462–1980	[95–100) – [295–300)
Taiwan	2004–2013	157–898	[55–60) – [350–355)	124–1199	[55–60) – [345–350)
Soviet Union	1966–1989	2–324	[60–65) – [605–310)	1–597	[55–60) – [310–315)
South Africa	2012–2014	200–528	[70–75)– [320–325)	733 – 1311	[70–75) – [310–315)

Data analyses

The following analyses were undertaken

1. Initial analyses of Portuguese data to look at various scenarios (e.g. using different life history parameters) to inform on base case by sex and combined sexes
2. Examination of USSR (1966-1973; 1974–1981; 1982–1989 time blocks) and Japanese data (1992–2013, by year), to see if there were any longer-term changes (noting that there may be gear-related and spatial factors as well as temporal changes)
3. Japanese data: This dataset provided the best temporal resolution for recent trends by sex and sexes combined

Nation or fleet-related differences: Analyses of Japanese (2009–2013; subset comparable to other nations), Portuguese (2011-2014; only 4-yr available), Taiwanese (2009–2013; 5-yrs of better data), and South African data (2012–2014;

only 3-yr available). Analyses were also conducted to see if LBI varied between fisheries over a relatively consistent period by sex and combined.

d. Results

Management Strategy Evaluation

Fourteen management procedures overtook the performance limit of at least 80% probability that biomass is above $0.20B_0$ in the last 40 years of the projection (Figure 4.4.1). Twelve management procedures met the requisites for the performance metric of at least an 80% probability that biomass is above $0.20B_0$ in the last 10 years of the projection period (Figure 4.4.2). All management procedures that passed the performance limit of at least 80% probability that biomass is above $0.20B_0$ in the last 40 years of the projection also passed the limit of at least an 80% probability that biomass is above $0.20 B_0$ in the last 10 years of the projection period.

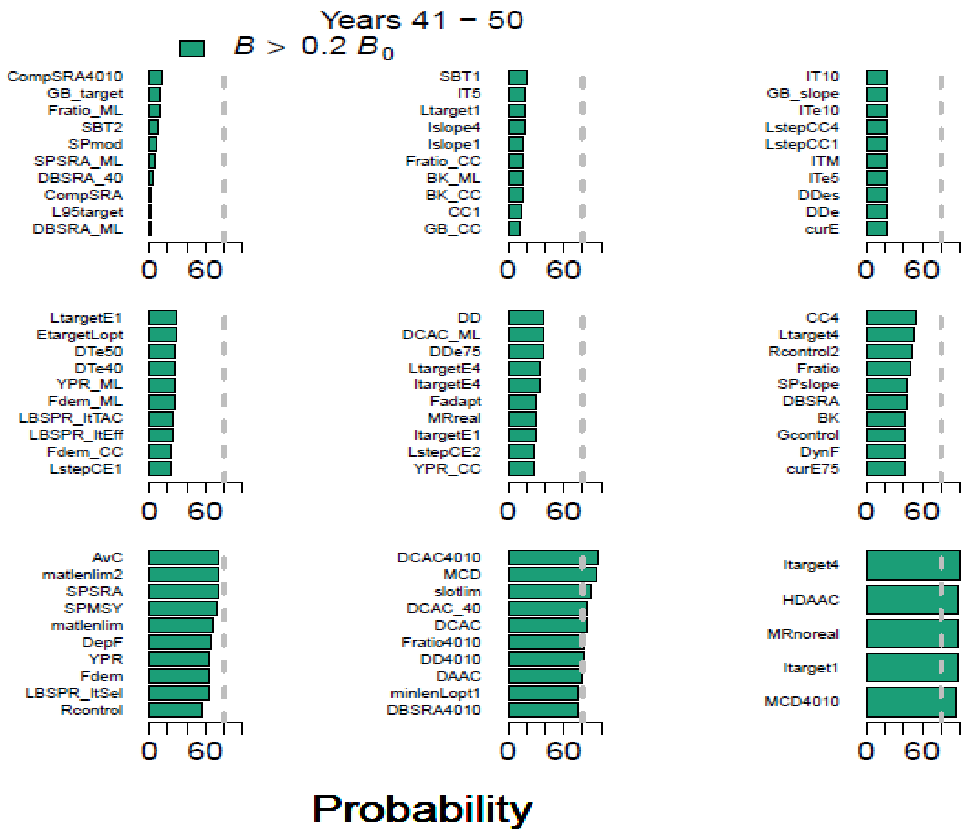


Figure 4.4.1. Probability of each management procedure meeting the performance limit of at least 80% probability that biomass is above $0.20B_0$ in the last 40 years of projection.

Two management procedures, DAAC and AVC[36], met the requirements for the first performance limit (at least 80% probability that biomass is above $0.20B_0$ in last 40 years; Figure 4.4.1), but did not pass the second performance limit (at least an 80% probability that biomass is above $0.20B_0$ in last 10 years of the projection period; Figure 4.4.2).

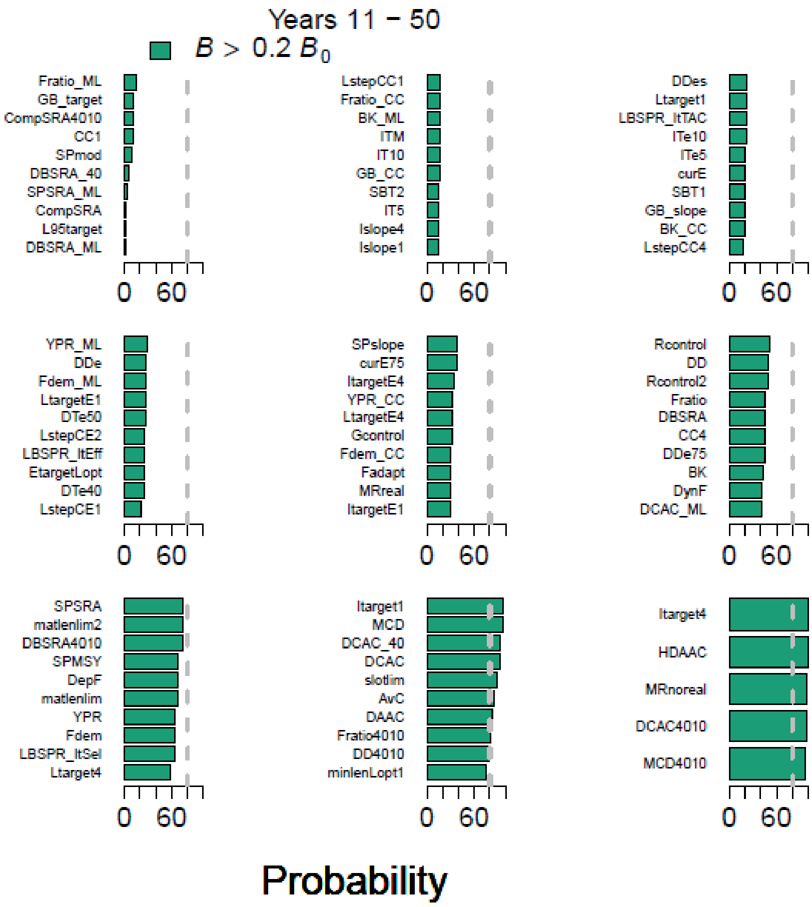


Figure 4.4.2. Probability of each management procedure meeting the performance metric of at least an 80% probability that biomass is above $0.20B_0$ in last 10 years of the projection period.

Nine management procedures passed the requirements for the management objective of at least 50% probability that biomass is above $0.25B_0$ in the last 10 years of the fifty-year projection period (Figure 4.4.3). Three of the management procedures that passed both performance limits did not pass the requirements for the management target.

---

[36] DAAC: Depletion Adjusted Average Catch; AvC: Average Catch

From the tested MPs, 9 were considered potentially acceptable management procedures for the Indian Ocean blue shark, specifically:

- DCAC: Depletion-Corrected Average Catch. An MSY proxy that accounts for catches occurring whilst dropping to productive stock sizes. *Output Control Method*.
- DCAC_40: DCAC assuming depletion is 40%. DCAC where stock depletion is fixed at 40%. *Output Control Method*.
- DCAC4010: Delay-Difference assessment linked to a 40-10 rule[37]. A 40-10 harvest control rule is added to the Delay-Difference management procedure. *Output Control Method*.
- MCD: Mean Catch Depletion management procedure. Management procedure to demonstrate high information content of depletion TAC = mean catches*2*depletion. *Output Control Method*.
- MCD4010: MCD linked to a 40-10 rule. A 40-10 harvest control rule is added to the MCD management procedure. *Output Control Method*.
- HDAAC: Hybrid Depletion Adjusted Average Catch. Essentially DCAC multiplied by 2*depletion and divided by B_{MSY}/B_0 (B_{peak}) when below B_{MSY}, and DCAC above B_{MSY}. *Output Control Method*.
- Itarget1: CPUE target management procedure. TAC is adjusted to achieve a target CPUE. *Output Control Method*.
- Itarget4. CPUE target management procedure (more biologically precautionary). TAC is adjusted to achieve a target CPUE. *Output Control Method.*
- MRnoreal. Area 1 Marine Reserve with no reallocation. Sets a marine reserve in Area 1 with no reallocation of fishing effort to area 2. *Input control methods-Spatial[38].*

---

[37] 40-10 rule: If the stock is estimated to be above 40% of its unfished size (B0) the target catch is the population size multiplied by F_{MSY}. If the stock is below 10% of its unfished size no catch is permitted. Between 10-40% of B_0 the fishing mortality rate increases from 0 to F_{MSY}.

[38] DLMtool uses a two-box spatial model and assumes homogeneous fishing and distribution of the fish stock. Current OM parameterization regarding spatial distribution and movement of the Indian Ocean blue shark is:
Size_area_1, the size of area 1 relative to area 2: Uniform distribution (0.5, 0.5): a mixed stock is assumed;
Frac_area_1, the fraction of the unfished biomass in stock 1. Uniform distribution (0.5, 0.5): a mixed stock is assumed;
Prob_staying, the probability of inviduals in area 1 remaining in area 1 over the course of one year. Uniform distribution (0.5, 0.5): a mixed stock is assumed.

The MPs include eight output control methods (methods that return a TAC) and one input control method (MRnoreal, a spatial control that prevents fishing in area 1 and does not reallocate this fishing effort to area 2).

A comparison of the median biomass and median yield over the last 5 years of the projection relative to the last year in the historical period is showed in Figure 4.4.4. All the acceptable management procedures imply a reduction in yield in the long term (five last years of the projection) with respect to current yield (last year of the historical period). Yield decrease in the range of 0.31 to 0.57.

There is an obvious trade-off with respect to the expected long-term yield relative to current yield and the expected long-term biomass relative to current biomass.

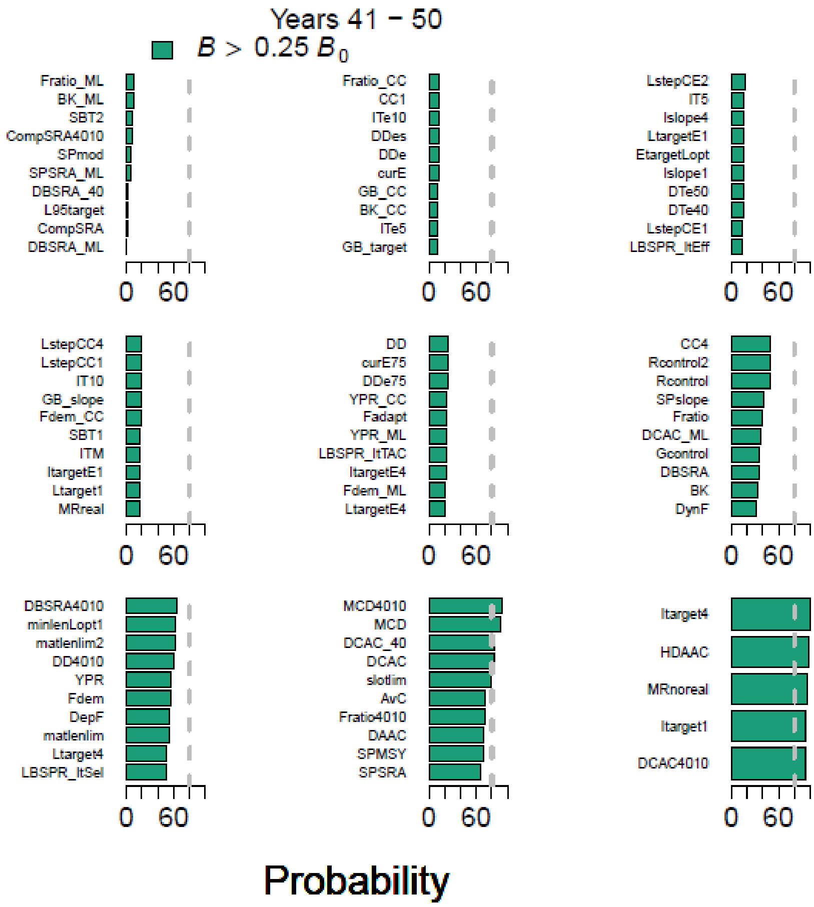


Figure 4.4.3. Probability of each management procedure meeting the management objective of at least 50% probability that biomass is above $0.25B_0$ in the last 10 years of the fifty-year projection period.

Itarget1 and MRnoreal are the management procedures that represent a smaller loss in yield. HDAAC shows the higher value in expected long-term biomass at the expense of decreased long-term yield. A lower reduction in long term yield comes at the expense of being less precautionary (lower expected long-term biomass).

The other acceptable management procedures have similar performance in terms of expected long term yield relative to current yield and expected long-term biomass relative to current biomass.

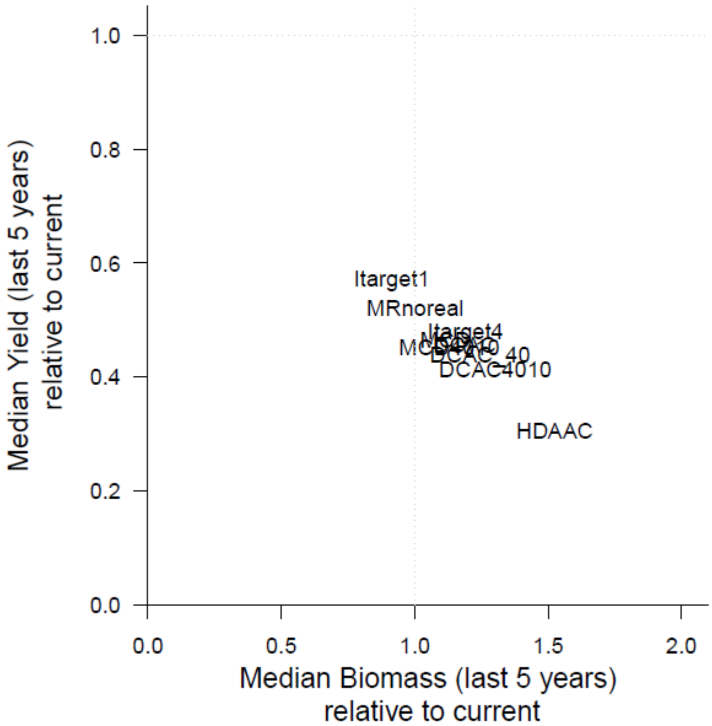


Figure 4.4.4. Median biomass and median yield over the last five years of the projection relative to the last year in the historical period.

Trends in biomass relative to biomass at maximum sustainable (B/B_{MSY}), and fishing mortality relative to the rate corresponding to maximum sustainable yield (F/F_{MSY}) for each simulation, management procedure and projection year are presented in Figure 4.4.5. In general, the relative biomass for the stock increases through the projection period for all the acceptable management procedures, with the median relative biomass increasing from the first year to the final year of the projection. Nevertheless, the distributions show quite notable variability, suggesting that although the methods work well on average, the final biomass was very low in some simulations.

The distribution of fishing effort for each management procedure in the final year of the projection period is shown in Figure 4.4.6, trends appear to be fairly flat for the projected years, and less variable than the biomass trends.

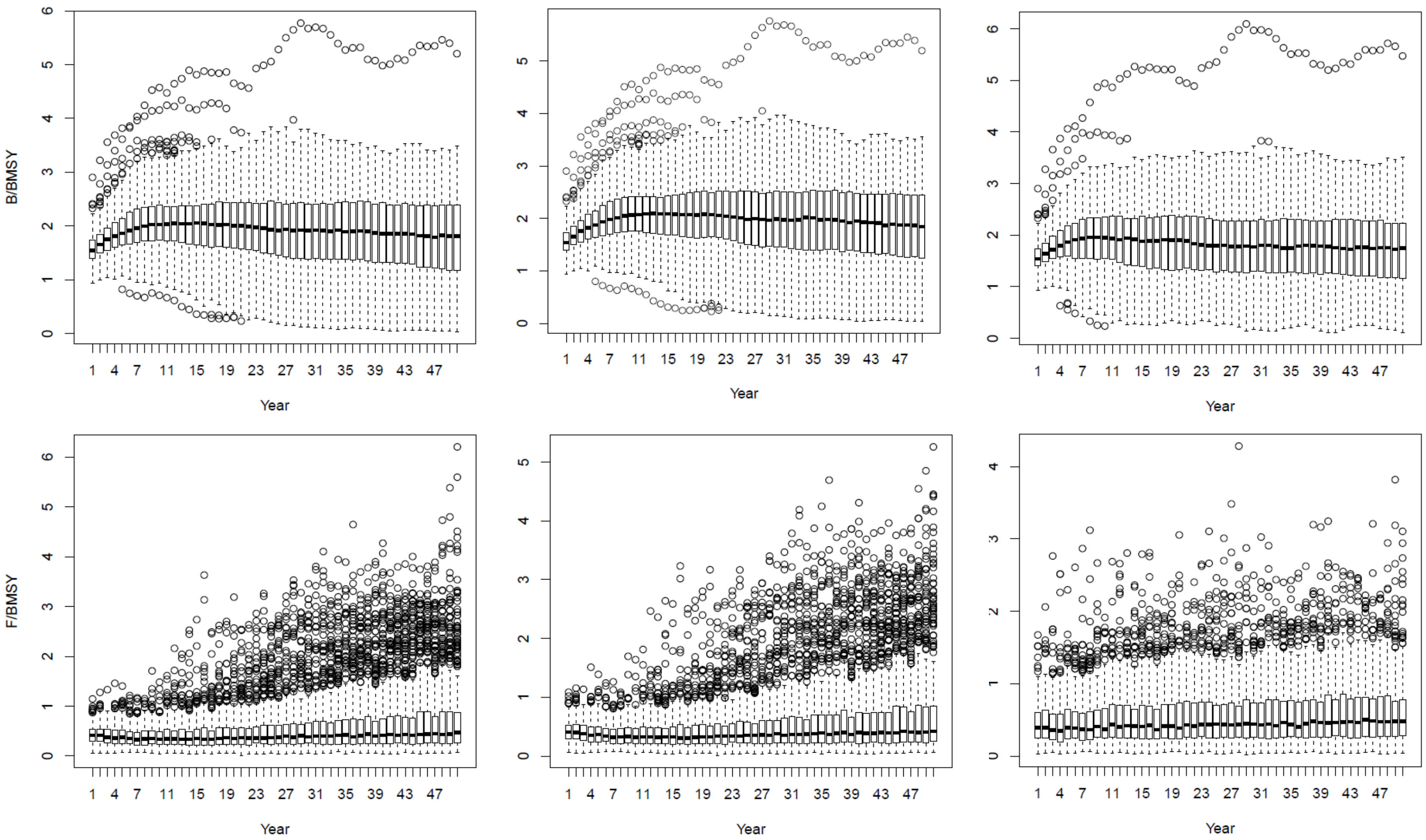


Figure 4.4.5. Distribution of B/B_{MSY} (top) and F/F_{MSY} (bottom) for the projection years for DCAC (left panels); DCAC_40 (middle panels) and MCD (right panels).

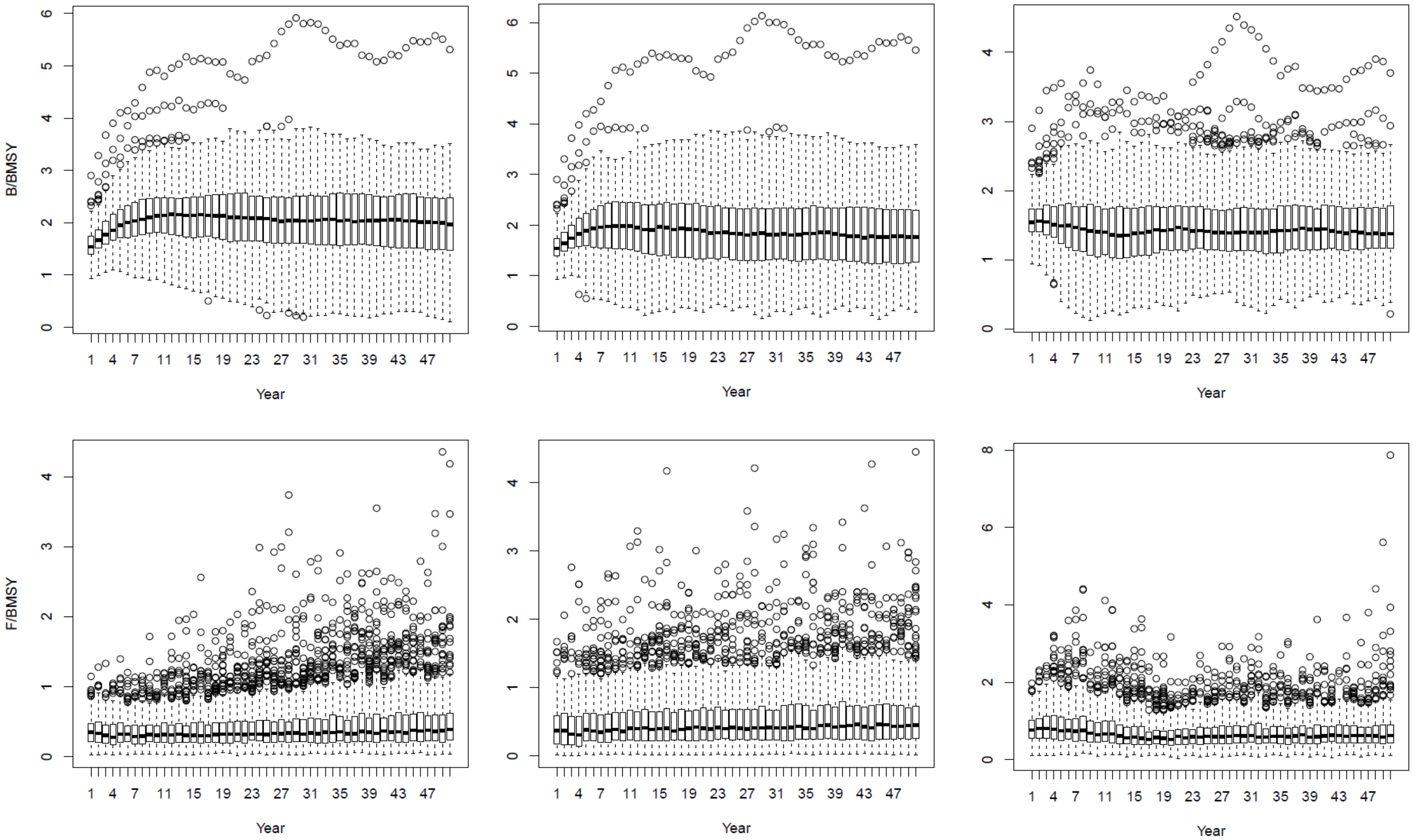


Figure 4.4.5.(continued) Distribution of B/B_{MSY} (top) and F/F_{MSY} (bottom) for the projection years for DCAC4010 (left panels); MCD4010 (middle panels) and Itarget1 (right panels).

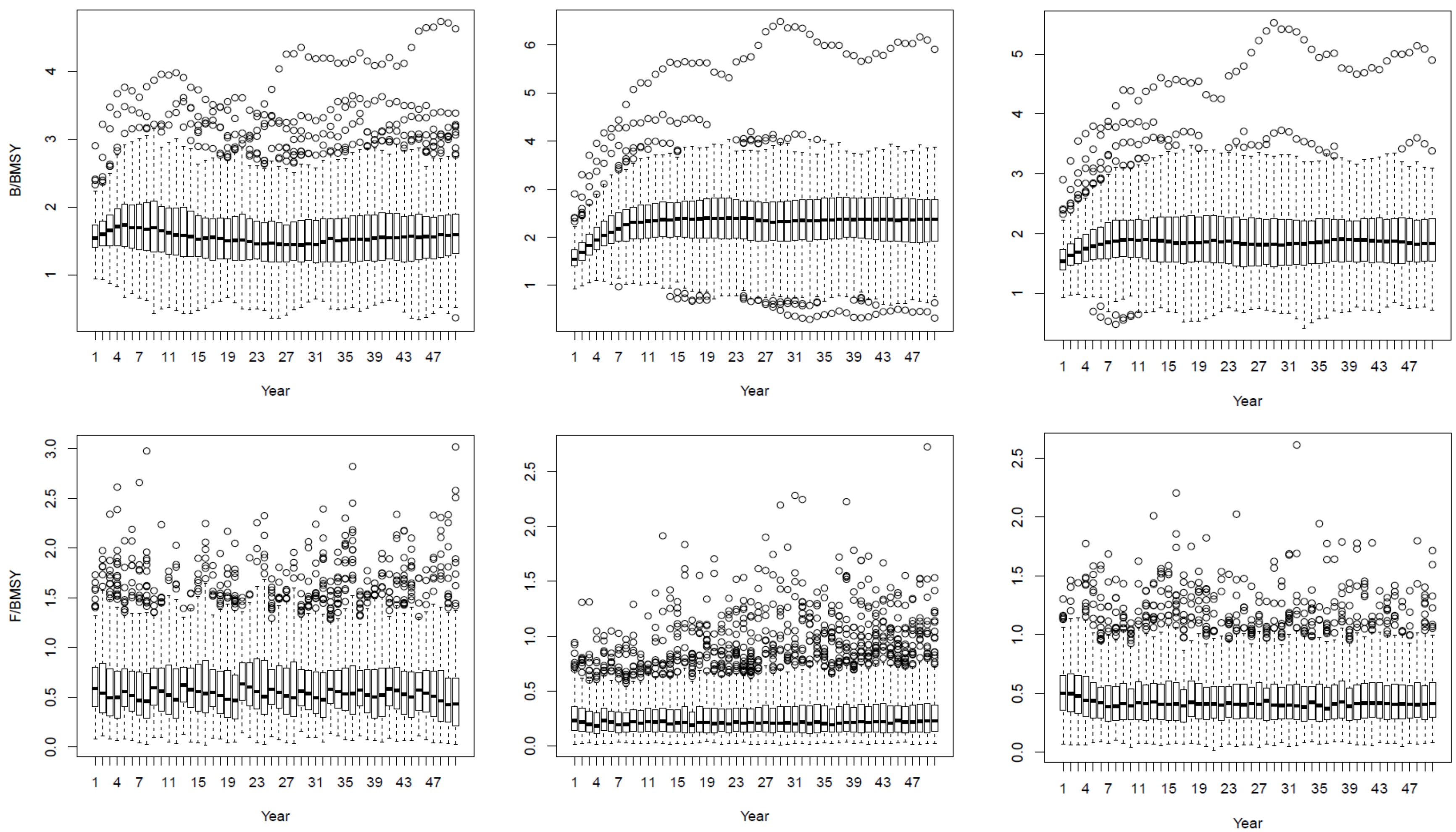


Figure 4.4.5.(continued) Distribution of B/B_{MSY} (top) and F/F_{MSY} (bottom) for the projection years for MRnoreal (left panels); HDAAC (middle panels) and Itarget4 (right panels).

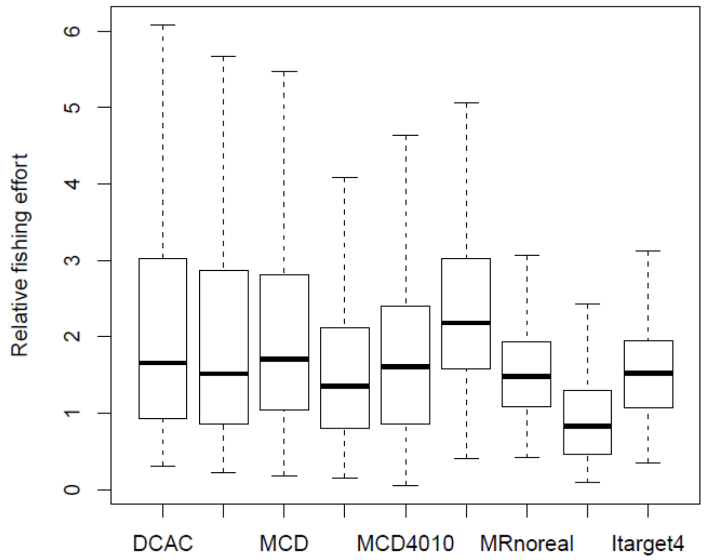


Figure 4.4.6. Relative fishing effort in the final year of the projection by management procedure

Trade-off between the expected relative yield and the probability of overfishing ($F>F_{MSY}$), and the probability of the biomass being below three different reference points ($B<B_{MSY}$, $B<0.5B_{MSY}$, $B<0.1B_{MSY}$) is presented in Figure 4.4.7. The Itarget1 management procedure results in the highest long-term yield with remarkably low probability of overfishing and biomass being below the different reference points ($B<B_{MSY}$, $B<0.5B_{MSY}$, $B<0.1B_{MSY}$). The HDAAC management procedure shows the lowest probabilities that the biomass will fall below the different reference points.

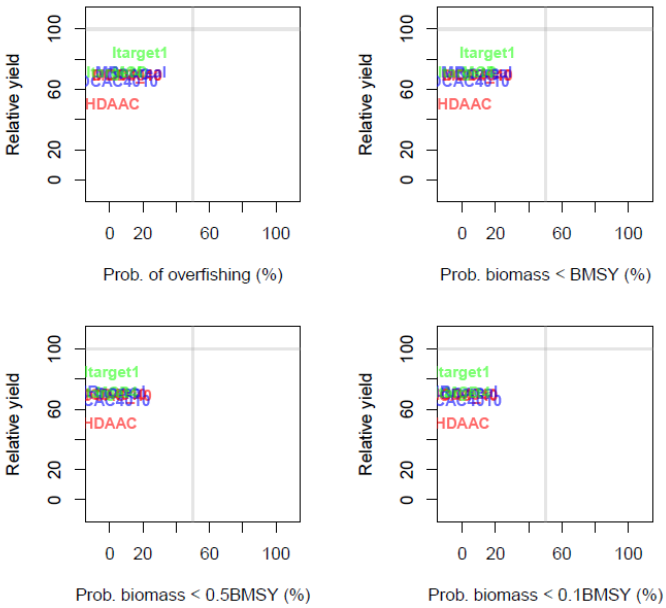


Figure 4.4.7. Trade-off between the expected relative yield and the probability of overfishing ($F>F_{MSY}$) and the probability of the biomass being below three different reference points: $B<B_{MSY}$, $B<0.5B_{MSY}$, $B<0.1B_{MSY}$.

Comparison of long-term yield (LTY: fraction of simulations getting over half F_{MSY} yield in the last ten years of the projection) vs short-term yield (STY: fraction of simulations getting over half F_{MSY} yield in the first ten years of the projection) and variability in yield (VY: fraction of simulations where average annual variability in yield is less than 10 percent) vs biomass level (B_{10}: the fraction of simulations in which biomass stays above 10 percent of B_{MSY}) is shown in Figure 4.4.8.

Only one MP (HDAAC) presents a probability lower than 50% of short term and long term yield getting over half F_{MSY} yield. The remaining MPs have similar probabilities, except for Itarge1 which presents more than 80% probability of short term and long term yield getting over half F_{MSY} yield. All MPs have a very high probability (close to 100%) of the biomass being above $0.1B_{MSY}$ but a very low probability (close to zero) that the VY in yield is less than 10%.

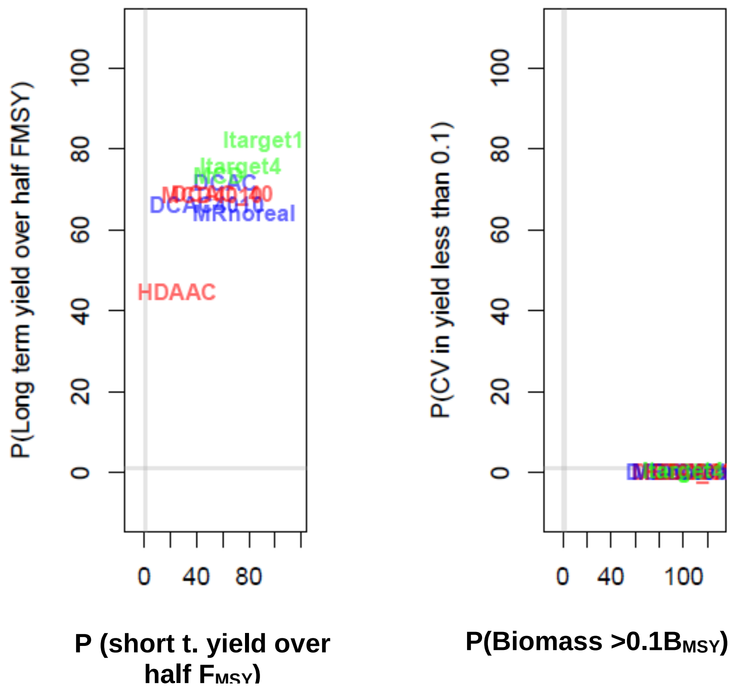


Figure 4.4.8. Trade-off between long-term and short-term yield, and the trade-off between biomass being above $0.1B_{MSY}$ and the expected variability in the yield.

The distribution of various statistics (performance metrics) can be examined for the acceptable (or all tested) management procedures using boxplots. In Figure 4.4.9 the distributions of the performance metrics B/B_0, B/B_{MSY}, F/F_{MSY}, average annual variation in yield (AAVY), average annual variation in effort (AAVE), and relative long-term yield in the last 10 years of the projection.

Regarding these performance metrics, all MPs have a high probability of biomass in the last 10 years of projection being above $0.2B_0$. Only DCAC and DCAC_40 present less than 90 percent probability that the biomass is above $0.2B_0$. From the acceptable MPs, three have more than 90 percent probability of the biomass in the last 10 years of projection being above B_{MSY}, the remaining MPs have a probability of being above B_{MSY} between 81 and 89 percent.

All acceptable MPs present a similar probability of AAVY being less than 30% in the last 10 years of the projected time, varying between 49 and 58 percent for the different MPs. Similarly, for the AAVE MPs presented similar probabilities of being below 30% variation in the last 10 years. Regarding the relative long-term yield most MPs presented similar relative long term yield, except HDAAC which had lower relative long-term yield and Itarget1 which presented a slightly higher relative long-term yield.

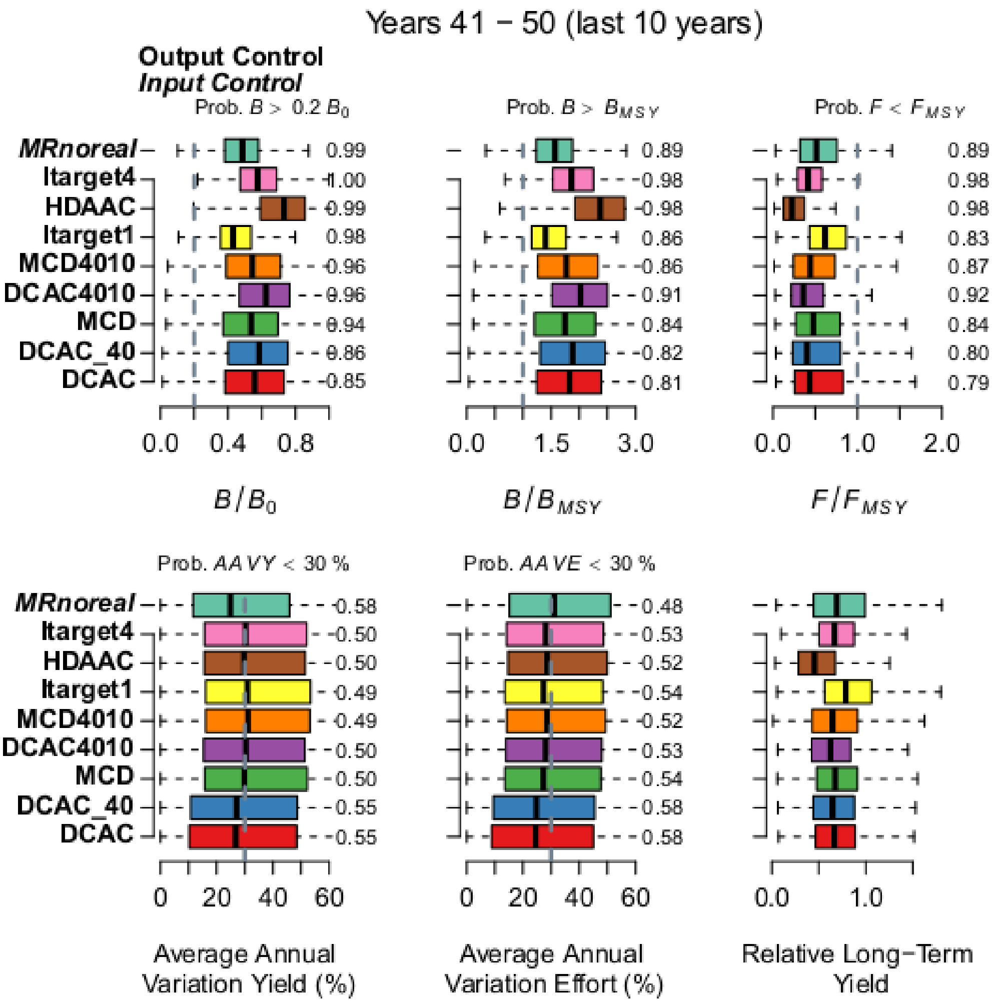


Figure 4.4.9. Performance metrics B/B_0, B/B_{MSY}, F/F_{MSY}, average annual variation in yield (AAVY), average annual variation in effort (AAVE), and relative long-term yield in the last 10 years of the projection for the acceptable management procedures. The proportion (%) of simulations ending up in each of the four quadrants - $F>F_{MSY}$ & $B<B_{MSY}$; $F<F_{MSY}$ & $B<B_{MSY}$; $F<F_{MSY}$ & $B>B_{MSY}$; $F>F_{MSY}$ & $B>B_{MSY}$ - of the Kobe phase plot by acceptable management procedure is presented in Figure 4.4.10.

Of the acceptable MPs, MRnoreal has the lowest probability of the stock being in the $F<F_{MSY}$ & $B>B_{MSY}$ quadrant of the Kobe phase plot. HDAAC and Itarget4 had the highest probability (97%) of the simulations ending up in the $F<F_{MSY}$ & $B>B_{MSY}$ quadrant of the Kobe phase plot. Except for DCAC and DCAC_40, which had a probability of being in the $F<F_{MSY}$ & $B>B_{MSY}$ quadrant of the Kobe phase plot of around 80 percent, but had the highest probabilities of the simulations ending up in the $F>F_{MSY}$ & $B<B_{MSY}$ quadrant of the Kobe phase plot, all remaining MPs had relatively high probability of being in the $F<F_{MSY}$ & $B>B_{MSY}$ quadrant and relatively low probability of being in the $F>F_{MSY}$ & $B<B_{MSY}$ quadrant of the Kobe phase plot.

Trade-off plot showing the probability of exceeding a biomass reference level (biomass over 75% of B_{MSY}) and a yield reference level (yield over 75% F_{MSY}) is shown in Figure 4.4.11. All MPs have a probability above 90 percent of the biomass being over 75% of B_{MSY}. Regarding yield, HDAAC had the lowest probability of yield being over 75% F_{MSY}, and Itarget1 the highest, while the remaining MPs had similar probabilities of yield being over 75% F_{MSY} (around 34 to 40 percent).

Trade-offs between the probability of not overfishing and long-term yield, and the probability of not being in an overfished state versus the probability of the annual variation in yield being less than 15% is presented in Figure 4.4.12.

Regarding the trade-off between the probability of not overfishing and long-term yield, HDAAC had a higher probability of not overfishing, but a lower long term yield compared with other MPs, while Itarget1 presents the reverse situation, with higher long-term yield but lower probability of not overfishing.

In relation to the probability of not being in an overfished state versus the probability of the annual variation in yield being less than 15%, all MPs have a very high probability of not being in an overfished state but all present an extremely low probability of the annual variation in yield being less than 15%.

Sensitivity of relative long-term yield and biomass with respect to the observation model parameters are presented in Figure 4.4.13. Relative long term-yield is mostly sensitive to bias in observed catches (Cbias) and bias in observed stock depletion (Dbias), especially for MP MCD, which shows that bias in depletion will have an effect on the relative long term-yield. Likewise, final biomass for MPs DCAC, DCAC_40 and DCAC4010 are highly sensitive to Cbias while MCD is mostly sensitive to Dbias.

Sensitivity of relative long-term yield and biomass with respect to the operating model parameters is shown in Figure 4.4.14. For both relative long-term yield and biomass all MPs are mostly sensitive to the mean fraction of TAC taken (FracTAC).

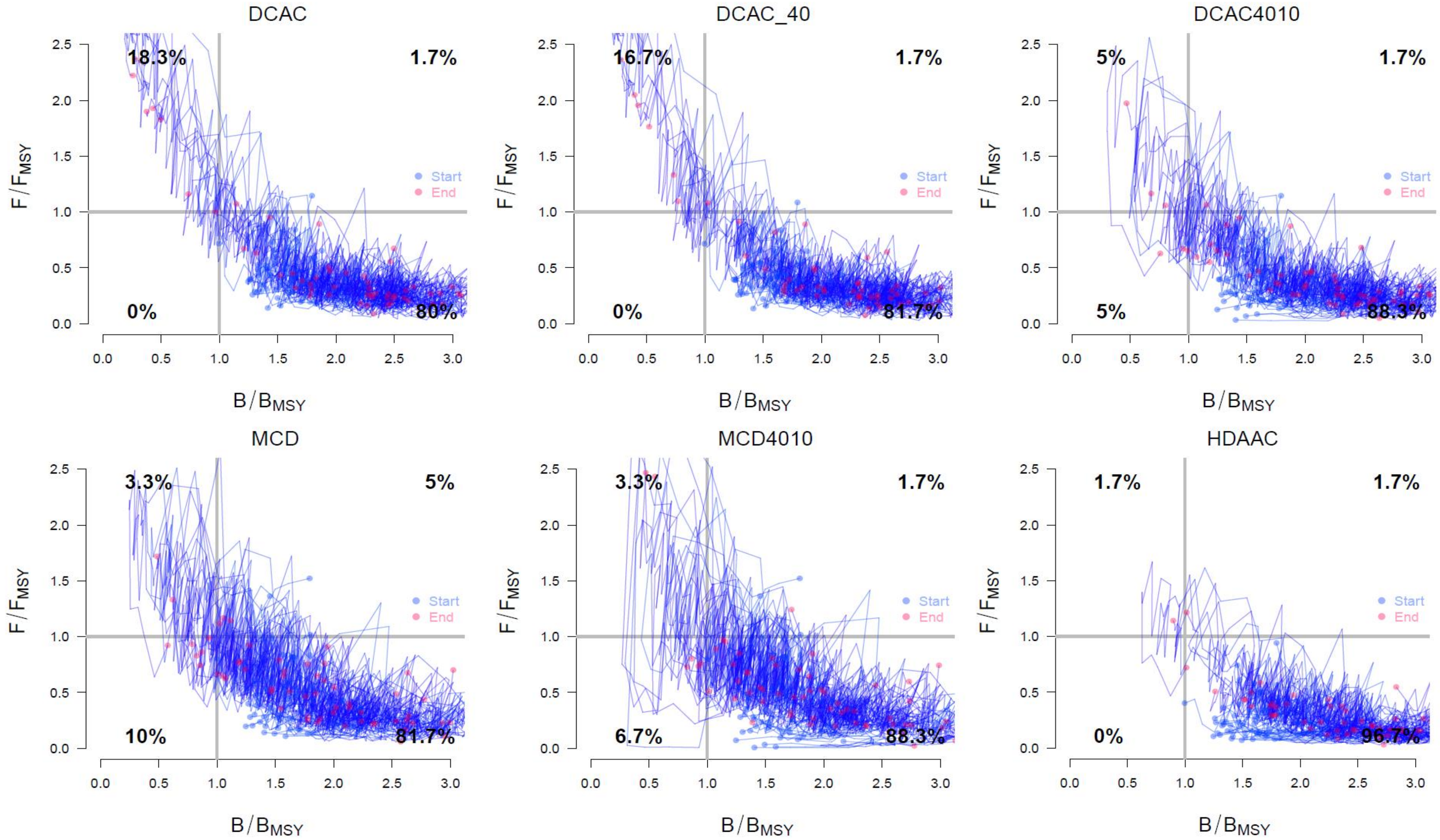


Figure 4.4.10. Proportion (%) of simulations ending up in each of the four quadrants of the Kobe phase plot for each acceptable management procedure.

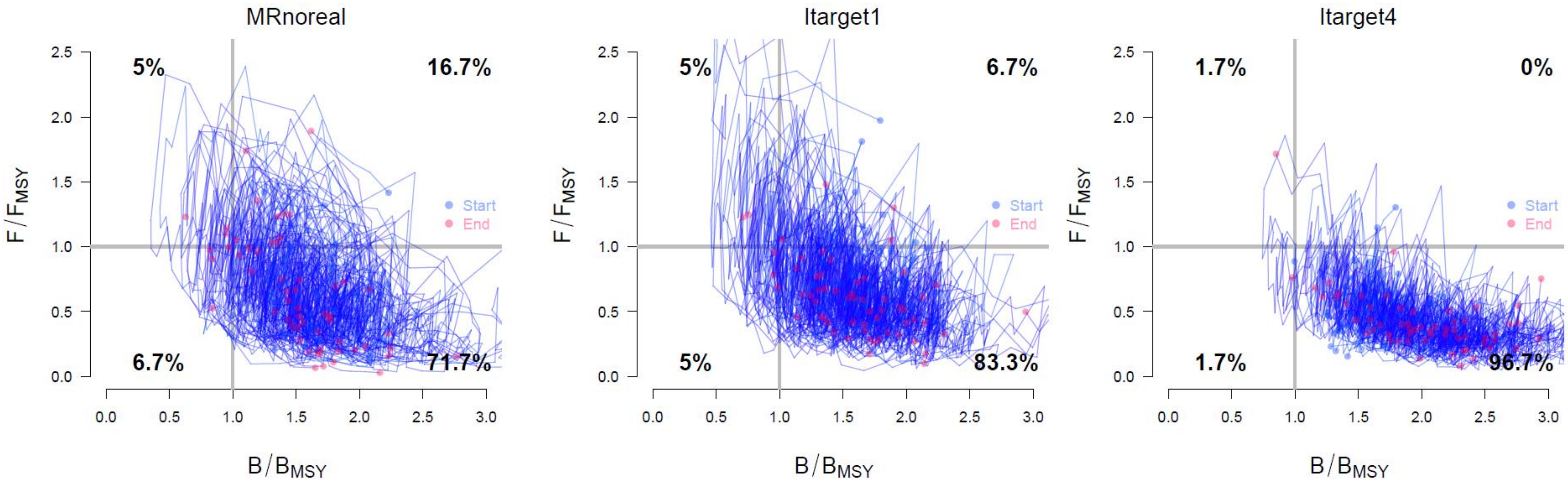


Figure 4.4.10. (continued) Proportion (%) of simulations ending up in each of the four quadrants of the Kobe phase plot for each acceptable management procedure.

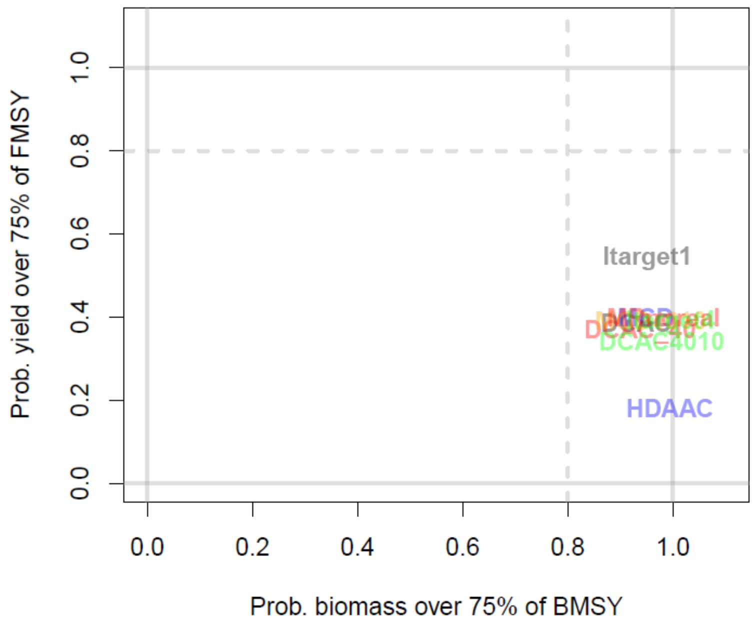


Figure 4.4.11. IOTC trade-off plot: probability of biomass being above 75% of B_{MSY} versus probability of yield being above 75% of F_{MSY}.

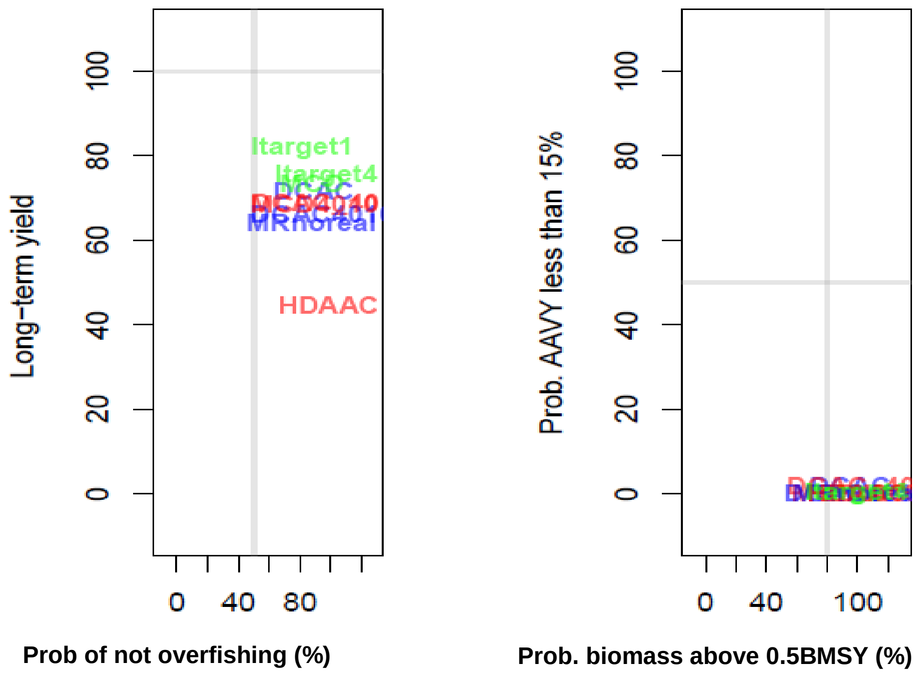


Figure 4.4.12. NOAA trade-off plot: probability of not overfishing and long-term yield (left), and the probability of not being in an overfished state versus the probability of the annual variation in yield being less than 15% (right).

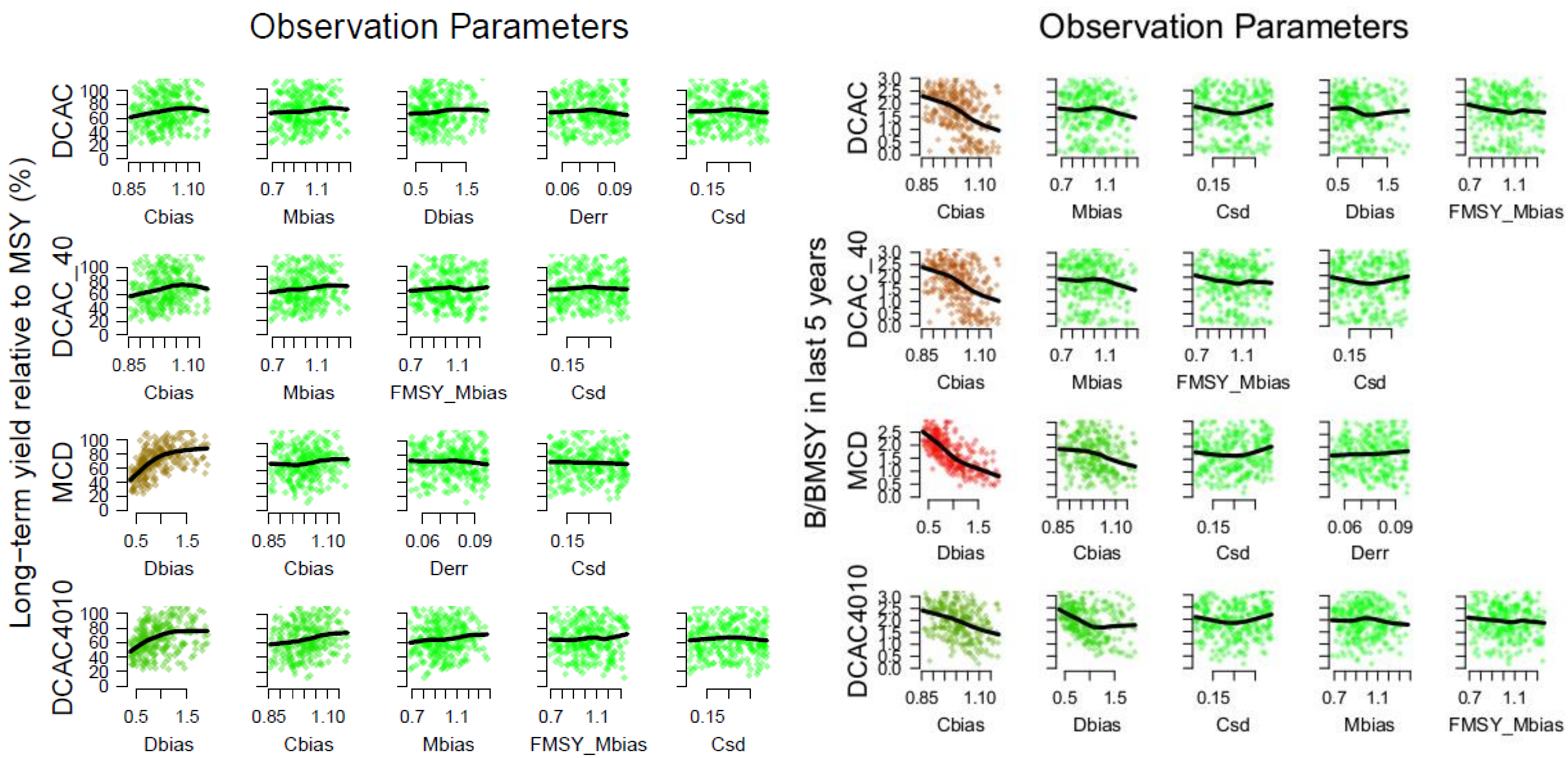


Figure 4.4.13. Relative long-term yield changes with respect to the observation error model (OEM) parameters (left panel) and final biomass (B/B_{MSY}) with respect to the OEM parameters (right panel). Parameters in red are more influential in the estimates and in green are less influential. Values in brown have an intermediate influence.

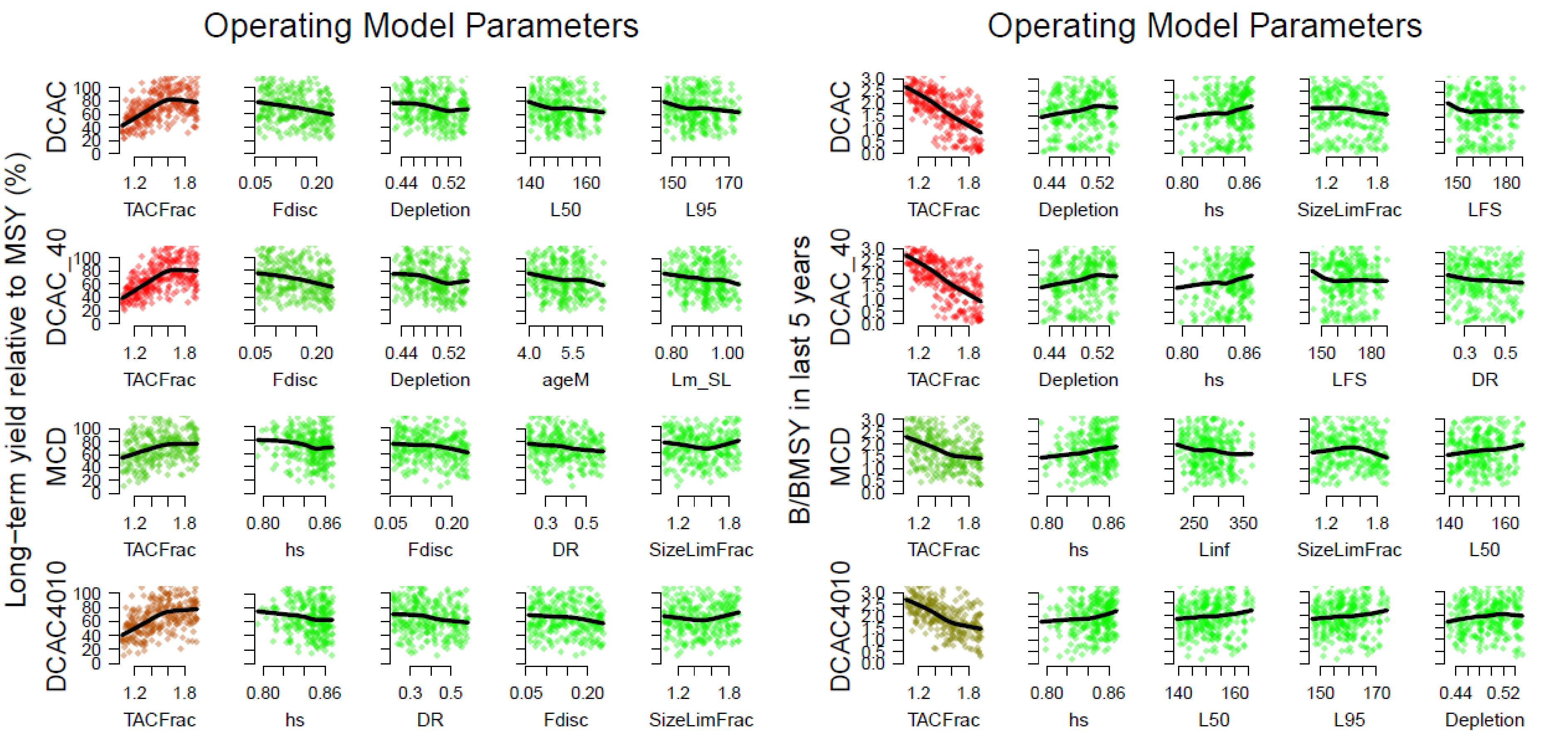


Figure 4.4.14. Relative long-term yield changes with respect to the operating model (OM) parameters (left panel) and final biomass (B/B_{MSY}) with respect to the OM parameters (right panel). Parameters in red are more influential in the estimates and in green are less influential. Values in brown have an intermediate influence.

Length based indicators

Analysis 1: Exploratory analysis of Portuguese data and selection of parameters

Assuming an M/K ratio of 1.5, indicators examining the effects of fishing on large individuals show all components of the stock (males, females and combined) to be doing quite well regardless of the value of L_∞, with few indicator ratios shifting from good to poor status when increasing L_∞ to its maximum value. Increasing L_∞ increased the optimal yield and MSY reference points, but made no difference to MSY traffic light status and little difference to optimal yield, with just a few shifts from poor to good when considering the mean length of individuals (Table 4.4.1).

Given the minor effect increasing L_∞ had on this stock, the maximum value of L_∞ = 283.37 cm was adopted for the rest of the analyses. This is the most precautionary value and consistent with observed data.

The ratios of L_c and $L_{25\%}$ to L_{mat} were close to the expected value of 1, so indicators for this stock will be sensitive to the value of L_{mat} chosen. Here the minimum value of L_{mat} = 162.41 cm was selected, which is most relevant for the Indian Ocean.

Both optimal yield L_{opt} and MSY $L_{F=M}$ reference points were sensitive to the ratio M/K, as is the indicator P_{mega}, which is calculated from L_{opt}. Decreasing M/K resulted in a more pessimistic assessment in terms of mega-spawners, with all components of the stock classified as poor when using the lowest value (0.58), and MSY. Subsequent analyses used the mean value of M/k = 1.45.

Table 4.4.1. Summary of LBI using the selected life history parameters. Cells in green indicate those indicators that are above the expected value (see Table 4.3.1) and theoretically represent 'good' status. L_{inf} =theoretical maximum length; L_{max5}_L_{inf} = (mean length of largest 5%)/L_{inf}

Males

Year	L_{max5}_L_{inf}	L_{95}_L_{inf}	P_{mega}	L_{25}_L_{mat}	L_c_L_{mat}	L_{mean}_L_{opt}	L_{maxy}_L_{opt}	L_{mean}_L_{FeM}
2011	0.97	0.94	0.66	1.24	1.18	1.21	1.29	1.07
2012	0.95	0.92	0.28	1	0.94	1.03	1.27	1.06
2013	0.96	0.92	0.45	1.03	0.91	1.09	1.32	1.14
2014	0.93	0.91	0.32	0.97	0.87	1.02	1.29	1.09

Females

Year	L_{max5}_L_{inf}	L_{95}_L_{inf}	P_{mega}	L_{25}_L_{mat}	L_c_L_{mat}	L_{mean}_L_{opt}	L_{maxy}_L_{opt}	L_{mean}_L_{FeM}
2011	0.94	0.91	0.74	1.27	1.31	1.23	1.27	1.02
2012	0.95	0.92	0.51	1.15	1.12	1.13	1.24	1.04
2013	0.94	0.91	0.39	1.09	1.06	1.08	0.93	1.03
2014	0.82	0.77	0.1	1.06	1.03	0.98	0.93	0.95

Both sexes

Year	L_{max5}_L_{inf}	L_{95}_L_{inf}	P_{mega}	L_{25}_L_{mat}	L_c_L_{mat}	L_{mean}_L_{opt}	L_{maxy}_L_{opt}	L_{mean}_L_{FeM}
2011	0.97	0.94	0.67	1.24	1.15	1.2	1.27	1.08
2012	0.95	0.92	0.35	1.06	0.94	1.06	1.27	1.09
2013	0.95	0.92	0.44	1.06	0.91	1.08	1.32	1.14
2014	0.93	0.91	0.29	1	0.87	1.01	1.29	1.08

Analysis 2: Exploratory analysis of longer-term trends in LBI from Soviet Union (1966–1989) and Japanese (1992–2009) fleets

Analyses of Soviet Union data (sexes combined, Figure 4.4.15) for 1966–1989 revealed a healthy presence of large individuals and showed the stock to have been fished sustainably according to MSY. L_c and $L_{25\%}$ decreased over the time series, indicating more fish being captured before reaching maturity. L_c fell below its expected value in 1974–1981, and $L_{25\%}$ in 1982–1989. L_{maxy} was above L_{opt} throughout the time-series, indicating targeting of fish above the optimum length, while L_{mean} decreased in relation to L_{opt}, indicating a shift towards smaller fish.

Analyses of Japanese data from 1992–2009 (Figure 4.4.16) showed few large individuals, with an increase towards- or obtained- expected levels from 2008 onwards. P_{mega} was close to zero most years and both indicators relating to the conservation of small individuals fell well below L_{mat} throughout the time series, showing an increase from 2007. The indicator ratio for MSY fluctuated close to, but mostly below, 1.

The longer-term shift from good to poor conservation status of large and small individuals, and drop in MSY indicator ratio values is likely due to differing selectivities between the Soviet Union and Japanese fleets rather than a longer-term change in population dynamics. This is supported by the L_{maxy} and L_{mean} indicators falling below L_{opt}, indicating targeting of fish below the optimum length by the Japanese fleet.

Analysis 3: Exploratory analysis of LBI derived from Japanese length-frequency data

Analyses of Japanese data (1992–2013) showed indicators for the conservation of large individuals to generally be lower and more stable for females than males (Figure 4.4.17 and 4.4.18). Although a slight increase in these indicator values was observed for males, the increase in combined sex status of large individuals from 2008 appeared to be driven by the female component.

P_{mega} was zero for females until 2003, and less than 0.1 for both sexes throughout most of the time-series. Contrarily, $L_{25\%}$, which focuses on the conservation of small individuals, was generally higher for females than males, but both indicators relating to immatures fell below L_{mat} for both sexes throughout the time-series. The increase in $L_{25\%}$ from 2007 was slightly more prominent for males.

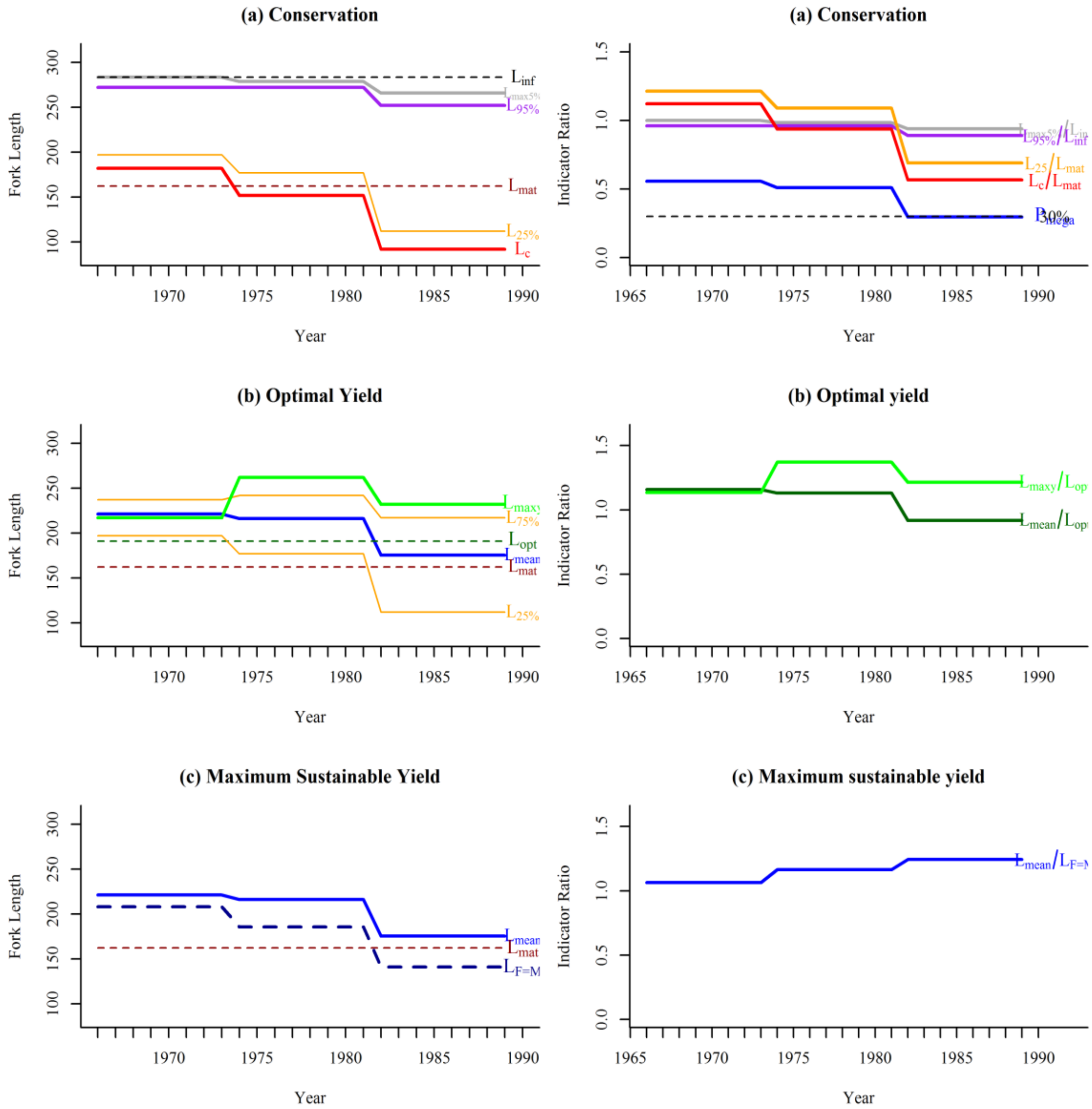


Figure 4.4.15. Length based indicators for Indian Ocean blue shark by time period (length data from USSR exploratory fleet).

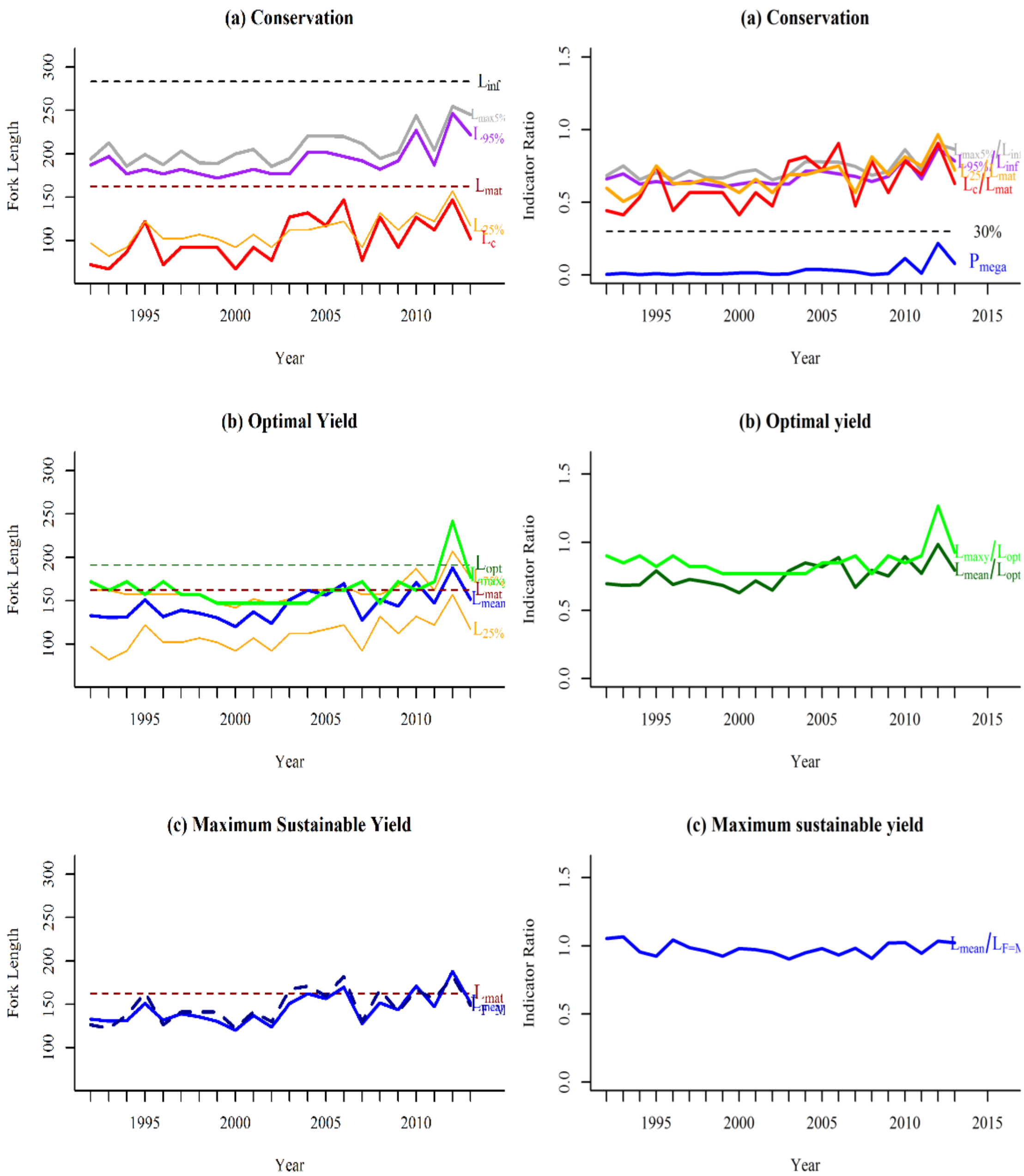


Figure 4.4.16. Length based indicators for Indian Ocean blue shark by year (length data from Japanese fleet).

The indicator L_{maxy} showed a pronounced decrease prior to 1998 and increased from then onwards for males and, to a much lesser extent, females and combined sexes. A shift towards larger individuals was also indicated by L_{mean} from 2000, although both indicators remained at or below L_{opt} for most of the time series. The indicator ratio for MSY fluctuated close to 1 though most of the time series.

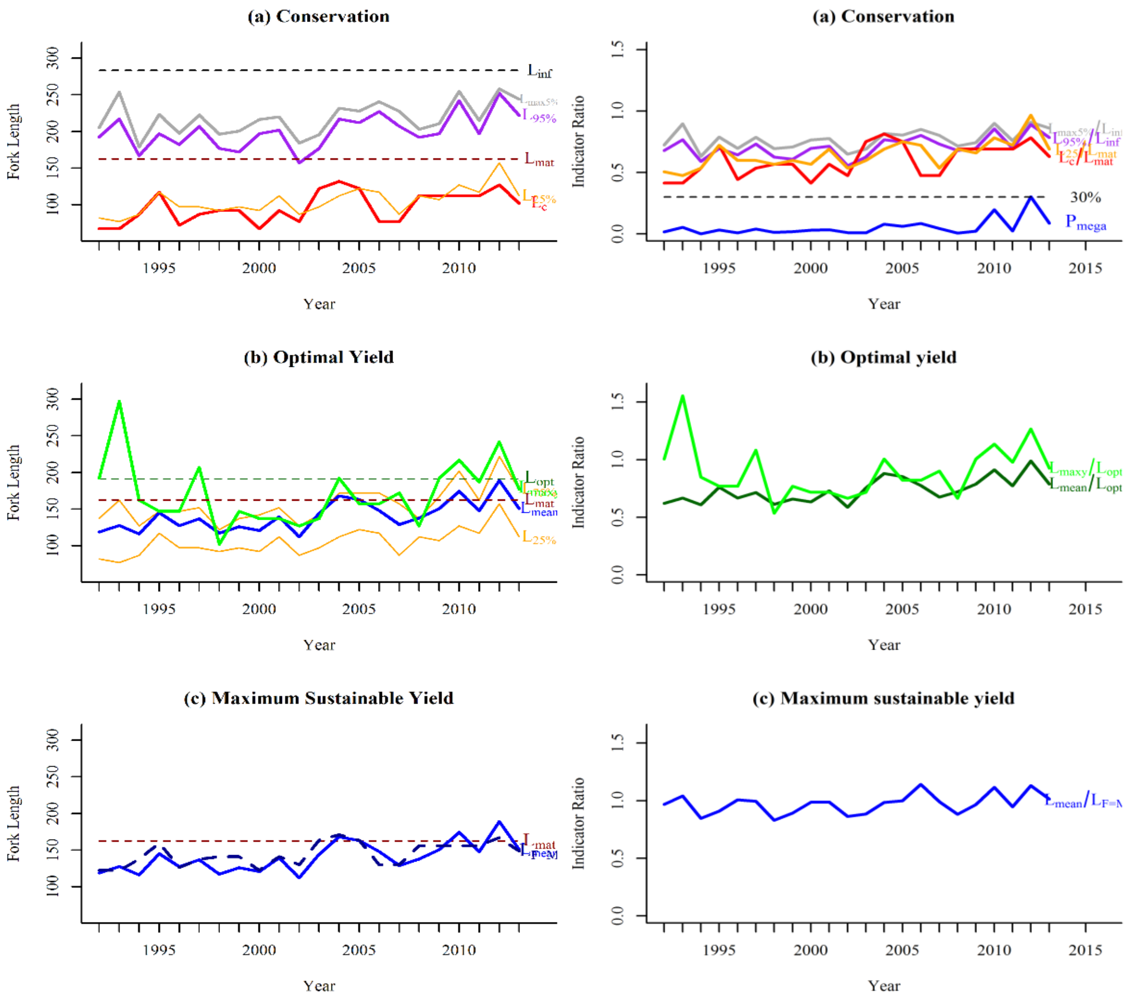


Figure 4.4.17. Indicators, reference points and indicator ratios for male blue shark in the Indian Ocean by year (length data from Japanese fleet).

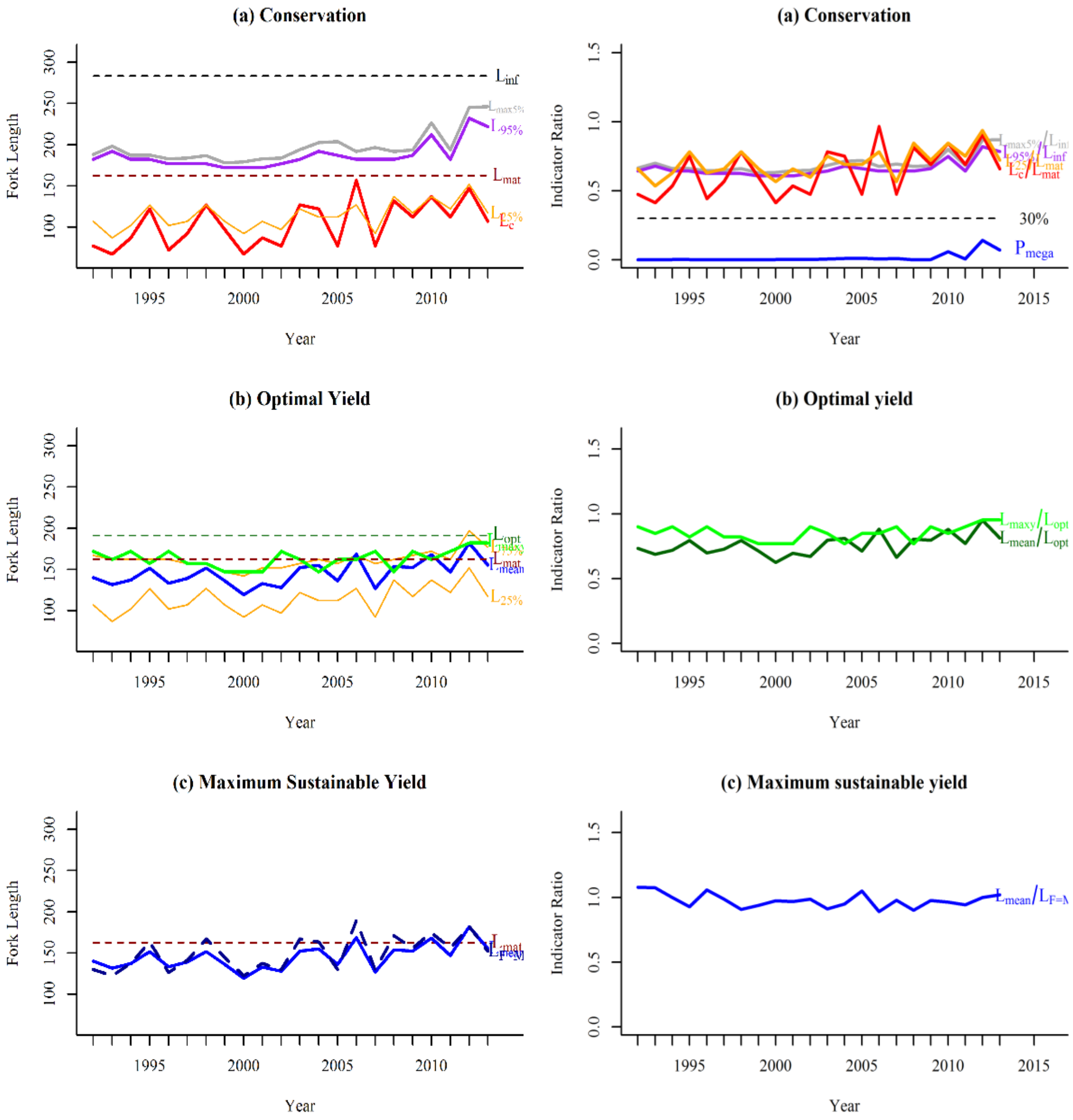


Figure 4.4.18._Indicators, reference points and indicator ratios for female blue shark in the Indian Ocean by year (length data from Japanese fleet).

Analysis 4: Exploratory analysis of LBI from different fleets

Analyses of data from four countries over a relatively consistent period (Table 4.4.2; Figure 4.4.19) revealed some differences in status between fleets over different components of the stock. Indicator ratios focusing on the conservation of large and small individuals (excluding L_c/L_{mat}) were generally below expected values for Japan, except $L_{max5\%}$ for males, while other nations met expectations, except for South Africa where P_{mega} for males was less than 0.3. L_c was below or equal to L_{mat} for all nations when considering males and for Japan and South Africa when considering females. Optimal yield indicators from Japanese data suggested that fishing was at or below L_{opt}, while data from other nations suggesting that fishing was at or above L_{opt}. These differences in selectivity were also indicated by length frequency distributions. All nations met MSY except Japan when considering females or both sexes combined.

Table 4.4.2. Summary of LBI using the selected life history parameters. Cells in green indicate those indicators that are at or above the expected value and theoretically represent 'good' status.

Males	L_{max5}_L_{inf}	L_{95}_L_{inf}	P_{mega}	L_{25}_L_{mat}	L_c_L_{mat}	L_{mean}_L_{opt}	L_{maxy}_L_{opt}	L_{mean}_L_{FeM}
Japan	0.86	0.78	0.08	0.72	0.69	0.82	0.98	1.01
Portugal	0.96	0.94	0.5	1.09	0.94	1.12	1.29	1.15
Taiwan	0.98	0.91	0.35	1.06	0.97	1.07	1.11	1.08
South Africa	0.94	0.89	0.26	1.06	1	1.04	1.01	1.03

Females	L_{max5}_L_{inf}	L_{95}_L_{inf}	P_{mega}	L_{25}_L_{mat}	L_c_L_{mat}	L_{mean}_L_{opt}	L_{maxy}_L_{opt}	L_{mean}_L_{FeM}
Japan	0.76	0.68	0.02	0.75	0.69	0.8	0.9	0.98
Portugal	0.94	0.91	0.52	1.12	1.06	1.12	1.27	1.07
Taiwan	1.02	0.94	0.43	1.09	1.06	1.12	1.11	1.06
South Africa	0.95	0.91	0.34	1.06	1	1.07	1.11	1.06

Combined	L_{max5}_L_{inf}	L_{95}_L_{inf}	P_{mega}	L_{25}_L_{mat}	L_c_L_{mat}	L_{mean}_L_{opt}	L_{maxy}_L_{opt}	L_{mean}_L_{FeM}
Japan	0.81	0.73	0.04	0.75	0.69	0.81	0.9	0.99
Portugal	0.96	0.92	0.5	1.09	0.97	1.12	1.29	1.13
Taiwan	1	0.92	0.38	1.06	1	1.09	1.11	1.08
South Africa	0.94	0.89	0.28	1.06	1	1.05	1.06	1.04

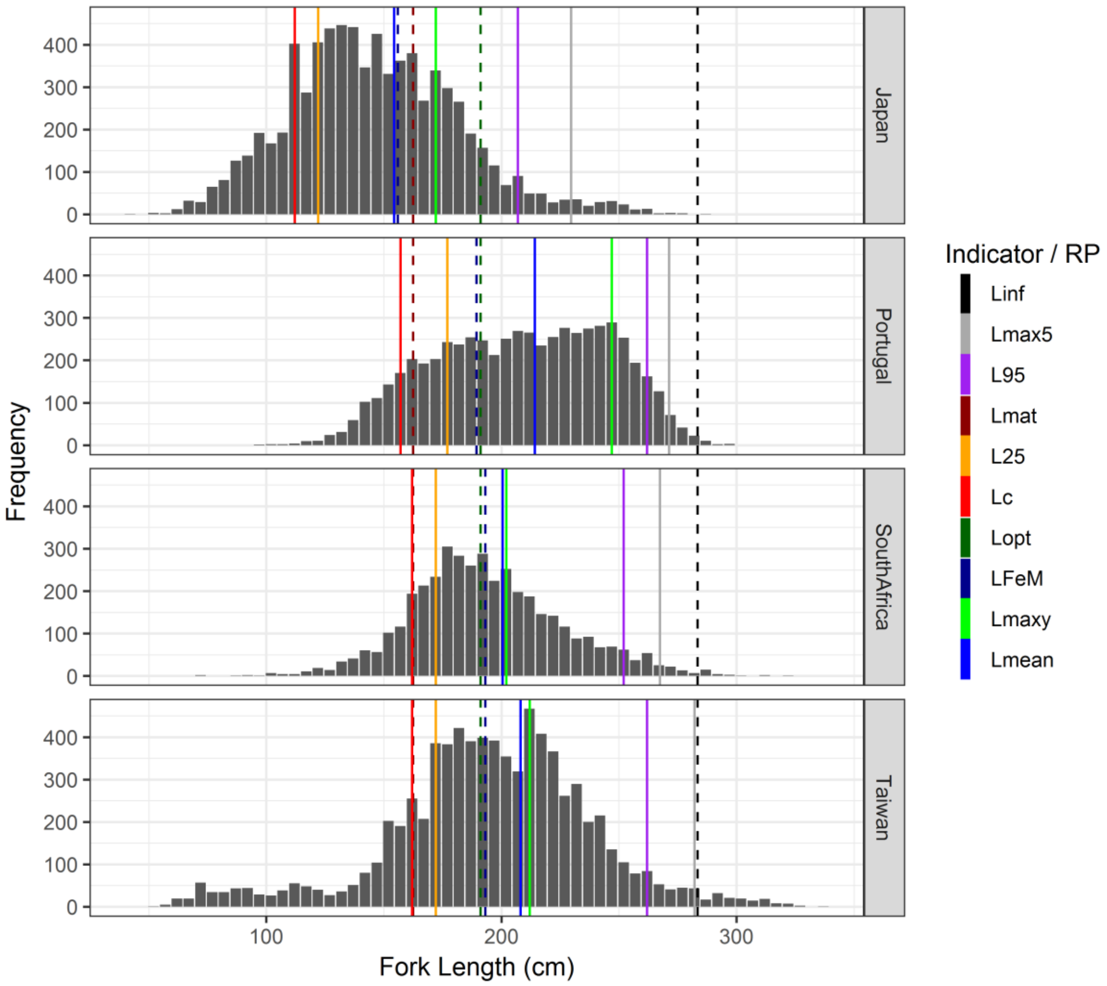


Figure 4.4.19. Length frequency of Indian Ocean blue shark (sexes combined) by nation with indicators (solid vertical line) and reference points (dashed vertical lines).

e. *Final Remarks*

Management Strategy Evaluation

Management Strategy Evaluation (MSE) allows uncertainty and error to be explicitly incorporated and to identify and select which Management Procedures (MP) among a set of candidate strategies are more robust to uncertainty (Punt et al., 2016). Furthermore, it enables fisheries scientists to advise managers on the trade-offs involved for each MP (Bunnefeld et al., 2011). Managers can then balance trade-offs and decide which MP is more suited for each management objective (Punt et al., 2016; Bunnfeld et al., 2011). MSE should allow the involvement of stakeholders, managers and fishery scientists since its inception. For the implementation of a MSE framework it is essential that management objectives and the associated performance metrics, as well as, decision on the minimum performance limits and targets, be decided in an integrated manner between all involved parties.

Since no reference points have yet been adopted for sharks in IOTC, for this preliminary work on Indian Ocean blue shark MSE we have tentatively used a 80% probability of biomass in years 11-50 and years 41-50 of the projected years (50) above $0.2B_0$ and a 50% probability that the biomass in the last ten years of the projection period (years 41-50) is above $0.25B_0$, but there are many options for performance metrics (e.g. probability of staying above 50% of SSB_{MSY}, spawning stock biomass at maximum sustainable yield, probability of achieving greater than 50% MSY yield). Management procedures that fulfilled both the minimum performance limits and the management targets were considered to be acceptable options for managing this fishery. The application of the limits and target detailed above led to 9 out of 89 MPs being considered acceptable.

Regarding the performance of the acceptable MPs, overall, there was a high probability of the final biomass being above B_{MSY}. Trade-offs between MPs were evident for biomass vs relative long-term yield, e.g. HDAAC being more conservative with a higher probability of the final biomass being above MSY at the expense of a lower relative long-term yield, while Itarget1 has a higher relative long-term yield but a lower probability of the biomass being above MSY. For this preliminary work we have focused mainly in trade-offs between biomass and yield, but according to the management objectives agreed for the fishery, other performance metrics can be applied (e.g. time to rebuild the stock).

Regarding the sensitivity analysis, this analysis does not identify specific data to be collected or improved but simply highlights where operating model uncertainty may lead to selection of MPs that are not performing as well as other MPs due to the risks associated with parameter uncertainty (Carruthers & Kell, 2017). For example, biomass and final yield were mostly sensitive to TacFrac, in this case, because no information on this was available and a high degree of variability in adherence to the TAC among years was set in the OM. Improved estimates of the adherence to the TAC would help improve the performance of the MPs.

Length based indicators

Exploratory analyses provided inconsistent results across nations, indicating that issues of gear selectivity and/or differences in the spatial distribution of the fleets in relation to various components of the blue shark stock may influence LBI.

Furthermore, there are potential issues of sample size (numbers of sharks measured, and number of trips), potential differences in the method of measurement (e.g. over the body or in line with the body) and type of measurement (e.g. total length or fork length).

The spatial population dynamics of sharks, which can include sex-based and size-based segregation, may potentially affect underlying data and subsequent LBIs. Previous studies have examined the spatio-temporal distributions of juveniles and mature blue shark, and males and females in the region, showing that there are indeed both sex and size related regional segregation (Coelho et al., 2018). There may also have been subtle changes in the fishery (e.g. depth of lines, leader type, hook size/type, bait) and that may influence size-based selection of blue shark, which should also be considered if possible.

Given the large size of elasmobranchs and the late age at maturity, the indicators based on conservation of immatures highlight that L_c and $L_{25\%}$ often occur before fish mature. It is considered unlikely to have a mixed fishery that captures elasmobranchs to meet this indicator. Hence, this LBI may not be appropriate for management decisions.

The LBI analysed above cannot be used at the current time for management advice, as there would need to be further interpretation of the data in relation to the fishery and spatial population structure of the stock. The current reference points being used in ICES were derived for teleost fish and shellfish stocks, and so further studies to determine appropriate reference points for elasmobranchs are required. This should be a research priority in the future.

Whilst several nations are collecting length data for meaningful sample sizes, aggregating these data to the stock level may better provide an overall suite of LBIs. Appropriate raising factors (accounting for effort, removals (i.e. landings and dead bycatch) and spatial factors) could usefully be estimated.

f. References

Aires-da-Silva, A.M. and Gallucci, V.F., 2007. Demographic and risk analyses applied to management and conservation of the blue shark (*Prionace glauca*) in the North Atlantic Ocean. *Mar. & Freshw. Res.* 58: 570–580.

Bigelow, H.W., Schroeder, W.C., 1948. Sharks. In: Tee-Van, J., Breder, C.M., Hildebrand, S.F., Parr, A.E., Schroeder, W.C. (Eds.), Fishes of Western North Atlantic, Part 1. Yale University, New Haven, CT, pp. 59–576.

Bunnefeld, N., Hoshino, E., Milner-Gulland, E. 2011. Management strategy evaluation: a powerful tool for conservation? *Trends Ecol. Evol*. 25(9): 441-447.

Cailliet, G.M. and Bedford, D.W., 1983. The biology of three pelagic sharks from California waters, and their emerging fisheries: a review. *CalCOFI Rep*. 24:57–69.

Carruthers, T., 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. *Fish. Res*. 153: 48:68.

Carruthers, T., Kell, L. 2017. Beyond MSE opportunities in the application of Atlantic Bluefin Tuna operating models. *Collect. Vol. Sci. Pap. ICCAT* 73(7): 2543-2551.

Coelho, R., Mejuto, J., Domingo, A., Yokawa, K., Liu, K.-M., Cortés, E., Romanov, E.V., da Silva, C., Hazin, F., Arocha, F., Mwilima, A.M, Bach, P., Ortiz de Zárate, V., Roche, W., Lino, P.G., García-Cortes, B., Ramos-Cartelle, A.M., Forselledo, R., Mas, F., Ohshimo, S., Courtney, D., Sabarros, P.S., Perez, B., Wogerbauer, C., Tsai, W.-P., Carvalho, F., Santos, M.N. 2018. Distribution patterns and population structure of the blue shark (*Prionace glauca*) in the Atlantic and Indian Oceans. *Fish Fish.* 19:90–106.

Cope, J.M. & Punt, A.E. 2009. Length-based reference points for data-limited situations: applications and restrictions. *Mar. Coast. Fish*. 1:169–186.

Cortés, E., Domingo, A., Miller, P., Forselledo, R., Mas, F., Arocha, F., Campana, S., Coelho, R., Da Silva, C., Holtzhausen, H., Keene, K., Lucena, F., Ramirez, K., Santos, M.N., Semba-Murakami, Y., Yokawa, K. 2015. Expanded ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Collect. Vol. Sci. Pap. ICCAT* 71: 2637-2688.

Ebert, D.A., Stehmann, M.F.W., 2013. Sharks, batoids, and chimaeras of the North Atlantic. FAO Species Catalogue for Fishery Purposes. No. 7. Rome, FAO. 523 pp.

Francis, M.P., Duffy, C., 2005. Length at maturity in three pelagic sharks (*Lamna nasus, Isurus oxyrinchus*, and *Prionace glauca*) from New Zealand. *Fish. Bull.* 103: 489–500.

Froese, R. 2004. Keep it simple: three indicators to deal with overfishing. *Fish Fish*. 5: 86–91.

Fujinami, Y., Semba, Y., Ijima, H., Tanaka S. 2016. Age and growth estimation of the blue shark, *Prionace glauca*, in the western North Pacific Ocean. ISC Shark Working Group. ISC document ISC/16/SHARKWG-1/02.

Hazin, F.H.V., Lessa, R., Ishino, M., Otsuka, K., Kihara, K., 1991. Morphometric description of the blue shark, *Prionace glauca*, from the southwestern equatorial Atlantic. *J. Tokyo Univ. Fish.* 78: 137–144.

Hsu, H.H., Joung, S.J., Lyu, G.T., Liu, K.M., Huang, C.C., 2011. Age and growth of the blue shark, *Prionace glauca*, in the northwest Pacific. ISC Shark Working Group Workshop. ISC document ISC/11/SHARKWG-2/16.

ICES. 2014. Report of the Workshop on the Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE IV). 27–31 October 2014, Lisbon, Portugal. ICES CM 2014/ACOM:54: 223 pp.

ICES. 2015a. Report of the Fifth Workshop on the Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE V). 5–9 October 2015, Lisbon, Portugal. ICES CM 2015/ACOM:56: 157 pp.

ICES. 2015b. Report of the Workshop to consider MSY proxies for stocks in categories 3 and 4 stocks in Western Waters (WKProxy). 3–6 November 2015, ICES Headquarters, Copenhagen, Denmark. ICES CM 2015/ACOM:61: 183pp.

IOTC. 2017. Report of the Thirteenth Session of the IOTC Working Party on Ecosystems and Bycatch. 4-8 September 2017, San Sebastián, Spain. IOTC–2017–WPEB13–R[E]: 125 pp.

ISC. 2017. Stock assessment and future projection of blue shark in the North Pacific Ocean through 2015. 17th Meeting of the ISC, 12–17 July 2017, Vancouver, Canada. ISC17/SHARKWG Annex 13: 96 pp.

Jolly, K.A., da Silva, C., Attwood, C.G., 2013. Age, growth and reproductive biology of the blue shark *Prionace glauca* in South African waters*. Afr. J. Mar. Sci*. 35: 99–109.

Joung, S.J., Hsu, H.H., Liu, K.M., Wu, T., 2011. Reproductive biology of the blue shark, *Prionace glauca*, in the northwestern Pacific. ISC Shark Working Group Workshop. ISC document ISC/11/SHARKWG-2/12.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M. A., Poos, J. J., Scott, F., Scott, R. D. 2007. FLR: an open-source framework for the evaluation and development of management strategies. *ICES J. Mar. Sci.* 64: 640–646.

Kohler, N.E., Casey, J.G. and Turner, P.A., 1996. Length-length and Length-weight relationships for 13 shark species from the western North Atlantic. NOAA Technical Memorandum NMFS-NE-110, 22 pp.

McKinnell, S., Seki, M.P., 1998. Shark bycatch in the Japanese high seas squid driftnet fishery in the North Pacific Ocean. *Fish. Res.* 39: 127–138.

Miethe, T., Dobby, H. 2015. Selection of length-based indicators for shellfish stocks and fisheries. Workshop on the Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE V). WKLIFE V document. 17 pp.

Murua, H., Coelho, R., Santos, M.S., Arrizabalaga, H., Yokawa, K., Romanov, E., Zhu, J.F., Kim, Z.G., Bach, P., Chavance, P., Delgado de Molina, A., Ruiz, J. 2012. Preliminary Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC). Working Party on Ecosystems and Bycatch. IOTC Document IOTC–2012–WPEB08–31: 16pp.

Myers, R.A. and Mertz, G. 1998. The limits of exploitation: a precautionary approach. Ecological Applications, 8 (Supplement): S165–S169.

Nakano, H. 1994. Age, reproduction and migration of blue shark in the North Pacific Ocean. *Bull. Nat. Res. Inst. Far Seas Res*. 31:141–219.

Nakano, H., Makihara, M., Shimazaki, K., 1985. Distribution and biological characteristics of the blue shark in the central North Pacific. *Bull. Fac. Fish. Hokkaido Univ.* 36: 99–113.

Nakano, H., Seki, M.P., 2003. Synopsis of biological data on the blue shark, *Prionace glauca* Linnaeus. Bull. Fish. Res. Agency Japan 18–55.

Probst, W.N., Kloppmann, M., Kraus, G. 2013. Indicator-based status assessment of commercial fish species in the North Sea according to the EU Marine Strategy Framework Directive (MSFD). *ICES J. Mar. Sci*. 70: 694–706.

Punt, A.E., Butterworth, D. S., de Moor, C. L., De Oliveria, José A. A., Haddon, M. 2016. Management strategy evaluation: best practices. *Fish Fish.* 17:303–334.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rice, J. 2017. Stock assessment blue shark (*Prionace glauca*) in the Indian Ocean using Stock Synthesis. Working Party on Ecosystems and Bycatch. IOTC document IOTC–2017–WPEB13–33: 37pp.

Rice, J., Semba, Y., 2014. Age and sex specific natural mortality of the blue shark (*Prionace glauca*) in the North Pacific Ocean. ISC Shark Working Group Workshop. ISC document ISC/14/SHARKWG-1.

Semba, Y., Yokoi, H., 2016. Update of Age and sex specific Natural mortality of the blue shark (*Prionace glauca*) in the North Pacific Ocean. ISC Shark Working Group Workshop. ISC document ISC/16/SHARKWG-1/06.

Tanaka, S. 1984. Present status of fisheries biology. In Elasmobranchs as fishery resources (T. Taniuchi and M. Suyama, eds.). *Jpn. Soc. Sci. Fish.*, Fish. Ser. 49: 46−59.

g. *Annex III. Indian Ocean blue shark management plan*

Blue Shark: Management Plan Summary of Information Available

Blue Shark (*Prionace glauca*)

No information on stock structure for blue shark in the Indian Ocean is available, but for assessment purposes it is considered to be a single stock. Blue shark is known to have an Indian Ocean wide distribution but there is no genetic evidence of distinct population structure within this single population as is seen in other oceans (e.g. Pacific populations, see Taguchi & Yokawa, 2013, where mixing is assumed within the populations).

Adult sharks have no known predators; however, subadults and juveniles may be taken by other sharks, such as shortfin makos, great white sharks and other adult blue sharks (IOTC, 2016). Fishing is the major cause of adult mortality and it is one of the main bycatch species in pelagic longline fisheries. However, it is not currently considered overfished or subject to overfishing future predictions at the present catch rates indicate that the stock may become overfished or be subject to overfishing with subsequent effects on ecosystem trophic functioning.

Although they are a pelagic species, blue sharks also come inshore to feed, particularly at night in areas with a narrow continental shelf or around oceanic islands (Compagno, 1984). Dietary studies have shown that they feed mainly on smaller pelagic bony fish and squid, although they also target other small invertebrates including swimming crabs, other small sharks and mammalian carrion such as whale carcasses where they have been known to gather in great numbers to strip the carcasses. The most important prey however are squid which they take from large breeding aggregations (Compagno, 1984; Rabehagasoa et al., 2012; Gubanov & Gigor'ev 1975; Romanov et al. 2009).

In general, blue sharks seem to prefer cooler waters, 7-16°C, although they also occur in the tropics. In the tropical Indian Ocean, they occur most commonly between 80 to 100 meters with temperatures between 12°C and 25°C.

In 2012 the IOTC Working Party on Ecosystems and Bycatch (WPEB) and Scientific Committee (SC) conducted an Ecological Risk Assessment (ERA) on the blue shark in the Indian Ocean (Murua et al., 2012) which was designed to assess the resilience of the species to different fishing gear types. It received a medium vulnerability rating (10) as although it was the second most susceptible to longline gear it was also the most productive shark species and able to recover well. It was not considered to be susceptible to purse seine gear. Although it has an IUCN status of 'Near Threatened', this applies to blue sharks globally rather than specifically to the Indian Ocean.

Critical information on the biology of the blue shark that is necessary for the Stock Synthesis assessment relates to sex-specific growth, natural mortality, maturity and fecundity (Rice, 2017).

Overview of the fishery

Catches of blue shark within the IOTC area are not well reported and as a result there is little information on the location or seasonality of the fishery. It is thought that it has a similar distribution to swordfish and is commonly caught alongside it, either as bycatch or by being targeted directly. Blue shark fishing grounds can therefore be considered to be the same as that of swordfish and plotting the locations of swordfish catches will give an indication of where they are caught.

Figure I.8 indicates where the main catches of swordfish have been taken since 2012, showing that the concentration catches is to the southwest Indian Ocean, although over 2014 and 2015 they did seem to spread further to the southeast.

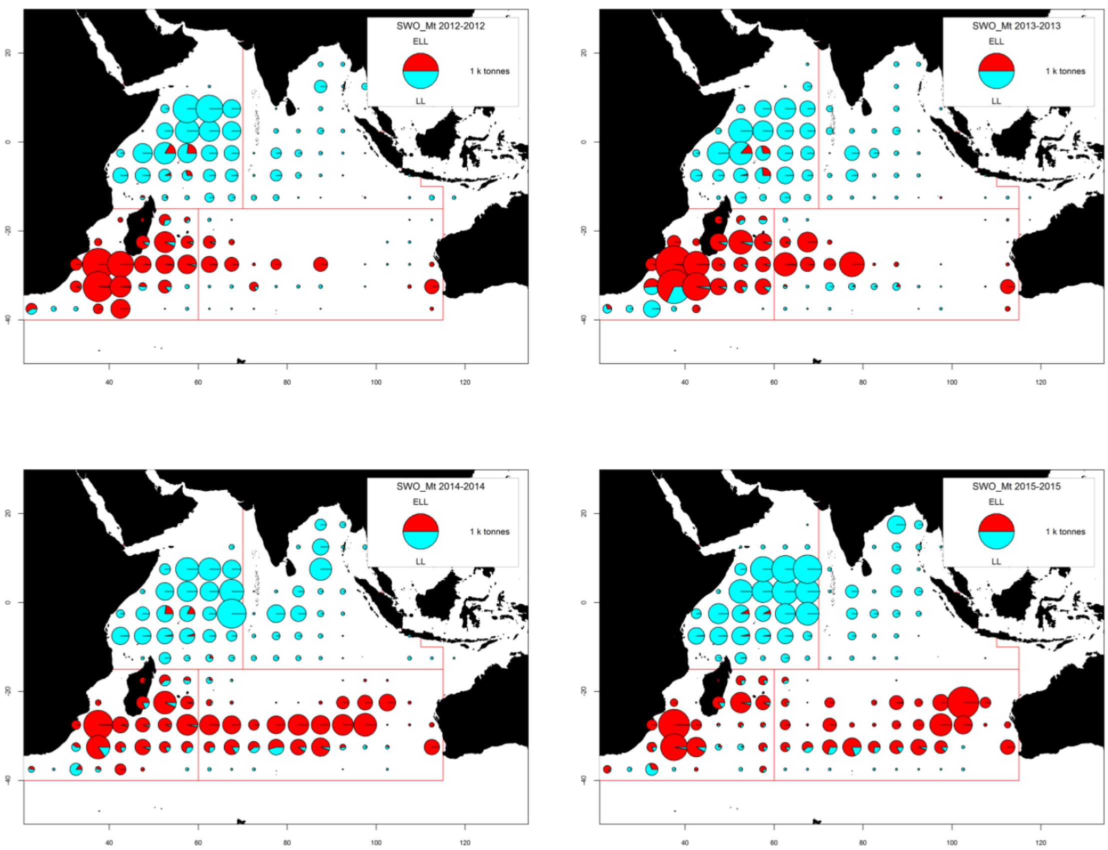


Figure I.8. Catches of swordfish (in red) and all longline species (in blue) from 2012 to 2015 (source: IOTC, 2017).

Within the Indian Ocean the majority of blue sharks in industrial fisheries are taken by other/unknown (OTH) and longline (LL) gears within the Indonesian and Taiwanese fleets. Although no EU fleets actively target blue shark they are commonly caught and retained as a main bycatch or a secondary target species in association with longline vessels targeting swordfish. Anecdotally, they are also occasionally caught as bycatch in the purse seine fishery, although this rarely seems to take place is not officially reported. In terms of reported catches, the main EU fleets covered by the plan will be:

- Spanish longline targeting swordfish;
- Portuguese longline targeting swordfish;
- French (Reunion) longline targeting swordfish; and,
- UK longline targeting swordfish.

Although no catches are reported, also to be considered are:

- Spanish purse seine targeting tropical tunas; and,
- French purse seine targeting tropical tunas.

The swordfish fishery operates mainly in the south-west Indian Ocean. Figure I.9 shows the locations of sets for the Portuguese fleet (similar for the Spanish fleet) and also for the French fleet which almost exclusively operates within the Malagasy and Reunion EEZs.

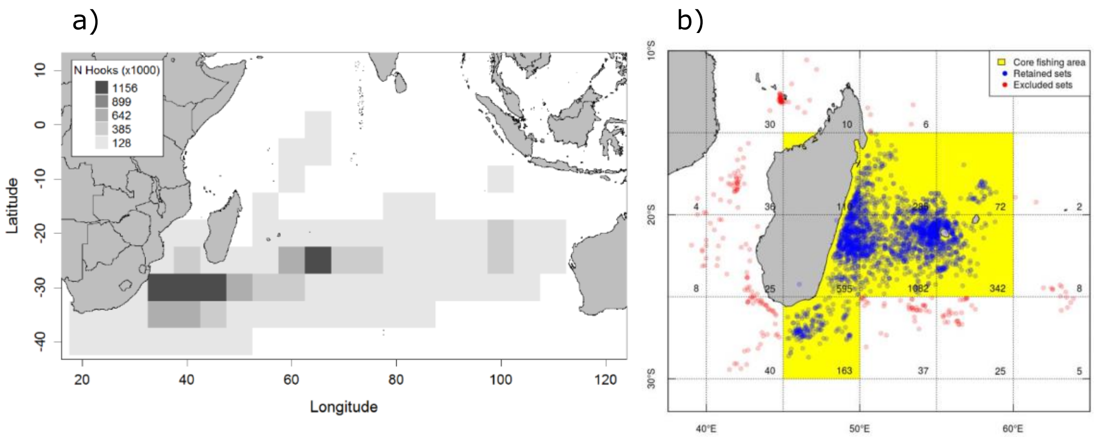


Figure I.9 Locations of a) Portuguese (1998 – 2016) and b) French (2007 – 2016) longline swordfish fisheries (sources: Coelho et al., 2017, Sabarros et al., 2017).

Effort for drifting longlines is given in Table I.5. In 2013, Portugal reported its effort in terms of days fished, it recorded a total of 2633 days.

Table I.5. Drifting longline effort (x 1000 hooks) for EU flagged vessels (source: IOTC – Catch and Effort Data).

Year	Spain	UK	Portugal	France
2010	3174	0	949	3781
2011	3758	0	903	3769
2012	4673	0	0	3367
2013	6262	0	0	4042
2014	6107	84	1496	3573
2015	4508	388	1398	3533

Martin et al. (2017) outlined the two key sources of error in reported catches of blue shark as being the fact that they are highly aggregated (many times reported as 'sharks NEI' - Not Elsewhere Identified) and often not reported at all. It went on to provide a series of estimates of blue shark catches using a number of different methods: disaggregating the 'sharks NEI' category into its component species; estimating the ratio of blue shark to target species catch to account for those catches reported as zero and using a GAM to predict the likely catch based on a number of variables (Year, Gear, Area, Fishing Ground, Target Catch). The results of this analysis between 2010 and 2015 are shown in Table I.6 and give the range of estimated catches between 42473 tonnes and 60400 tonnes per year. Table I.7 gives the total reported catches of sharks (all species) by CPC over the same time period, the EU.Spain accounts for 3.9% of all catches.

Table I.6. IOTC nominal catches and catch estimates 2010-2015 (source: Martin et al., 2017).

Year	IOTC Nominal	Estimated - disaggregated	Estimated - ratios	Estimated - GAM
2010	26,563	33,807	46,214	48,336
2011	28,033	46,974	56,587	49,034
2012	28,159	35,109	44,140	52,931
2013	32,302	39,091	51,675	60,400
2014	29,124	30,472	42,300	57,867
2015	29,916	31,671	46,473	54,735

Table I.7. Sharks (all species) total reported catches by fleet from 2000 to 2015. Only fleets until cumulative catches of 90% are shown (source: IOTC nominal catches database).

Flag	Total catch (t)	%	Cum %
Indonesia	299,040.8	18.5	18.5
Pakistan	197,164.0	12.2	30.7
Yemen	162,617.0	10.1	40.8
Iran Islamic Rep.	159,573.4	9.9	50.6
Sri Lanka	146,402.6	9.1	59.7
Oman	92,310.7	5.7	65.4
Madagascar	91,000.3	5.6	71.0
Taiwan,China	66,421.5	4.1	75.1
EU.Spain	63,791.0	3.9	79.1
Maldivas	61,611.3	3.8	82.9
Tanzania	41,770.4	2.6	85.5
India	36,172.7	2.2	87.7
Un. Arab Emirates	29,298.5	1.8	89.5

Discards, when reported are summarised at the annual meeting of the Working Party on Data Collection and Statistics (WPDCS). Table I.8 gives summary of the reported discards from the EU fleet over the last five years (2012 – 2016), the level of reporting has been poor with discards only reported for the EU fleet from French longliners during 2015 and 2016. No discards have been reported from other EU fleets or from the purse seine fishery. During 2016, 72 *Carcharhinus* sharks NEI were also reported (IOTC, 2017a) from the French longline fleet which may also have contained blue shark.

Table I.8. Reported discards of blue shark from EU fleets 2012 – 2016 (source: WPDCS reports 2013 – 2017).

Year	Fleet	Discarded (numbers)
2012	N/A	None reported
2013	N/A	None reported
2014	N/A	None reported
2015	EU(France) Longline	283
2016	EU(France) Longline	2,072

Management objectives

While there are no specific management objectives set for the blue shark, resolution 17/05[39] outlines the general plan for all sharks caught in association with

[39]http://ww.w.iotc.org/sites/default/files/documents/compliance/01_RES17-05_4P_MAJ.pdf

fisheries managed by IOTC and applies to all CPC flag States. It requires ICCAT members (known as Contracting Parties and Cooperating non-Contracting Parties, hereinafter referred to as CPCs) to report nominal catch, catch and effort and size frequency data of catches of sharks collected on the high seas through the IOTC logbook programme, the same data must also be reported in the same format from the CPC coastal fleets. All fleets except the longline fleets must submit data annually by the 30 June to the Secretariat email address[40].

The templates for the logbooks have been developed through the Secretariat and are available in Excel format[41]. They cover the reporting requirements outlined under Resolution 15/02, for sharks forms 1RC, 3CE, 3AR and 4SF apply.

In addition, resolution 17/05 highlights a number of obligations on the industry:

- Full utilization of the shark catches;
- Live release of sharks where possible;
- For sharks landed fresh: CPCs shall prohibit the landing, retention on-board, transhipment and carrying of shark fins which are not naturally attached to the shark carcass until the first point of landing;
- For sharks landed frozen, vessels to not have on-board fins that total more than 5% of the weight of (finned) shark carcasses on-board, up to the first point of landing;
- Vessels are prohibited from retaining on board, transhipping or landing any fins harvested in contravention to this resolution.

The ban on finning on sharks landed fresh and fin/carcass ratios of 5% of sharks landed frozen will be reviewed by the Commission based on advice from the Scientific Committee and case studies from other CPCs, such as the EU, that already prohibit the removal of shark fins on board vessels.

As advised by the Scientific Committee, stocks of blue shark should stay within the MSY based reference points (F_{msy} and B_{msy}) with at least a 50% probability.

[40] iotc-secretariat@fao.org
[41] Available from http://www.iotc.org/data/requested-statistics-and-submission-forms

Conservation reference points

There are no defined reference points for blue shark within IOTC, but current assessments define the stock as not overfished nor subject to overfishing. However, it is thought that maintaining catches at current levels will be likely to decrease the biomass, so the stock might become overfished and subject to overfishing. Current management advice recommends that the catches should be reduced by at least 10% of the estimated 2015 catch of 54,735 tonnes (to 49,262 tonnes) to increase the probability of maintaining the stock biomass above the MSY reference levels ($B>B_{MSY}$) over the next eight years. To better monitor catches and landings, CPCs should be encouraged to meet their reporting requirements under Resolution 16/06.

The most recent stock assessment for blue shark was conducted in 2017, the only previous assessment being carried out in 2015. Four models were applied to the most recent assessment (compared to three in 2015):

- a data limited catch only model (SRA);
- two Bayesian biomass dynamic models; and,
- an integrated age structured model (Stock Synthesis III - SS3) using catch, effort and size data from eight different fisheries.

All models produced a similar result indicating that the stock is not currently overfished nor subject to overfishing and a base case model was selected using the SS3 model, based on the best available data. Figure I.10 shows the Kobe plot from the 2017 assessment and the trend towards the overfished and subject to overfishing quadrant of the plot.

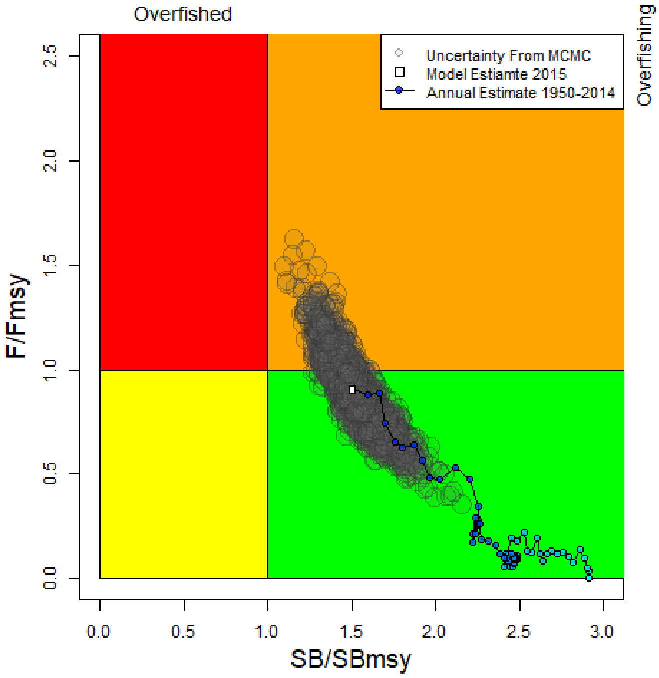


Figure I.10. Aggregated Indian Ocean stock assessment Kobe plot for the 2017 estimate based on the base case model and a range of sensitivity models run using SS3 – Stock Synthesis III. Trajectory shows trend towards overfished and overfishing quadrant of the Kobe plot (source: Rice, 2017).

Catch and discard limits

Although there was a scientific recommendation, following the 2017 assessment, that if the IOTC Commission wished to increase the probability of maintaining the stock biomass above MSY reference levels over the next 8 years. Therefore, a reduction of a least 10% in catches was advised, although not enforced, and there are currently no catch and discard limits in place within IOTC.

Conservation measures that apply to blue shark are related to the reporting requirements of the CPCs, these are outlined in Table I.9, along with resolution 16/06 on the measures that can be put in place in case of non-fulfilment of reporting obligations. Despite these requirements reporting of sharks and other bycatch is thought to be very incomplete overtime, with most reported catch just referring to retained specimens. The reported catches are normally just for the dressed weight with no indication of how the catches were processed and although EU fleets have a fin-attached policy for both fresh and frozen products, to allow better monitoring of retained catches, this does not apply to other fleets, although this will be reviewed by the Commission in 2019. This has made monitoring of both catches and discards and subsequently total removals difficult and any catch or discard limits put in place would involve better reporting and enforcement, through resolution 16/06, of the requirements under resolution 17/05.

Table I.9. CMMs applicable to blue shark.

CMM	Description
Res. 17/05	**On the conservation of sharks caught in association with fisheries managed by IOTC.** CPCs shall encourage the release of live sharks where possible, especially juveniles and pregnant females, where sharks are an unwanted species. In addition, they should aim to improve handling practices to maximise post-release survival. Sharks landed fresh must have fins attached, sharks landed frozen should not have more than 5% of the weight of finned carcasses on board.
Res. 16/06	**Measures applicable in case of non fulfilment of reporting obligations in the IOTC.** CPCs that did not report nominal catch data (including zero catches) for one or more species in a given year will be prohibited from retaining that species for the following year.
Res. 15/01	**Recording of catch and effort data by fishing vessels in the IOTC area of competence.** Sets out minimum logbook requirements CPC vessels authorised to fish in IOTC area of competence. Retained and discarded shark, listed in Annex II, must be recorded and be reported every year, by 30th June, on an aggregated basis.
Res. 15/02	**Mandatory statistical reporting requirements for IOTC contracting parties and cooperating non-contracting parties (CPCs)** Requires CPCs to report total catch by species and gear (separated if possible by retained and discarded live weight and numbers).
Res. 11/04	**Regional observer scheme.** Observers shall monitor catches to estimate catch composition, discards, by-catch and size frequency as much as is possible. Includes the requirement to collect and report data on blue shark interactions.

Bycatch mitigation

While there are no CMMs specific to blue shark there are two which encourage the release of live sharks, summarised in Table I.10.

Best practice guidelines for the release of sharks can be found in a report produced by the Convention on Migratory Species - Memorandum of Understanding on the Conservation of Migratory Sharks (CMS / MoU-Sharks) (CMS, 2016). To mitigate the impacts of purse seiners and longliners on shark species it advocated three main methods, which are outlined in Annex I:

Table I.10. CMMs encouraging the live release of sharks.

CMM	Description
Res. 17/04	**On a ban on discards of bigeye tuna, skipjack tuna, yellowfin tuna, and non-targeted species caught by purse seine vessels in the IOTC area of competence.** Requires that the vessels take reasonable steps to ensure the safe release of all non-targeted species taken alive in purse seine operations.
Res. 17/05	**On the conservation of sharks caught in association with fisheries managed by IOTC.** CPCs shall encourage the release of live sharks where possible, especially juveniles and pregnant females, where sharks are an unwanted species. In addition, they should aim to improve handling practices to maximise post-release survival.

A working paper produced by China for WPEB in 2014 (Huihui, 2014) also outlined a number of policy mechanisms in place to reduce or prevent the retention and finning of sharks which included enacting their National Shark Conservation Action Plan, improving the data reporting system, controlling the shark fin trade and promoting public awareness of the effects of consuming shark products on the marine ecosystem.

Indicators

Indicators developed during the 2017 assessment are summarised in the executive summary for the blue shark[42] and are reproduced in Table I.11.

The main conclusions of this assessment were

- The stock status is highly dependent on the CPUE series used to fit the model. Among the candidate CPUE models in this assessment no CPUE series runs through the entire time series.
- The estimates of catch are highly influential in the model, but mostly in terms of scale, as the current depletion and fishing mortality indicators are approximately equal across all catch estimates for a given CPUE series.

[42] Available at http://www.iotc.org/sites/default/files/documents/science/species_summaries/english/Blue_shark_Executive_Summary.pdf

- The scale of the assessment is influenced by the CPUE series chosen and by the catch estimates used, estimates of B0 range from approximately 700,000 metric tons to over 3 million metric tons.
- The stock status implied by the estimates of and $F_{current}/F_{MSY}$ across the grid showed multiple scenarios in which $F_{current}/F_{MSY} > 1$.

The current assessed status shows a 72.6% probability that the stock is not overfished and not subject to overfishing, although while the reported catch for 2016 is below MSY, the estimated catch, based on including a proportion of the 'sharks nei.', or using a GAM, is considerably above. As indicated in the Kobe plot in Figure I.10, the trajectory from the assessment is showing a consistent trend towards overfished and subject to overfishing and maintaining the current level of catches may place the stock in this quadrant. The management advice provided by the IOTC SC, based on the last assessment, is to reduce catches by at least 10% to maintain the stock above MSY reference levels. The Commission has not adopted reference points or harvest control rules for any shark species.

Table I.11. Status of blue shark in the Indian Ocean (from the IOTC blue shark executive summary).

Area	Indicators		2017 stock status determination
Indian Ocean	Reported catch 2016	32,312t	72.6%
	Estimated catch 2015	54,735t	
	Not elsewhere identified (nei) sharks	54,495t	
	Average reported catch 2012-2016	30,563t	
	Average estimated catch 2011 – 2015	54,993t	
	Average nei. sharks	49,152t	
	MSY (1,000t)(80% CI)	33.0 (29.5 – 36.6)	
	F_{MSY} (80% CI)	0.30 (0.30 – 0.31)	
	SB_{MSY} (1,000t)(80% CI)	39.7 (35.5 – 45.4)	
	F_{2015}/F_{MSY}(80% CI)	0.86 (0.67 – 1.09)	
	SB_{2015}/SB_{MSY} (80% CI)	1.54 (1.37 – 1.72)	
	SB_{2015}/SB_0 (80% CI)	0.52 (0.46 – 0.56)	

Timeframe

Assessments of blue shark are undertaken by the Working Party on Ecosystems and Bycatch (WPEB) and fall under their five-year plan of work (IOTC, 2017b). The current plan of work runs from 2018 through to 2022, and outlines the assessment schedules for the bycatch species covered by the Working Party. Any timeframe for the assessment if indicators should be tied into this, the current schedule is to revisit the Ecological Risk Assessment (ERA) in 2018, develop or refine indicators in 2020 and conduct another blue shark full assessment in 2021.

Table I.12 Draft assessment schedule for the blue shark by the Working Party on Ecosystems and Bycatch 2018 – 2022 (source: IOTC, 2017b).

Species	2018	2019	2020	2021	2022
Blue shark	Revisit ERA	-	Indicators	Full assessment*	Indicators

*including data poor stock assessment methods, the assessment schedule may be changed dependent on the annual review of fishery indicators or SC and Commission requests.

Monitoring and evaluation

Monitoring and evaluation should be done through the IOTC WPEB; presented and endorsed by the IOTC SC.

References

CMS. 2016. Draft best practice guidelines for sharks and rays taken in purse seine and longline fisheries. Prepared by S. L. Fowler. First Workshop of the Conservation Working Group of the Memorandum of Understanding on the Conservation of Migratory Sharks, Bristol, United Kingdom, 31 October – 01 November 2016.

Coelho, R., Pedro, G. Lino, P., G., Rosa, D. 2017. Blue Shark Catches and Standardized CPUE for the Portuguese Pelagic Longline Fleet in the Indian Ocean. Working Party of Ecosystems and Bycatch. IOTC document IOTC-2017-WPEB13-24.

Compagno, L.J.V. 1984. FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2. Carcharhiniformes. *FAO Sish. Synop.,* (125) Vol.4, Pt.2: 251-655.

Gubanov, E.P., Gigor'ev, V.N. 1975. Observations on the distribution and biology of the blue shark *Prionace glauca* (Carcharhinidae) of the Indian Ocean // Raspredelenie i nekotorye cherty biologii goluboj akuly *Prionace glauca* L. (Carcharhinidae) Indijskogo okeana. *Voprosy Ikhtiologii*, 15: 43-50.

Huihui, S. 2014. China's Practice of Shark Bycatch Mitigation in Tuna Fisheries. Working Party on Ecosystems and Bycatch. IOTC document IOTC-2014-WPEB10-INF23.

IOTC. 2016. Blue shark supporting information. Available from http://www.iotc.org/sites/default/files/documents/science/species_summaries/english/Blue_Shark_Supporting_Information.pdf.

IOTC. 2017a. Report on IOTC Data Collection and Statistics. Working Party on Data Collection and Statistics. IOTC document IOTC-2017-WPDCS13-07.

IOTC. 2017b. Report of the 13th Session of the Working Party on Ecosystems and Bycatch. 4–8 September 2017, San Sebastian, Spain. IOTC-2017-WPEB13-R[E]: 125pp.

Martin, S., Fiorellato, F., Rice, J. 2017. Approaches to the Reconstruction of Catches of Indian Ocean Blue Shark *(Prionace Glauca)*. Working Party on Ecosystems and Bycatch. IOTC document IOTC-2017-WPEB13-23.

Murua, H., Coelho, R., Santos, M.S., Arrizabalaga, H., Yokawa, K., Romanov, E., Zhu, J.F., Kim, Z.G., Bach, P., Chavance, P., Delgado de Molina, A., Ruiz, J. 2012. Preliminary Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC). Working Party on Ecosystems and Bycatch. IOTC Document IOTC–2012–WPEB08–31.

Rabehagasoa, N., Lorrain, A., Bach, P., Potier, M., Jaquemet, S., Richard, R., Ménard, F. 2012. Isotopic niches of the blue shark *Prionace glauca* and the silky shark *Carcharhinus falciformis* in the southwestern Indian Ocean. *Endangered Species Research*, 17: 83-92.

Rice, J. 2017. Stock assessment blue shark (*Prionace glauca*) in the Indian Ocean using Stock Synthesis. Working Party on Ecosystems and Bycatch. IOTC document IOTC-2017-WPEB13-33: 37pp.

Romanov, E., Potier, M., Zamorov, V., Menard, F. 2009. The swimming crab *Charybdis smithii*: distribution, biology and trophic role in the pelagic ecosystem of the western Indian Ocean. *Marine Biology*, 156: 1089–1107.

Sabarros, P., S., Coelho R., Bach, P. 2017. Standardized CPUE of blue shark caught by the French swordfish fishery in the south-west Indian Ocean (2007-2016). Working Party on Ecosystems and Bycatch. IOTC document IOTC-2017-WPEB13-27: 15 pp.

Taguchi, M, Yokawa, K. 2013. Genetic population structure of blue sharks (*Prionace glauca*) in the Pacific Ocean inferred from the microsatellite DNA marker. ISC Shark Working Group Workshop. ISC document ISC/13/SHARKWG-1/09.

12.4. *CASE STUDY 4 – SHORTFIN MAKO - IOTC*

a. Background

Current knowledge and stock status

The shortfin mako (*Isurus oxyrinchus*) is a highly migratory species found in tropical and temperate waters worldwide (Compagno, 2001). As with other pelagic shark species, *I. oxyrinchus* is commonly caught as bycatch by pelagic fisheries; it is the second most common shark species in these fisheries (Mejuto et al., 2008). Contrary to other shark species, shortfin makos are usually retained for their valuable meat and fins (Compagno, 2001). Ecological risk assessment conducted in Atlantic, Indian and Pacific Oceans considered the shortfin mako as one of the most vulnerable species due to its high susceptibility and low productivity (Murua et al., 2012; Cortés et al., 2015; Griffiths et al., 2017).

Despite its importance as by-catch species and high vulnerability, catches in the Indian Ocean are considered to be underreported, or reported in the aggregated form (e.g. fleets reporting mako, which can include both shortfin and longfin makos). Additionally, few data on discards and size composition is available for the Indian Ocean. Regarding life history traits, there is information on age and growth, including a von Bertalanffy growth equation and longevity estimates, and on reproductive biology.

In regards to other oceans stock status and advice, a quantitative stock assessment was performed in the Atlantic Ocean in 2017. The assessment results for the North Atlantic showed that biomass was bellow biomass at maximum sustainable yield (MSY) and fishing effort was well above the fishing effort at MSY (Anon., 2017). For the South Atlantic, there is high uncertainty in model estimations; however it is not possible to rule out that in recent years the stock may have been overfished and suffering overfishing (Anon., 2017).

In the Indian Ocean, a quantitative stock assessment has been planned by the Working Party on Ecosystems and Bycatch (WPEB) for 2020 (IOTC, 2017). Currently, no stock status information is available for shortfin mako in the IOTC area, also so far few indicators of stock abundance have been provided. Specifically, to this date only Japanese (Kimoto et al., 2011) and EU.Portugal (Coelho et al., 2013; Coelho et al., 2017) have provided standardized catch-per-unit-of-effort (CPUE) for shortfin makos from those fleets. Both the Japanese and Portuguese series present a decrease in the first years of the series and an increase in abundance in the most recent years.

Obstacles preventing quantitative scientific advice

At present, the key obstacles preventing the quantitative scientific advice of shortfin mako stock status in the Indian Ocean are:

- Incomplete catch information
- Limited availability of abundance trends indices (e.g. standardized CPUEs)
- Absence of information of the composition of the catches (mainly length frequency distribution)

b. Objectives

Shortfin mako is the second most captured species by the EU fleets, particularly by longline fisheries, with a stock assessment planned for 2020 for shortfin mako in the Indian Ocean. Here, we assessed this stock using a data limited assessment method and to provide a preliminary stock status for this species in the Indian Ocean, through the following steps:

- Reconstructing shortfin mako catch time series for the period 1971-2015.
- Estimating catch-per-unit-effort time series based on the longline fisheries that target swordfish and have bycatches of shortfin mako.
- Estimating a probability density distribution for shortfin mako intrinsic population growth rate (r) for later use as a prior in assessment models.
- Implementing feasible stock assessment models for Indian Ocean shortfin mako (specifically, models based on catch, resilience and qualitative stock status information).

c. Material and Methods

Catch reconstruction

Catches were reconstructed between 1971 and 2015 using Task 1 (EUPOA) method (see Coelho et al., 2018).

Catch per unit of effort (CPUE) standardization

Portuguese series standardization

A continuous effort over the last years has been made by the Portuguese Institute for the Ocean and Atmosphere (IPMA) to collect current and historical catch and effort data from the Portuguese longliners targeting swordfish in the Indian Ocean. This includes information on the catches, fishing effort (number of sets or hooks per set) and geographical location (integrated from VMS data). Such data mining effort has allowed IPMA to recover most of the time series for the Portuguese pelagic longline fleet operating in Indian Ocean (Table 5.3.1.).

Table 5.3.1. Number of fishing sets with catch, effort (hooks) and location information carried out by the Portuguese pelagic longline fleet in the Indian Ocean between 1998 and 2016. The percentage of sets per year analyzed for this paper is also indicated. Note that the 2 first years of the series (1998 and 1999) were not used for the CPUE standardization analysis due to lower effort in the Indian Ocean.

Year	Sets (n)	Sets with effort (Hooks)	Sets with locations (VMS)	Sets used for analysis (%)
1998	113	113	113	100.0
1999	147	147	147	100.0
2000	275	275	275	100.0
2001	631	631	631	100.0
2002	687	687	647	94.2
2003	575	575	575	100.0
2004	370	370	370	100.0
2005	143	143	143	100.0
2006	1801	1801	1801	100.0
2007	1325	1325	1325	100.0
2008	238	238	238	100.0
2009	482	482	482	100.0
2010	457	457	457	100.0
2011	633	633	633	100.0
2012	516	516	516	100.0
2013	1312	1312	1312	100.0
2014	863	863	863	100.0
2015	1302	1302	1302	100.0
2016	1445	1445	1445	100.0
Total	**13315**	**13315**	**13275**	**99.7**

For the CPUE analysis, this operational level data from logbooks was used, with the catch data referring to the total (round) weight of shortfin makos captured per fishing set. The available catch data started in 1998 and was available until 2016. However, the first 2 years of the series (1998 and 1999) were not used for the model because there was more limited information in those initial years of the fisheries. For the CPUE standardization, the response variable considered was catch per unit of effort (CPUE), measured as biomass of live fish (kg) per 1000 hooks deployed. The standardized CPUEs were estimated with Generalized Linear Mixed Models (GLMMs).

Coelho et al. (2014) has previously tested 10 sensitivity runs in blue shark CPUE standardization models, including sensitivities to the model type, the use of ratio factor and the definition of the area effects. The base case used for the present work on shortfin mako was based on the best model approaches selected in that work. Additionally, Coelho et al. (2015) tested targeting effects to this fleet by using ratios versus cluster analysis, demonstrating that both had very similar behaviours (fleet targeting mainly swordfish -SWO- but with sharks, mainly blue shark as a secondary target).

As the shortfin mako shark is a bycatch from the fishery, there were considerable trips or sub-trips with zero catches that results in a response variable of CPUE=0. As these zeros can cause mathematical problems for fitting the models, a Tweedie model was used, as described in Coelho et al. (2012) for the shortfin mako shark (SMA) CPUE standardization for the Portuguese fleet in the Atlantic Ocean.

The tweedie model uses an approach in which only one model is fitted to the data, with that model handling the mixture of continuous positive values with a discrete mass of zeros. The tweedie distribution is part of the exponential family of distributions, and is defined by a mean (μ) and a variance ($\varphi\mu^p$), in which φ is the dispersion parameter and p is an index parameter. In this study, the index parameter (*p-index*) was calculated by maximum likelihood estimation (MLE).

Based on the sensitivities and tests reported by Coelho et al (2014), the covariates considered and tested in the base case models for this work were:

- Year: analyzed between 2000 and 2016;
- Quarter of the year: 4 categories: 1 = January to March, 2 = April to June, 3 = July to September, 4 = October to December;
- Area: Using a GLM Tree area stratification based on Ichinokawa & Brodziak (2010) approach;
- Ratio: based on the SWO/(SWO+BSH) ratio of captures;
- Interactions: first order interactions were tested and would be used if significant with the AIC criteria;

Interactions were considered and tested in the models. Specifically, interactions not involving the year factor were considered as fixed factors in the GLM, while interactions involving the year factor were considered as random variables within GLMMs.

The significance of the explanatory variables was assessed with likelihood ratio tests comparing each univariate model to the null model (considering a significance level of 5%), and by analyzing the deviance explained by each covariate. Goodness-of-fit and model comparison was carried out with the Akaike Information

Criteria (AIC). Model validation was carried out with a residual analysis. The final estimated indexes of abundance were calculated by Least Square Means (marginal means), that for comparison purposes were scaled by the mean standardized CPUE in the time series.

Spanish series standardization

Data for the analysis was compiled from the logbooks of the Spanish pelagic longline fishery operating in the Indian Ocean (FAO IO divisions 51, Western Indian Ocean; 58 Indian Ocean, Antarctic and Southern; 57, Eastern Indian Ocean) for the period 2006-2016 (with the exception of year 2008, for which there was no information available). The information, recorded on a trip basis, included vessel identification, date and geographical position by fishing operation, and catch by species in kg.

Data inspection basically entailed the elimination of incomplete and erroneous records. Whenever possible, incorrect measurement units were corrected. As a result, approximately one per cent (1%) of the records available for the period 2006-2016 was discarded for later analysis. A total of 624 fishing trips for the period 2006-2016 were available for further analysis.

Based on the estimated annual percentages of shortfin mako fishing sets with zero catch (Table 5.3.2) and the observed skewed distribution of shortfin mako positive catches, a Generalized Additive Mixed Model (GAMM) assuming a Tweedie distributed error was implemented for CPUE standardization (Winker et al, 2014, Ono *et al*., 2015; see description above in the Portuguese CPUE standardization).

Table 5.3.2. Estimated annual percentages of shortfin mako fishing sets with zero catch.

Year	Zero catch (%)
2006	56.72
2007	54.93
2008	NA
2009	44.79
2010	51.70
2011	40.16
2012	44.04
2013	37.04
2014	19.62
2015	28.57
2016	56.29

The final model formulation included as explanatory variables *year, month*, and a random intercept for *vessel.*

Demographic analysis

A stochastic population dynamics model (demographic analysis) using age-based Leslie Matrices was carried out to estimate the population intrinsic growth rate (r) (Caswell, 2001). Since only females produce off-spring, the demographic analysis was carried out exclusively for the female component of the population (Simpfendorfer, 2004). The age-structured model conceived was a pre-breeding survey model, where reproduction and natality take places first, followed by the probability of survivorship-at-age. Thus, the age-specific fecundity values of the Leslie matrix (Fx) were calculated as the products of the age-specific fertilities (mx) and the first-year survivorship (s0): Fx=s0*mx. In terms of survivorship, the age-specific survivorship was estimated based on several indirect life history equations, specifically Pauly (1980), Hoenig (1983), Jensen (1996), Peterson and Wroblewski (1984), Chen and Watanabe (1989).

Four different scenarios were analysed and compared (Table 5.3.3). These scenarios accounted for different information on life history parameters available from the literature (Barreto et al., 2016; Rosa et al., 2017) and different possible alternatives that can be used to estimate fecundity (either a 2 or 3-year reproductive cycle, still uncertain for the species).

Table 5.3.3. Biological data inputs for the demographic analysis for different scenarios.

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	References
	Barreto et al., 2016		Rosa et al., 2017		
Theoretical maximum length (L_{inf})	407.56		350.3		
Growth coefficient (k)	0.04		0.064		
Theoretical age at length zero (t_0)	-7.08		-3.09		
Lifespan	32				Natanson et al. (2006)
Reproductive cycle	2	3	2	3	Mollet et al. (2000)
Intercept of maturity ogive	-53.14				
Slope of maturity ogive	19.46				
Sex ratio at birth	1:1				
Scalar coefficient of litter size on TL	0.81				
Power coefficient of litter size on TL	2.346				
Scalar coefficient of weight on length	0.0000349				Romanov & Romanova (2009)
Power coefficient of weight on length	2.76544				
Slope of TL to FL relationship	0.929				Kohler et al. (1995)
Intercept of TL to FL relationship	1.7101				

Uncertainty in the analysis was introduced in the survivorship and fecundity parameters. Uncertainty in the survivorship parameters was introduced by generating age-specific random survivorship values from a uniform distribution with support defined between the minimum and maximum empirical age-specific estimates. For the fecundity parameters, uncertainty was considered by generating random age-specific fertilities based on a normal distribution, with the expected values and standard deviations based on the fertility-at-age values. Each scenario was simulated using 10000 Monte Carlo replicates varying each input parameter (survivorship and fecundity) based on the previously assumed distributions. The resulting 10000 Leslie matrices were analysed, and the distributions of the output parameters summarized as the mean r values and the corresponding 95% confidence intervals (0.025 and 0.975 quantiles).

Assessment models

Considering the information available, effort was focussed on the implementation of the CMSY model developed by Froese et al. (2017).

In essence, this model implements a stock reduction analysis using default priors for the intrinsic rate of population growth (r), based on resilience; for the carrying capacity or unexploited stock size k, based on maximum observed catch and estimated priors for r; and start, intermediate, and final year depletion levels (B/k), based on a set of simple rules. It allows for the inclusion of priors for the input parameters (r, k and depletion) based on expert knowledge or estimated by any other feasible method. The stock reduction analysis uses a Schaefer biomass dynamic model and an algorithm for identifying feasible r-k combinations to estimate biological and management quantities (r, K, MSY, B_{MSY}, F_{MSY}) as well as time series of biomass, fishing mortality, and stock status benchmarks (B/B_{MSY}, F/F_{MSY}).

It is worth noting that in its current version CMSY addresses the overestimation of productivity at very low stock sizes (general shortcoming of production models) by implementing a linear decline of surplus production when biomass falls below 1/4k.

Data and CMSY run configuration

Input data

Estimated catches for the period 1971 to 2015 were used. Although CMSY is primarily a catch-only assessment method, the package also offers the possibility to fit a Bayesian surplus production model (Schaefer) if abundance indices are available. The two abundance indices available for shortfin mako, specifically the Portuguese and Spanish longline indexes, were used.

Range of parameters explored

The largest and smallest r values from the demographic analysis (0.008-0.048) were used to define the range of r values explored in CMSY. In addition to this, CMSY was also run using the default approach, in which the resilience value available on FishBase is used to define the range of r. For shortfin mako, resilience is estimated to be very low (Froese & Pauly, 2015), which for CMSY defaults corresponds to values of r in the range 0.015-0.100 (see Froese et al., 2017), a little wider and centred on higher values than the first option.

As regards the range of depletion rates (B/k), at the start of the time series (1971), the stock is believed to be already lightly exploited. An initial depletion rate (B/k) of 0.7-0.9 was therefore used. In order not to constrain too much the estimated stock trajectory, a wider range, between 0.2 and 0.7, was used for the final year (2015) depletion rate.

By default, CMSY uses an intermediate depletion rate (10 years before the end of the available time series) with values in the range 0.2-0.6. Preliminary runs using this default option showed that this range is very restrictive. In order to give the model more freedom, a larger range was set (0.1-0.9, for year 2000).

Further model configuration involved both the choice of variance for the catch data (observation error), and variance of the process error. For both the default value was 0.1, which seemed considerable low (especially given that the catches were estimated by using a model); hence, higher values (0.2) were tested. This was found to have no effect on the output of CMSY.

d. Results

Catch reconstruction

There are differences of shortfin mako reported *versus* estimated catches along the entire time series, even when considering the reported catch of *Isurus* spp. In both series there is a steady increase until the early 1990's. In the reported time series the catches continue to increase until 2015, while in the estimated catches there is a rapid increase in the early 1990’s followed by a steadily increase thereafter (Figure 5.4.1).

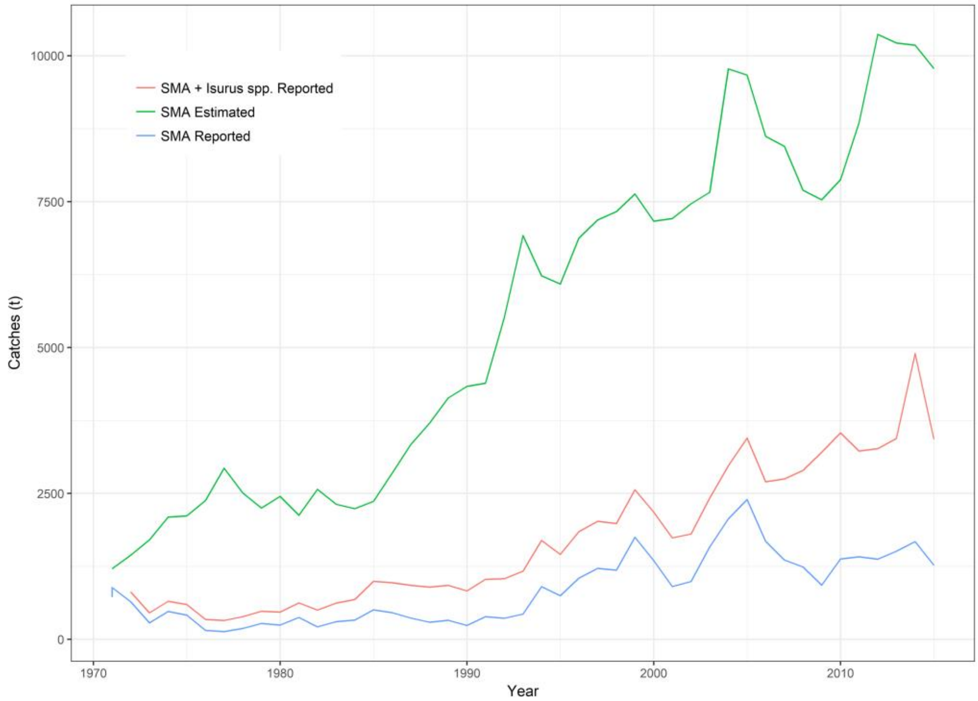


Figure 5.4.1. Time series of reported shortfin mako (SMA) and shortfin mako + reported catch of *Isurus* spp. and estimated shortfin mako catches, between 1971 and 2015, for the Indian Ocean.

Catch per unit of effort (CPUE) standardization

Two abundance indices were prepared and available for shortfin mako, based on the Portuguese and Spanish pelagic longline fleets (Figure 5.4.2). The series cover the period 2000-2016 and 2006-2016, respectively, and show globally an increasing trend over the last decade.

Figure 5.4.2. Shortfin mako scaled standardised CPUE series for Portugal (2000–2016) and Spain (2006-2016).

Demographic analysis

Using different biological scenarios (see Table 5.3.3) had an effect on the estimated r, both between growth models and periodicity of the reproductive cycle (Figure 5.4.3). Scenarios 1 and 4 had higher estimates of r (0.048 and 0.032, respectively) than scenarios 2 and 3 (0.008 and 0.025, respectively). When comparing between periodicity of the reproductive cycle, the scenarios with a 2-year cycle (Scenarios 1 and 3) estimated a higher r than scenarios with 3-year cycles (Scenarios 2 and 4).

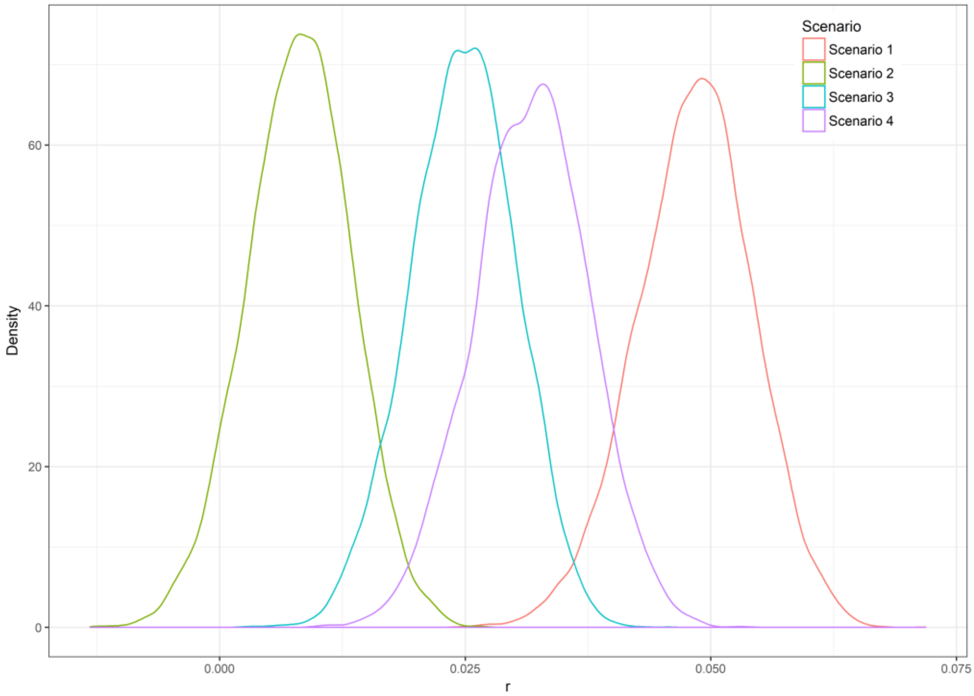


Figure 5.4.3. Plot of intrinsic rate of growth (r) estimates from stochastic demographic analysis for the different biological scenarios (see Table 5.3.3).

Assessment model

Influence of the choice of the prior on r

The two options tested for the prior on r did not do not fully overlap. As a result, the "best" r estimate using the Leslie model based range is lower than with the resilience based approach (0.031 and 0.062 respectively, Figure 5.4.4). The corresponding K values are 462 thousand tonnes (kt) and 309 kt respectively.

Output of the final CMSY configuration

The final configuration of the model included the Leslies based r prior since they provide a more realistic range of r value for this species than values taken from Fishbase, the expert knowledge based initial and final depletion rates and a broad range of depletion for the intermediate year (with a view to minimizing the impact in the CMSY results).

Final model configuration estimates of r, k and related quantities are given in Table 5.4.1.

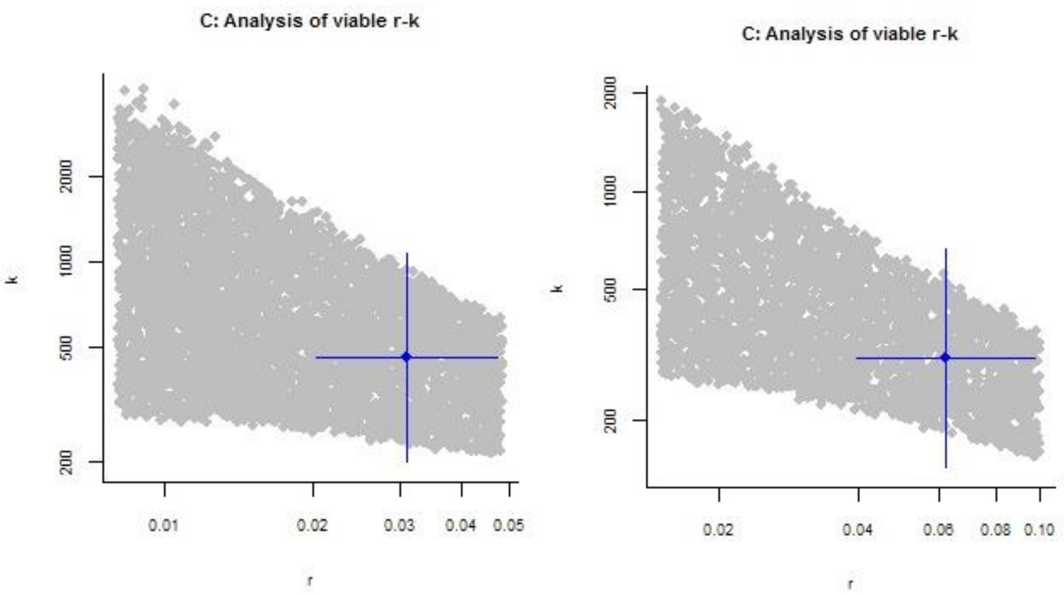


Figure 5.4.4. Viable r/K pairs (grey dots), and "best estimates" (and associated uncertainty), blue crosses, for the runs of CMSY using the Leslie based priors (0.008-0.048) on r (left) and the resilience based priors on r (0.015 – 0.1) (right).

Table 5.4.1. Model configuration estimates from CMSY.

Parameter	Estimate	95% CI
r	0.031	0.0203-0.0473
k	462 (1000 t)	199-1072 (1000 t)
MSY	3.58 (1000 t)	1.57-8.13 (1000 t)
Relative biomass last year (2015)	0.531 k	0.213-0.696
Exploitation F/(r/2) last year (2015)	2.57	

The stock is believed to have been at almost pristine state in 1971 (B/k around 0.8), started declining in the 1990s to close to B_{MSY} in 2015. The exploitation rate was low in the early years, increasing strongly since the early 1990s to a value of 2.6 times F_{MSY} currently. Therefore, the results give the perception that the stock biomass is still above B_{MSY} (stock is not overexploited), but the current fishing mortality is high, around 2.6 times higher than F_{MSY} (stock is currently under over-exploitation)

When using the Bayesian Schaefer model (BSM), the two abundances indices available indicate an increasing stock, which is contradictory with the biomass trend calculated by CMSY. The BSM r estimates are lower than CMSY, with both surveys having an estimated r of 0.02 (CMSY r estimate is 0.031) and higher K (768 kt based on Portuguese survey and 936 kt based on the Spanish survey, against 462 for CMSY).

The estimated biomass from both BSMs is (following the variation in the indices used) increasing from a situation just under B_{MSY} in the early 2000s to well above B_{MSY} in 2015 (Figure 5.4.5). Exploitation rates are expected to be high (from both BSMs), well above F_{MSY}, with no marked trend. For these models this stock is currently overexploited and under over-exploitation.

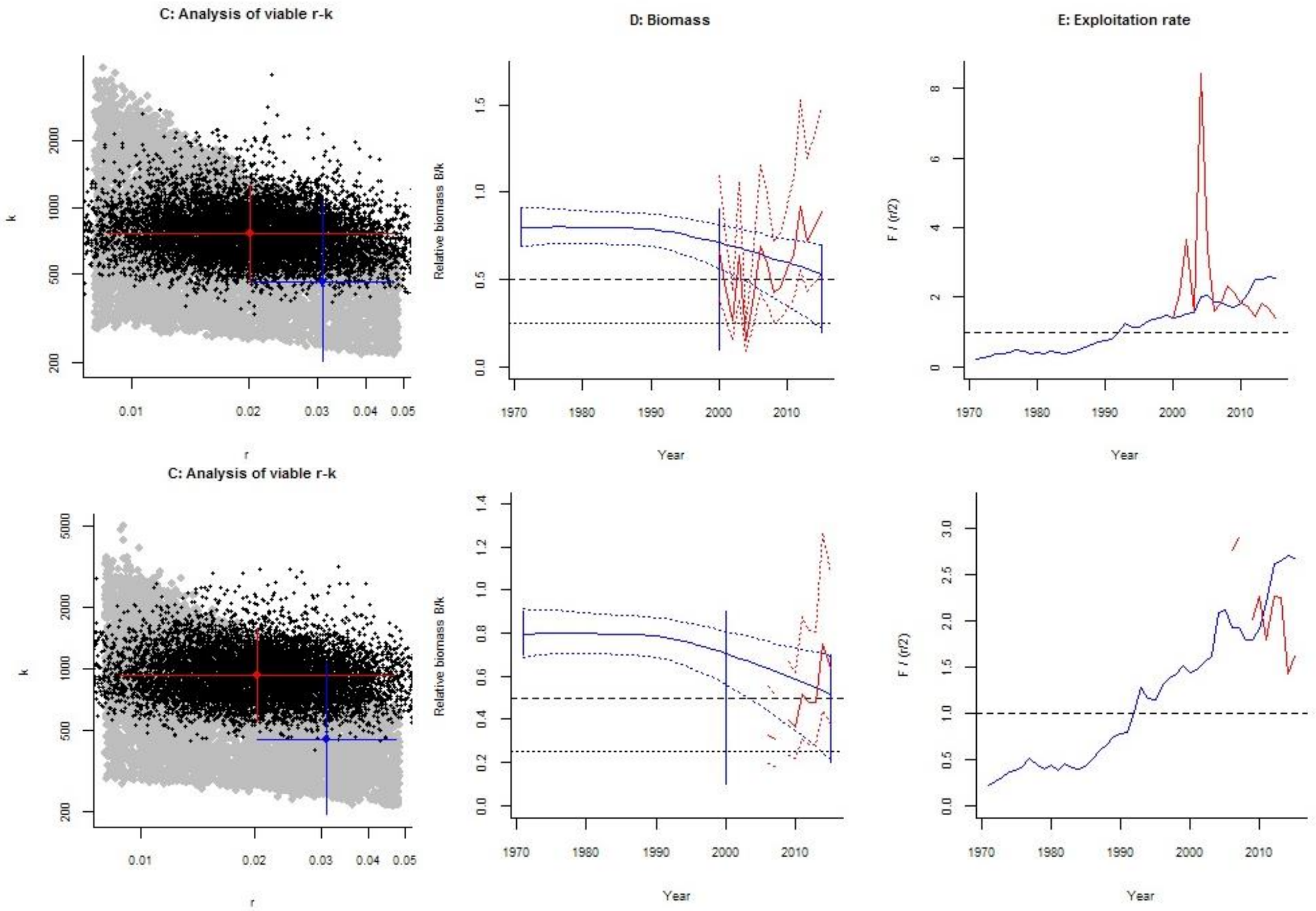


Figure 5.4.5. Output of the Bayesian Schaefer model using the Portuguese CPUE index (top) and the Spanish CPUE index (bottom). Panel C: comparison of the CMSY and Bayesian Schaefer estimates of r and K (blue and red respectively, with grey dots depicting the viable estimates from CMSY and the black dots depicting the distribution of the Bayesian estimates from the Bayesian Schaefer model);

Panel D: estimated biomass (relative to K) and Panel E: exploitation rate from the CMSY run (blue) and the Bayesian model (red).

Stock status and management recommendations

Regarding the conflicting trends in biomass between BSM and CMSY, stock status and management recommendations are given mainly based on the CMSY results. Catches exceeded maximum sustainable yield before the 1990's, with an upward trend until the end of the reconstructed time series (Figure 5.4.6). As regards to exploitation, it was below the MSY-level in the years before the early 1990's; from then on, the exploitation increased beyond the levels compatible with maximum sustainable yield. The exploitation rate for year 2015 (last in the available time series) was predicted to be well above the MSY-level (F_{2015}/F_{MSY} = 2.57) with a wide margin of uncertainty around that prediction (Figure 5.4.6). CMSY predicts biomass above B_{MSY} from the beginning of the time series with a decreasing trend until the end of the series. The estimation of current biomass (2015) to biomass at MSY was close to 1, with a considerable margin of uncertainty in the prediction (Figure 5.4.6). According to the CMSY predictions, at present the shortfin mako stock would be subjected to overfishing but not overfished, however with the trajectories showing consistent trends towards the overfished and subject to overfishing status (Figure 5.4.6).

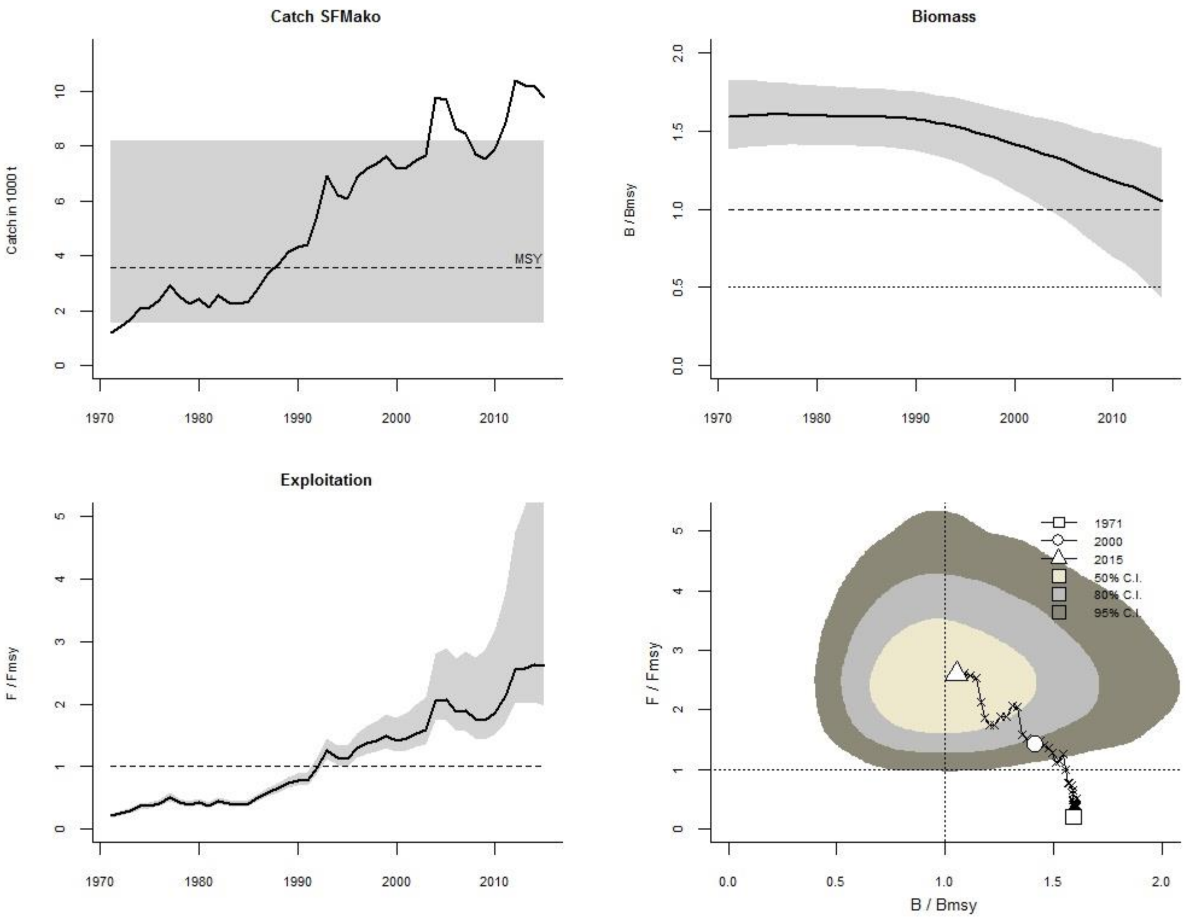


Figure 5.4.6. CMSY stock status results. A) Line represents reconstructed catch time series (1971-2015). Horizontal dashed line indicates MSY, and the shaded area indicates the confidence limits of MSY. B) Predicted biomass with confidence limits (shaded area). Horizontal dashed line indicates B_{MSY} and the dotted line indicates $0.5B_{MSY}$. C) Exploitation rate (solid line) and associated uncertainty (shaded area). Dashed horizontal line indicates exploitation compatible with MSY. D) Temporal evolution of biomass and exploitation relative to B_{MSY} (vertical dashed line) and F_{MSY} (horizontal dashed line), respectively. Bivariate experimental confidence intervals correspond to the last year in the available time series (2015).

e. <u>Final remarks</u>

Due to the considerable amount of uncertainty in the estimates, management advice is not clear from this preliminary work.

Recent fishing mortality levels appear to be likely in excess of F_{MSY}. Fishing reduction to the levels observed during the early years in the 1990's would likely be sustainable. Precautionary management may restrict catches at levels observed in late 1980s and early 1990s (around 3000t) until additional information allows for a more detailed analysis. However, given the current level of uncertainty on the estimated reference points, the estimated lower 95% confidence limit of maximum sustainable yield (1570t) may serve as a more conservative guidance for total allowed catches. Management measures designed to reduce catch and effort directed at Indian Ocean shortfin mako should be implemented.

f. References

Anon. 2017. Report of the 2017 ICCAT shortfin mako stock assessment meeting. 12-16 June 2017. Madrid, Spain. 64 pp.

Barreto, R.R., de Farias, W.K.T., Andrade, H., Santana, F.M., Lessa, R. 2016. Age, Growth and Spatial Distribution of the Life Stages of the Shortfin Mako, *Isurus oxyrinchus* (Rafinesque, 1810) Caught in the Western and Central Atlantic. *PLoS ONE* 11(4): e0153062. doi: 10.1371/journal.pone.0153062.

Caswell, H. 2001. Matrix Population Models: Construction, Analysis, and Interpretation, 2nd ed. Sinauer Associates, Sunderland, Massachusetts.

Coelho, R., Lino, P.G., Santos, M.N. 2012. Standardized CPUE for the shortfin mako (*Isurus oxyrinchus*) caught by the Portuguese pelagic longline fishery. ICCAT SCRS/2012/072. 15pp.

Coelho, R., Santos, M.N., Lino, P.G. 2013. Standardized CPUE series for blue and shortfin mako sharks caught by the Portuguese pelagic longline fishery in the Indian Ocean between 1999 and 2012. Working Party on Ecosystems and Bycatch. IOTC document IOTC–2013–WPEB09–22. 18pp.

Coelho, R., Santos, M.N., Lino, P.G. 2014. Blue shark catches by the Portuguese pelagic longline fleet between 1998-2013 in the Indian Ocean: Catch, effort and standardized CPUE. IOTC-2014-WPEB10-24. 32pp.

Coelho, R., Santos, M.N., Lino, P.G. 2015. Standardized CPUE of blue shark in the Portuguese pelagic longline fleet operating in the north Atlantic. ICCAT SCRS/2015/037. 31pp.

Coelho, R., Rosa, D., Lino, P.G. 2017. Fishery indicators for shortfin mako shark (*Isurus oxyrinchus*) caught by the Portuguese pelagic longline fishery in the Indian Ocean: Catch, effort, size distribution and standardized CPUEs. Working Party on Ecosystems and Bycatch. IOTC document IOTC-2017-WPEB-35: 21pp.

Coelho, R., Apostolaki, P., Bach, P., Brunel, T., Davies, T., Díez, G., Ellis, J., Escalle, L., Lopez, J., Macias, D., Merino, G., Mitchell, R., Murua, H., Overzee, H., Poos, J.J., Richardson, H., Rosa, D., Sánchez, S., Santos, C., Séret, B., Urbina, J.O., Walker, N. 2018. Improving scientific advice for the conservation and management of oceanic sharks and rays. Draft Final Report. European Commission. Specific Contract No. 1 under Framework Contract No. EASME/EMFF/2016/008.

Chen, S., Watanabe, S. 1989. Age dependence of natural mortality coefficient in fish population dynamics. *Nippon Suisan Gakk.* 55: 205-208.

Compagno, L.J.V., 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). *FAO Spec. Cat. Fish. Purp.*, 1(2): 1-269. Rome: FAO.

Cortés, E., Domingo, A., Miller, P., Forselledo, R., Mas, F., Arocha, F., Campana, S., Coelho, R., Da Silva, C., Holtzhausen, H., Keene, K., Lucena, F., Ramirez, K., Santos, M.N., Semba-Murakami, Y., Yokawa, K. 2015. Expanded ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Collect. Vol. Sci. Pap. ICCAT* 71: 2637-2688.

Froese, R., Demirel, N., Coro, G., Kleisner, K.M., Winker, H. 2017. Estimating fisheries reference points from catch and resilience. *Fish Fish.* 18: 506–526.

Froese, R., Pauly, D. eds. 2015. FishBase. World Wide Web electronic publication. www.fishbase.org.

Griffiths, S., Duffy, L., Aires-da-Silva, A. 2017. A preliminar ecological risk asssessment of the larg-scale tuna longline fishery in the Eastern Pacific Ocean using productivity-susceptibility analysis. 8th Meeting of the Scientific Advisory Committee of the IATTC, 8-12 May 2017, La Jolla, California. IATTC document SAC-08-07d. 21 pp.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. *Fish. Bull.* 82:898-903.

Ichinokawa, M., Brodziak, J. 2010. Using adaptive area stratification to standardize catch rates with application to North Pacific swordfish (*Xiphias gladius*). *Fisheries Research*, 106: 249-260.

IOTC. 2017. Report of the 20th Session of the IOTC Scientific Committee. 30 November – 4 December 2017, Mahé, Seychelles. IOTC document IOTC–2017–SC20–R[E]: 232 pp.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Can. J. Fish. Aquat. Sci.* 53: 820-822.

Kimoto, A., Hiraoka, Y., Ando, T., Yokawa, K. 2011. Standardized CPUE of shortfin mako shark (*Isurus oxyrinchus*) caught by Japanese longliners in the Indian Ocean in the period between 1994 and 2010. Working Party on Ecosystems and Bycatch. IOTC document IOTC–2011–WPEB–34. 8pp.

Kohler, N., Casey, J.,Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull*., 93: 412-418.

Mollet, H.F., Cliff, G., Pratt, H.L., Stevens, J.D. 2000. Reproductive biology of the female shortfin mako, *Isurus oxyrinchus* (Rafinesque, 1810), with comments on the embryonic development of lamnoids. *Fish. Bull.* 98: 299–318.

Murua, H., Coelho, R., Santos, M.S., Arrizabalaga, H., Yokawa, K., Romanov, E., Zhu, J.F., Kim, Z.G., Bach, P., Chavance, P., Delgado de Molina, A., Ruiz, J. 2012. Preliminary Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC). Working Party on Ecosystems and Bycatch, IOTC Document IOTC–2012–WPEB08–31: 16pp.

Natanson, L.J., Kohler, N.E., Ardizzone, D., Cailliet, G.M., Wintner, S.P., Mollet, H.F. 2006. Validated age and growth estimates for the shortfin mako, *Isurus oxyrinchus*, in the North Atlantic Ocean. *Environ. Biol. Fish.* 77: 367–83.

Ono, K., Punt, A. E., Hilborn, R. 2015. Think outside the grids: An objective approach to define spatial strata for catch and effort analysis. *Fish. Res.* 170:89-101.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperatures in 175 fish stocks. *J. Cons. Int. Explor. Mer.* 39: 175-192.

Peterson, I., Wroblewski, J.S. 1984. Mortality rates of fishes in the pelagic ecosystem. *Can. J. Fish. Aquat. Sci.* 41: 1117-1120.

Romanov, E., Romanova, N. 2009. Size distribution and length-weight relationships for some large pelagic sharks in the Indian Ocean. Working Party on Ecosystems and Bycatch. IOTC document IOTC-2009-WPEB-06: 12 p.

Rosa, D., Mas, F., Alyssa, M., Natanson, L.J., Domingo, A., Carlson, J., Coelho, R. 2017. Age and growth of shortfin mako in the North Atlantic, with revised parameters for consideration to use in the stock assessment. ICCAT document SCRS/2017/111: 22 pp.

Simpfendorfer, C.A., Bonfil, R., Latour, R.J. 2004. Mortality estimation. In: Musick, J.A., Bonfil, R. (Eds.) Elasmobranch Fisheries Management Techniques, APEC Secretariat, Singapore, pp. 165–186.

Winker, H., Kerwath, S. E., Attwood, C. G. 2014. Proof of concept for a novel procedure to standardize multi-species catch and effort data. *Fish. Res.* 155:149-159.

13. TASK 10 – IDENTIFY KNOWLEDGE GAPS

13.1 Key findings and recommendations

Whilst there have been improved assessments of the main oceanic shark species, several key data gaps still exist. Although the data gaps vary between species, stocks and management areas, the following areas require further data collection (monitoring) and/or research:

- Quantitative data on at-vessel and post-release mortality by species and métier, and bycatch mitigation measures;
- More robust estimates of catch (landings and estimates of dead and live discards), including reconstruction of historical catch scenarios;
- Catch composition data (species, sex and length composition);
- Spatial data (geo-referenced data on species distributions/occurrence and by life-history stage);
- More robust biological parameters (age and growth parameters, natural mortality estimates, reproductive parameters) where current studies are lacking or data is inadequate;
- Reliable indices of stock abundance;
- Testing the applicability of recently developed data-limited assessment methods;
- Overall status of by-caught sharks and rays that are not currently assessed;
- Development of appropriate management frameworks;
- Improved evaluation of the stock units, landings, catches and status of oceanic sharks in the Mediterranean Sea, in particular.

Some of these data gaps require dedicated scientific investigations, including either field and/or laboratory studies, some relate to (often ongoing) monitoring programmes, and others relate to studies requiring data compilation and analysis. Table 13.1.1 broadly attributes the key data gaps by discipline, time frame and importance. However, given the range of data gaps, the different skills and timelines required, and that perceptions of ‘priority’ can vary between species (commercial importance/conservation interest), geographical area, and policy needs, an overall ranking is not provided. It should also be noted that some data gaps that may be of ‘high’ priority in the short-term may require an inter-related topic to be completed first.

Table 13.1.1. Preliminary list of higher priority data gaps (short, medium and longer term) relating to the assessment of oceanic sharks, the sustainable management of commercial stocks, and conservation management of threatened species.

Investigations needed		**Short-term (<5 y)**	**Medium-term (5-10 y)**	**Longer-term**
Scientific investigations (including field studies)	Post-release mortality of vulnerable shark species (e.g. thresher sharks, hammerheads, oceanic white-tip)	**High**		
	Post-release mortality of commercial shark species (increased sample sizes and studies for blue shark, shortfin mako etc.)	**Medium**		
	Bycatch mitigation measures (Importance varies with encounter rates and capture mortality)	**Medium (but priority depends on status and discard mortality)**		
	Biological investigations (Design and implementation of coordinated data collection programmes for age/growth, reproduction etc.)	**High**		
	Biological investigations (analysis/reporting)		**High**	
	Field investigations to validate potentially important habitats		**Medium-High**	
	Studies to elucidate stock units	**Medium-High**		
Monitoring programmes	Collection of contemporary catch data (landings, live/dead discards)	**High (all stocks)**		
	Biological sampling of catches (length data, sex composition)	**High (all stocks)**		
	Observer programmes (review adequacy of data collection programmes)	**High**		
	Trial the utility of scientific longline surveys (in collaboration with commercial vessels)	**Medium**		
Data collation and analysis (i.e. desk-based studies)	Reconstruction/Estimation of historical catch data	**Medium-High**		
	Development of assessment methods, including data-limited approaches	**High**		
	Updated assessments of main shark species (porbeagle, shortfin mako, blue shark etc.)	**High**		
	Syntheses of available data for data-limited species taken by EU fleets, including stock delineation	**High**		
	Exploratory assessments of vulnerable species (e.g. hammerheads, threshers)		**High**	
	Collation of spatial data (earlier information) by species and life-history stage, and identification of potential critical sites	**High**		
	Collation of data for Mediterranean Sea	**High**		
	Management frameworks		**High**	

13.2 Objectives

The objective of Task 10 was to identify and prioritise gaps in knowledge and research that could contribute to progress in the implementation of the EUPOA sharks and the MoU Sharks. Also, identify research needs to fill gaps that hinder the elaboration of sound scientific advice for the species concerned.

13.3 Methodology

Previous sections identified many of the data and knowledge gaps relating to oceanic sharks and rays, including knowledge of life history and fisheries ecology, commercial fisheries data, abundance information, and assessments. The findings of these sections are synthesised and discussed here in relation to both the EUPOA-Sharks, the MoU-Sharks, and the main data gaps and research needs for the development of improved scientific management advice highlighted.

13.4 Results and Discussion

EUPOA-Sharks

Background

The European Community Action Plan for the Conservation and Management of Sharks (CEC, 2009) aims to "*ensure the conservation and management of sharks and their long-term sustainable use*" by "*ensuring the rebuilding of many depleted stocks fished by the Community fleet within and outside Community waters*".
Within this, the EUPOA-Sharks has three 'specific objectives':

(a) To broaden the knowledge both on shark fisheries and on shark species and their role in the ecosystem;

(b) To ensure that directed fisheries for shark are sustainable and that by-catches of shark resulting from other fisheries are properly regulated; and

(c) To encourage a coherent approach between the internal and external Community policy for sharks.

The third objective is a policy question and therefore not addressed further here, although it is noted that the scientific community can play an important role on this.

Issues noted within the EUPOA-Sharks include the following:

- Strategies to address the various issues relating to elasmobranchs (e.g. as seen in the recent improvements to species-specific landings data; developments of assessments of stock status and an increasing number of stocks with scientific advice).
- The need to support the work and strengthen the roles of RFMOs.
- An integrated framework of actions, whereby relevant management measures (input and output controls and technical measures) are developed, data collection improved and more scientifically robust management advice provided.

Gaps in the progress of the EUPOA-Sharks

The EUPOA-Sharks lists various actions for the first two 'specific objectives' (see above) which are allocated across five 'objectives' (see Table 13.4.1), with these actions to be undertaken at either the Member State or the EU-level, or to be encouraged at the RFMO-level.

Table 13.4.1. Summary of the objectives in the EUPOA-Sharks, and how these have developed since 2009 in relation to oceanic sharks

Objective in the EUPOA-Sharks	Progress relating to oceanic sharks	Future needs
To deepen knowledge both of shark fisheries and of shark species and their role in the ecosystem		
To have reliable and detailed species-specific quantitative and biological data on catches and landings as well as trade data for high and medium priority fisheries.	• There has been progress in the **quality of landings data**, but some data quality issues remain (e.g. species identification, coding errors). Oceanic stocks are also taken by a range of other nations, where data quality can be variable. • There has been an increase in **biological data** collection (e.g. length composition of catches) for some species and in some fisheries. Whilst information on reproductive parameters are often available, estimates of other life history parameters (**especially natural mortality and age/growth parameters**) are often lacking or of uncertain quality. • There has been an increase in biological studies, including age, growth and reproduction, particularly for the main pelagic shark species. Some recent studies have involved international and inter-laboratory collaborations. However, such studies are still needed for many species, especially those sampled infrequently.	• Ensuring more robust standardisation of length measurement protocols in research and observer programmes. • The prohibited status of some species can hamper data collection from commercial platforms. **Improved observer coverage** on fleets operating in areas where 'prohibited species' may occur in higher numbers may facilitate improved data collection. It is also noted that the retention of biological material from scientific observer programmes can be hampered by some listings (e.g. CITES). • The development of more robust **estimates of dead discards** are required, which requires data on both discards as well as at-vessel and **post-release mortality by métier**. Partial data on this are collected from the observer programs. • The improved coordination on **protocols for biological sampling and collation of data** for data-limited oceanic sharks across tRFMOs and other bodies (e.g. NAFO and ICES) could be considered. • Further analyses of catch data, including reported landings and estimates of dead discards, and comparison with trade data.

Objective in the EUPOA-Sharks	Progress relating to oceanic sharks	Future needs
To be able to efficiently monitor and assess shark stocks on a species-specific level and develop harvesting strategies in accordance with the principles of biological sustainability and rational long term economic use.	• There has been an increase in the number of oceanic shark stocks being addressed by relevant tRFMOs, with most emphasis on blue shark, shortfin mako and porbeagle. • The stock assessments being applied to the main oceanic sharks generally use published biological information, landings/catch data supplied to the tRFMO and indices of standardised CPUE from commercial fisheries. • Improved expertise in elasmobranch biology and assessment in various Member States. • Most tRFMOs have undertaken Ecological Risk Assessments (ERAs) for the wider oceanic shark assemblage.	• For the assessment models that have been developed, improved data quality would allow more robust assessments, with less uncertainty in estimates. • Developing an appropriate timetable for when the various stocks would be assessed by the competent body, and advice provided. • Some of the ERA approaches undertaken to date may underscore the vulnerability of those pelagic elasmobranchs that are taken in both oceanic and shelf fisheries (e.g. common thresher and hammerhead sharks). **Further studies on those oceanic sharks and rays that are frequently taken in shelf fisheries should be undertaken**. • **Collation of available data for those species that have not yet been assessed is required**, with the aim of applying DLS approaches to better assess stock status and inform management advice. • In most instances, stock units have not been defined. Whilst it may be possible to infer nominal stock units from available distributional information for some species, improved delineation of stock units (e.g. through tagging data, genetic studies) is required for several species.
To improve and develop frameworks for establishing and	• There have been improvements in stakeholder discussions with regards to many shelf fisheries in EU waters (e.g. Advisory Councils) and fact	• Improvements to collaborative work with stakeholders would be beneficial, including for safe handling and release protocols, technical

Objective in the EUPOA-Sharks	Progress relating to oceanic sharks	Future needs
coordinating effective consultation involving stakeholders in research, management and educational initiatives	sheets for safe handing/release and species identification developed in some areas.	mitigation and, potentially, for using commercial vessels as platforms for more robust monitoring surveys of shark stocks.
To ensure that directed fisheries for shark are sustainable and that by-catches of shark resulting from other fisheries are properly regulated		
To adjust catches and fishing effort to the available resources with particular attention to high priority fisheries and vulnerable or threatened shark stocks.	• The EU has prohibited Union vessels from targeting thresher sharks in the ICCAT convention area, and several species of oceanic and pelagic elasmobranch are listed as prohibited species on EU fishery regulations (e.g., porbeagle, mobulids, white shark, basking shark).	• Developing and implementing science-based limits (on landings/catch/effort, as appropriate) for the main oceanic elasmobranchs. • If those species listed as 'prohibited' are still taken in fisheries and are subject to a mortality rate that still impairs population growth, then additional management measures would need to be developed.
To minimize waste and discards from shark catches requiring the retention of sharks from which fins are removed and strengthening control measures.	• The EU brought in finning regulations in 2003 (Council Regulation (EC) No 1185/2003), with amendments brought in 2013 (Regulation (EU) No 605/2013).	• Improved enforcement and monitoring to ensure compliance.

Convention on the Conservation of Migratory Species (CMS) and the MoU-Sharks

<u>*Background*</u>

The Convention on the Conservation of Migratory Species of Wild Animals (CMS) is an environmental treaty, and legally-binding instrument, that aims to support the conservation, sustainable use and development of internationally-coordinated conservation measures for migratory animals and their habitats. The European Union has been a party to the CMS since 1983[43].

Migratory animals listed by the CMS can be found in Appendix I. CMS Appendix I lists migratory species that are considered endangered, and CMS Parties that are range state to these species "*shall endeavour to strictly protect them by prohibiting the taking of such species*". CMS Appendix II lists those migratory species that have an unfavourable conservation status and would benefit significantly from international cooperation. CMS Parties and range states are encouraged to "*conclude global or regional Agreements for the conservation and management of individual species or groups of related species*".

Under the auspices of the CMS, there is also the Memorandum of Understanding on the Conservation of Migratory Sharks (MoU-Sharks), which was initiated in 2010 and amended in 2016. This is an international forum for the conservation of migratory elasmobranchs, but it is a legally non-binding instrument. The MoU-Sharks aims to achieve and maintain a favourable conservation status for those migratory elasmobranchs listed within Annex I of the MoU. The MoU has various Signatories, as well as Cooperating Partners[44].

The elasmobranchs listed under the CMS and under the MoU-Sharks are summarised in Appendix IX. In 2017, a further five elasmobranch species were added to the CMS Appendices, but these have not yet been adopted under the MoU-Sharks.

As noted above, CMS Appendix I lists a range of migratory elasmobranchs that relevant CMS Parties should "*endeavour to strictly protect … by prohibiting the taking of such species*". European fishing regulations identify which species for which "*It shall be prohibited for Union fishing vessels to fish for, to retain on board, to tranship or to land*". The most recent regulations (EU, 2018) list all elasmobranchs listed on Appendix I of CMS as prohibited species, except for the recently listed whale shark (Appendix IIX). EU fishing regulations also prohibit some species that are listed only on Appendix II, and also prohibit species in selected RFMO areas, supporting relevant RFMO regulations.

---

[43] http://www.cms.int/en/legalinstrument/cms
[44] http://www.cms.int/sharks/en/legalinstrument/sharks-mou

Gaps in the progress of the MoU-Sharks

The MoU-Sharks Conservation Plan also has five overarching Objectives:

(A) *Improving understanding of migratory shark populations through research, monitoring and information exchange*.

(B) *Ensuring that directed and non-directed fisheries for sharks are sustainable – In pursuing activities described under this objective Signatories should endeavour to cooperate through RFMOs, the FAO, Regional Seas Conventions and Action Plans (RSCAPs) and biodiversity-related Multilateral Environmental Agreements MEAs, as appropriate*.

(C) *Ensuring to the extent practicable the protection of critical habitats and migratory corridors and critical life stages of sharks*.

(D) *Increasing public awareness of threats to sharks and their habitats, and enhance public participation in conservation activities.*

(E) *Enhancing national, regional and international cooperation*.

Within each of these higher-level Objectives, there are 2–6 activities that should be undertaken by either the MoU-Sharks Advisory Committee, the MoU-Sharks Secretariat, the Signatories and/or by multilateral organisations.

As with the EUPOA, there are elements of the MoU-Sharks that have been implemented whilst other elements are in various stages of progress.

In relation to *'Ecological research, monitoring and information exchange',* whilst some relevant work is ongoing to varying degrees within relevant Member States, the current project itself is a stage in synthesising current knowledge, with high priority knowledge gaps discussed in more detail in the subsequent section.

In relation to *'Ensuring that directed and non-directed fisheries for sharks are sustainable'*, there has been progress in assessing the stocks of the main oceanic sharks by RFMOs, albeit with the caveats associated with the quality of the underlying data. Whilst the introduction of science-based catch limits has not been fully implemented, EU regulations to prevent 'finning' and the addition of CMS Appendix I listed species to the prohibited species list on fishing regulations demonstrates clear progress in some areas.

The '*protection of critical habitats and migratory corridors and critical life stages of sharks'* has not been achieved, but this in part relates to the inherent uncertainties in the location, scale, relative importance and temporal fidelity of any such habitats used by oceanic and migratory sharks in EU waters.

The need for '*Increasing public awareness of ... sharks'* and '*Enhancing national, regional and international cooperation*' are generally more focused on policy issues, although the framework under which the current project clearly helps enhance cooperation across the

EU, as does the collaborative work undertaken by the national institutes under the auspices of the various RFMOs and other groups, such as ICES expert groups.

Further examples of progress and future needs in relation to these objectives are given in Appendix IX.

Research needs to aid the development of scientific advice

A range of research needs are required to better understand the status of oceanic elasmobranchs and to ensure their sustainable exploitation. Such information is needed to formulate evidence-based and sound scientific advice for management frameworks and conservation, and for supporting the objectives of both the EUPOA-Sharks and MoU-Sharks.

Some of the data needs involve longer-term data collection programmes, with other data needs requiring more short-term research projects to address specific questions. The main data needs are summarised below, although it should be recognised that data needs will vary between species, stocks and management areas (see Task 3 and Task 4 for individual species).

There is an overall need to improve the quality of data that are already being collected, and to maximise the amount of data that can be collected through activities that are already in place (e.g., industry log books; observer and market-sampling programmes etc.).

Quantitative data on at-vessel and post-release morality by species and métier, and bycatch mitigation measures

Capture mortality is used here to include at-vessel mortality (AVM; the proportion of the catch that is dead when brought on board) and post-release mortality (PRM; the proportion of the discards that die following the capture process).

As highlighted under Task 6, an improved knowledge of capture mortality is required, both for understanding total removals from the stock (i.e. landings + dead discards) and for identifying where capture mortality is high and may require technical mitigation, spatial management or changes to fishing practices to be developed. For example, whilst several bodies have prohibited the retention of some species of hammerhead and thresher shark, the capture mortality of these species is usually higher than for other sharks caught in the same fishery (Ellis *et al.*, 2017 and references therein), and so mandatory release alone might not provide the required benefit to the stock.

Further studies on capture mortality are required, including addressing data-gaps (Ellis *et al*., 2017; see Appendix IIX). Whilst there are now estimates for post-release mortality in some of the main species (e.g. blue shark and shortfin mako taken in longline fisheries;

silky shark captures in purse seines), studies to estimate the PRM for some of the 'prohibited species', which can include oceanic white-tip, hammerhead sharks, thresher sharks and mobulid rays, are required. Studies on bycatch mitigation are also required, especially for those combinations of species and fishery for which estimated capture mortality may be considered 'high'.

Catch data

As noted in preceding sections of the report (Tasks 1–2), catch data for many stocks of oceanic elasmobranchs are uncertain and incomplete. Whilst there have been improvements in species-specific reporting of landings in many parts of the world, uncertainty in the quantities being discarded, and the proportion of discards that are alive and dead, hampers estimates of dead removals from the stock.

Whilst data are thought to have improved for some of the main commercial species (e.g. blue shark and shortfin mako) taken by 'developed' nations, data for some 'developing' nations remain limited. For example, the IOTC Working Party on Data Collection has highlighted the need for adoption and implementation of minimum data requirements for sharks.

The availability and accuracy of species-specific data for some taxa (e.g. hammerheads and thresher sharks) can be variable. Based on our analysis, all four tRFMOs hold data for hammerhead sharks as a group, not for all the individual species; and the same is true for thresher sharks. The fact that many species have been reported in aggregated form is an important issue that undermines data quality and it means that it will be difficult (or impossible) to reliably quantify the longer-term impacts of fishing on individual species. As such, the collection and reporting of species-specific data should be a clear requirement for all tuna RFMOs.

Whilst there have been improvements in the reporting of recent landings data, historical estimates are uncertain for most species (see Task 1), which is an important data gap when examining the status of long-lived species. Discard estimates are not available for all fleets, and the proportion of discards surviving can vary between fleets and in relation to fisher behaviour. Ongoing data collection of landings data needs appropriate data checking and quality assurance, with future work also required to compile estimates of both landings and total catch.

Catch composition data

Some length-frequency data are available (e.g. from at-sea observer programmes and market sampling programmes; see Task 1), which may help inform on temporal, spatial or fleet-based differences in the size composition of the stock. However, various caveats to such data are highlighted below.

- Given the complex nature of sexual and ontogenetic segregation documented for many elasmobranch species, there may need to be more careful consideration of survey design for such data collection. Annual data on the length- and sex-composition data should be representative of the exploited stock and, particularly where data are limited (by sample size and numbers of trips), should not be unduly influenced by seasonal, fleet-related or spatial differences that may mask inter-annual trends.
- Length composition may also be influenced by gear type (e.g. hook size and type, type of leader), and such factors may change over time.
- More robust guidelines as to how such data are recorded will help improve the robustness of length data analysis, as different approaches to length measurements may be used across disparate programmes which can introduce bias (e.g. stretched total length, total length, fork length, pre-caudal length; measurements recorded under the body or over the body and including a degree of curvature).

Consequently, further work on biological sampling programmes is needed to ensure more standardized collection and supply of such data, including the collection of other biological parameters.

Spatial data

The use of spatial management has often been promoted for elasmobranchs, although the utility and efficacy of such management approaches for wide-ranging, oceanic sharks is questionable because there isn't often sufficient information on the spatial agregations by size and sex.

Analyses of distributional data are, however, required for improved understanding of stock structure and dynamics, and may also assist in the interpretation of stock assessments and selection of input data. An improved understanding of the spatial distribution of oceanic sharks (by length, sex and, if available, maturity) could help in the preliminary identification of nominal pupping and nursery grounds, and potentially sites where 'threatened' species may occur regularly, which are currently undefined.

Whilst data collation exercises are required in the first instance, field studies to better validate any nominal sites considered to comprise 'critical habitat' should be undertaken, so as to better understand habitat utilization, if there was to be consideration of spatial management in those areas.

Biological parameters

Whilst various aspects of the life history of the more common oceanic elasmobranchs are known (see Appendix III), life history data are rarely complete for all stocks and some estimated parameters may have been derived from small sample sizes or just collected for limited parts of the stock area.

Life-history parameters can also vary between the constituent stocks of any given species. Whilst the biological stock units are quite well established for some species, improved spatial stock delineation is required for several other species, which would be the case for most pelagic sharks. A clear and accurate definition of the stock unit is a fundamental requirement to any robust stock assessment.

Coordinated studies to address data gaps, provide a more detailed critique of available data and to provide agreed life history parameters (age and growth, length at maturity, length at maternity, fecundity at length (or age), reproductive cycle, natural mortality) for stock assessments are required. Opportunities to modify/augment current data collection schemes, to facilitate the collection of relevant data on sharks, and approaches to collate data from disparate sources, need to be identified and prioritised by both scientists and policy makers.

Indices of stock abundance

Currently, indicators of stock abundance are almost exclusively based on fishery-dependent data, given the lack of fishery-independent surveys. It is possible that fishery-dependent data, which would aim to operate in areas with high catch rates of target and higher-value by-catch species, may not accurately reflect the relative abundance of some bycatch species over the wider stock area.

Collaborative studies between scientists and fishers to inform on the potential merits of using some dedicated trips on commercial vessels to undertake a more robust, survey-based approach to fishing/sampling could usefully be trialled.

Testing the applicability of recently developed data-limited assessment methods

Whilst there has been some progress in assessing the main stocks of oceanic sharks (see Tasks 2 and 3), uncertainties in some of the input data can lead to variable results. Data-limited approaches are being developed by many bodies (e.g. ICES; see Task 4) and further examination of these approaches for oceanic sharks and rays are required, with case studies presented under Task 9. The development of data-limited approaches often involves expert groups comprising analytical scientists to develop and refine methods which are subsequently made available to the wider community. However, providing a forum for scientists from other disciplines (e.g. biologists, fisheries observers) who may have a better understanding of the input data (including data quality and associated caveats), knowledge of the fishery and the biology of the species are also required. This is addressed through some of the ongoing processes of some RFMOS, such as ICCAT, who have dedicated data preparatory workshops and subsequent assessment workshops.

In terms of species for which no quantitative assessments have been undertaken, these include silky shark, hammerheads, threshers and longfin mako in ICCAT, shortfin mako and porbeagle in IOTC, and all species except silky shark in IATTC (see Table 5.4.5). As some of these species are also among the most vulnerable oceanic sharks in each region (see Task 1), efforts to collate data, improve data collection and develop quantitative analyses are required.

Status of by-catch species

In recent years, RFMOs have given more focus to assessing the main oceanic sharks (e.g. shortfin mako, porbeagle, silky shark and blue shark). Whilst it is clear that developing assessment methods addressing the more data-rich stocks is valuable, and the results can inform on management advice, this should not preclude efforts to better understand the status of more data-limited species, especially when such species may also be unproductive and susceptible to overexploitation.

Ecological Risk Assessments have been used to rank the potential vulnerability of elasmobranchs to defined fisheries (e.g. pelagic longline fleets), however some pelagic elasmobranchs (including mobulids, hammerheads and common thresher) occur in both oceanic and shelf seas. Whilst such species may appear less ‘susceptible’ to the main tuna fisheries, they can also be susceptible to a range of other fisheries, including those under the management of other national and regional bodies. A better understanding of the cumulative impacts of all relevant fisheries is required. Improved collaboration between relevant RFBs, RFMOs and other appropriate bodies to better understand the status of those oceanic sharks for which shelf seas are important habitats is required. In the absence of this, it is possible that such straddling stocks could be overlooked by relevant authorities.

Blue shark and shortfin mako shark species executive summary sheets are presented in Appendix X. These include information on fishery statistics, stock assessment used, stock status, current management advice as well as future recommendations.

Development of appropriate management frameworks

Whilst some management measures relevant to oceanic elasmobranchs are now in force in some regions (see Tasks 2 and 5), the development of more detailed management frameworks are still required (see Task 7). The development of appropriate management frameworks for regions and fleets requires a range of appropriate data, as indicated above.

Improved evaluation of the stock units, landings, catches and status of oceanic sharks in the Mediterranean Sea

In relation to EU waters, there has been progress through ICCAT and, to a lesser extent ICES, in addressing the main oceanic shark species occurring in the North-East Atlantic. The pelagic elasmobranchs occurring in the Mediterranean Sea, however, have often been subject to less investigation, with a lack of monitoring surveys and data quality issues surrounding catch rates and species identification. More focused studies in this area and action to improve the quality of data reported by industry is essential to better understand stock units, areas of particular importance, landings, catches and status.

14 REFERENCES

Aires-da-Silva, A., Lennert-Cody, C., Maunder, M.N., Román-Verdesoto, M. 2014. Stock status indicators for Silky shark in the Eastern Pacific Ocean. 5th Meeting of the Scientific Advisoty Committee of the IATTC, 12-16 May 2014, La Jolla, California. IATTC document SAC-05-11a: 18pp.

Aires-da-Silva, A., Lennert-Cody, C., Maunder, M.N., Román-Verdesoto, M., Hinton, M.G. 2015. Updates stock status indicators for Silky shark in the Eastern Pacific Ocean (1994-2014). 6th Meeting of the Scientific Advisoty Committee of the IATTC, 11-15 May 2015, La Jolla, California. IATTC document SAC-06-08b: 11pp.

Akçakaya, H. R., Ferson, S., Burgman, M. A., Keith, D. A., Mace, G. M., Todd, C. R. 2000. Making consistent IUCN classifications under uncertainty. *Conserv. Biol.,* 14: 1001–1013.

Alessandro, L., Antonello, S. 2009. An overview of loggerhead sea turtle (*Caretta caretta*) bycatch and technical mitigation measures in the Mediterranean Sea. *Rev. Fish Biol. Fish*., 20: 141–161.

Alverson, D.L., Freeberg, M.H., Murawski, S.A. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries and Aquaculture Technical Paper No 339. Rome, FAO. 233 pp.

Amorim, S., Santos, M.N., Coelho, R., Fernandez-Carvalho, J. 2015. Effects of 17/0 circle hooks and bait on fish catches in a Southern Atlantic swordfish longline fishery. *Aquat. Conserv. Mar. Freshw. Ecosyst*., 25: 518–533.

Anon. 2012. Report of the Shortfin mako stock assessment and ecological risk assessment meeting. 11-18 June 2012, Olhão, Portugal. 105 pp.

Anon. 2015. Report of the 2015 ICCAT blue shark stock assessment session. 27-31 July 2015, Lisbon, Portugal. 116 pp.

Anon. 2016a. Report of the 2016 inter-sessional meeting of the Shark Species Group. 25-29 April 2016, Madeira, Portugal. 27 pp.

Anon. 2016b. Report of the Standing Committee on Research and Statistics. 3-7 October 2016, Madrid, Spain. 429 pp.

Anon. 2017. Report of the 2017 ICCAT shortfin mako stock assessment meeting. 12-16 June 2017, Madrid, Spain. 64 pp.

Anon. 2017a. Report of the 2017 ICCAT swordfish data preparatory meeting. Madrid, Spain 3-7 April, 2017. 63 pp.

Anon. 2014. A collaborative attempt to conduct a stock assessment for the silky shark in the Eastern Pacific Ocean (1993-2010): Update Report. 5th Meeting of the Scientific Advisoty Committee of the IATTC, 12-16 May 2014, La Jolla, California. IATTC document SAC-05 INF-F: 28pp.

Arrizabalaga, H., De Bruyn, P., Diaz, G.A., Murua, H., Chavance, P., De Molina, A.D., Gaertner, D., Ariz, J., Ruiz, J., Kell, L.T. 2011. Productivity and susceptibility analysis for species caught in Atlantic tuna fisheries. *Aquat. Living Resour.*, 24: 1–12.

Arrizabalaga, H., Mina, X., Artetxe, I., Iriondo, A. 2001. Analysis of supply vessel activities during the 1998-1999 moratorium in the Indian Ocean. 3rd Working Party on Tropical Tunas Indian Ocean Tuna Commission, 19-27 June 2001, Victoria, Seychelles. IOTC document WPTT01-11: 12 pp.

Auger, L., Trombetta, T., Sabarros, P., Rabearisoa, N., Romanov, E., Bach, P. 2015. Optimal fishing time window: an approach to mitigate bycatch in longline fisheries. 11th Working Party on Ecosystems and Bycatch, 7-11 September 2015, Olhão, Portugal. IOTC document IOTC–2015–WPEB11–15: 12 pp.

Babcock, E. A. 2014. Application of a Bayesian Surplus Production model to preliminary data for south Atlantic albacore. *Collect. Vol. Sci. Pap. ICCAT*, 70(3): 1326-1334.

Bach, P., Dagorn, L., Bertrand, A., Josse, E., Misselis, C., 2003. Acoustic telemetry versus monitored longline fishing for studying the vertical distribution of pelagic fish: bigeye tuna (*Thunnus obesus*) in French Polynesia. *Fish. Res.*, 60: 281–292.

Bach, P., Gamblin, C., Lucas, V. 2008. The effect of bait type on hooking responses of target and non-target species on pelagic longlines: preliminary results from fishing Experiments in the Seychelles. *West. Indian Ocean J. Mar. Sci*., 7: 151–161.

Bach, P., Hodent, T., Donadio, C., Romanov, E., Dufossé, L., Robin, J.-J. 2012a. Bait innovation as a new challenge in pelagic longlining. Presented at the Mitigating impacts of fishing on pelagic ecosystems: Towards ecosystem-based management of tuna fisheries Symposium, 15-19 October 2012, Montpellier, France.

Bach, P., Lucas, V., Capello, M., Romanov, E. 2012b. Is the fishing time an appropriate bycatch mitigation measure in swordfish-targeting longline fisheries? Presented at the Mitigating impacts of fishing on pelagic ecosystems: Towards ecosystem-based management of tuna fisheries Symposium, 15-19 October 2012, Montpellier, France. Bach, P., Robin, J.-J., Hodent, T. 2013. Système de pêche comprenant un leurre et appât comprenant un tel système de pêche. EP2567615 A1.

Bayse, S.M., Kerstetter, D.W. 2010. Assessing bycatch reduction potential of variable strength hooks for pilot whales in a Western North Atlantic pelagic longine fishery. *J. N. C. Acad. Sci.*, 126: 6–14.

Beerkircher, L., Cortes, E., Shivji, M. 2002. Characteristics of Shark Bycatch Observed on Pelagic Longlines Off the Southeastern United States, 1992-2000. *Mar. Fish. Rev.* 64(4):40–49.

Beverly, S., Curran, D., Musyl, M., Molony, B. 2009. Effects of eliminating shallow hooks from tuna longline sets on target and non-target species in the Hawaii-based pelagic tuna fishery. *Fish. Res.* 96: 281–288.

Bigelow, K.A., Boggs, C.H., He, X. 1999. Environmental effects on swordfish and blue shark catch rates in the US North Pacific longline fishery. *Fish. Oceanogr.*, 8, 178–198.

Bigelow, K.A., Kerstetter, D.W., Dancho, M.G., Marchetti, J.A. 2012. Catch rates with variable strength circle hooks in the Hawaii-based tuna longline fishery. *Bull. Mar. Sci.*, 88: 425–447.

Boggs, C.H. 2001. Deterring albatrosses from contacting baits during swordfish longline sets. pp. 79–94. In Melvin, E.F., Parrish, J.K. (Eds.), Seabird Bycatch: Trends, Roadblocks, and Solutions. University of Alaska Sea Grant, Fairbanks, Alaska.

Boggs, C.H. 1992. Depth, capture time, and hooked longevity of longline-caught pelagic fish: Timing bites of fish with chips. *Fish. Bull*. 90: 642–658.

Bravington, M.V. Skaug, H.J., Anderson, E.C. 2016a. Close-Kin Mark-Recapture. *Stat. Sci.*, 31(2) : 259–274.

Bravington, M.V., Grewe, P.M., Davies, C.R. 2016b. Absolute abundance of southern bluefin tuna estimated by close-kin mark-recapture. *Nat. commun*., 7:13162.

Bromhead, D., Clarke, S., Hoyle, S., Muller, B., Sharples, P., Harley, S. 2012. Identification of factors influencing shark catch and mortality in the Marshall Islands tuna longline fishery and management implications. *J. Fish Biol.*, 80: 1870–1894.

Brooks, E.N., Powers, J.E., Cortés, E. 2010. Analytical reference points for age-structured models: application to data-poor fisheries. *ICES J. Mar. Sci.*, 67: 165-175.

Cambiè, G., Muiño, R., Mingozzi, T., Freire, J. 2013. From surface to mid-water: Is the swordfish longline fishery "hitting rock bottom"? A case study in southern Italy. *Fish. Res.*, 140: 114–122.

Camhi, M., Pikitch, E.K., Babcock, E.A. 2008. Sharks of the open ocean: biology, fisheries and conservation. Blackwell Science, Oxford. Ames, Iowa.

Camhi, M.D., Valenti, S.V., Fordham, S.V., Fowler, S.L., Gibson, C. 2009. The Conservation Status of Pelagic Sharks and Rays: Report of the IUCN Shark Specialist Group Pelagic Shark Red List Workshop. IUCN Species Survival Commission Shark Specialist Group. Newbury, UK. x + 78p.

Campana, S.E., Joyce, W., Fowler, M., Showell, M. 2016. Discards, hooking, and post-release mortality of porbeagle (*Lamna nasus*), shortfin mako (*Isurus oxyrinchus*), and blue shark (*Prionace glauca*) in the Canadian pelagic longline fishery. *ICES J. Mar. Sci.* 73: 520–528.

Campana, S.E., Joyce, W., Manning, M.J. 2009. Bycatch and discard mortality in commercially caught blue sharks *Prionace glauca* assessed using archival satellite pop-up tags. *Mar. Ecol. Prog. Ser*. 387: 241–253.

Capietto, A., Escalle, L., Chavance, P., Dubroca, L., Delgado de Molina, A., Murua, H., Floch, L., Damiano, A., Rowat, D., Merigot, B. 2014. Mortality of marine megafauna induced by fisheries: Insights from the whale shark, the world's largest fish. *Biol. Conserv.* 174: 147–151.

Carruthers, E.H., Neilson, J.D., Smith, S.C. 2011. Overlooked bycatch mitigation opportunities in pelagic longline fisheries: Soak time and temperature effects on swordfish (*Xiphias gladius*) and blue shark (*Prionace glauca*) catch. *Fish. Res.*, 108: 112–120.

Carruthers, E.H., Neis, B. 2011. Bycatch mitigation in context: Using qualitative interview data to improve assessment and mitigation in a data-rich fishery. *Biol. Conserv.* 144: 2289–2299.

Carruthers, E.H., Schneider, D.C., Neilson, J.D. 2009. Estimating the odds of survival and identifying mitigation opportunities for common bycatch in pelagic longline fisheries. *Biol. Conserv.*, 142: 2620–2630.

Cavanagh R.D., Kyne, P.M., Fowler, S.L., Musick, J.A., Bennett, M.B. (Eds). 2003. The Conservation Status of Australian Chondrichthyans: Report of the IUCN Shark Specialist Group Australia and Oceania. Regional Red List Workshop. The University of Queensland, School of Biomedical Sciences, Brisbane, Australia. x + 170pp.

Cavanagh, R.D., Gibson, C. 2007. Overview of the Conservation Status of Cartilaginous Fishes (Chondrichthyans) in the Mediterranean Sea. IUCN, Gland, Switzerland and Malaga, Spain. vi + 42 pp.

CEC. 2009. Communication from the Commission to the European Parliament and the Council on a European Community Action Plan for the Conservation and Management of Sharks. COM (2009) 40 final, Brussels, 5.2.2009. 15 pp.

Citores, L., Ibaibarriaga, L., Jardim, E. 2017. Uncertainty estimation and model selection in stock assessment models with non-parametric effects on fishing mortality. *ICES J. Mar. Sci.,* 75(2) : 585-595.

Clarke, S. 2011. A Status Snapshot of Key Shark Species in the Western and Central Pacific and Potential Management Option. 7th Regular Session of the Scientific Committee of the WCPFC, 6-14 August 2013, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC7-2011/EB-WP-04: 37 pp.

Clarke, S. 2018. Safe Release Guidelines for Sharks and Rays. WCPFC-SC14-2018/EB-IP-03, 8-16 August 2018, Busan, Korea.

Clarke, S., Sato, M., Small, C.J., Sullivan, B., Inoue, Y., Ochi, D. 2014. Bycatch in longline fisheries for tuna and tuna-like species: a global review of status and mitigation measures. FAO Fisheries and Aquaculture Technical Paper No. 588. FAO, Rome. 199 pp.

Clarke, S.C., Harley, S.J., Hoyle, S.D., Rice, J.S. 2011. An Indicator-based Analysis of Key Shark Species based on Data Held by SPC-OFP. 7th Regular Session of the Scientific Committee of the WCPFC, 6-14 August 2013, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC7-2011/EB-WP-01: 89 pp.

Clarke, S.C., Harley, S.J., Hoyle, S.D., Rice, J.S. 2013. Population trends in Pacific oceanic sharks and the utility of regulations on shark finning. *Conserv. Biol*., 27: 197–209.

Coelho R., Mejuto J., Domingo A., Liu K-M, Cortés E., Yokawa K., Hazin F., Arocha F., da Silva C., García-Cortés B., Ramos-Cartelle A.M., Lino P.G., Forselledo R., Mas F., Ohshimo S., Carvalho F., Santos M.N. 2015a. Distribution patterns of the blue shark *Prionace glauca* in the Atlantic Ocean from observer data of the major fishing fleets. 2015 ICCAT Blue Shark Stock Assessment Meeting, 27-31 July 2015, Lisbon, Portugal. ICCAT document SCRS/2015/039: 24 pp.

Coelho R., Rosa D. 2017a. An alternative hypothesis for the reconstruction of time series of catches for North and South Atlantic stocks of shortfin mako shark. *Collect. Vol. Sci. Pap. ICCAT,* 74(4): 1746-1758.

Coelho, R., Rosa, D. 2017b. An alternative hypothesis for the reconstruction of time series of catches of blue shark in the Indian Ocean. 13th Working Party on Ecosystems and Bycatch, 4-8 September 2017, San Sebastian, Spain. IOTC Document IOTC-2017-WPEB13-22: 15 pp.

Coelho, R., Domingo, A., Courtney, D., Cortés, E., Arocha, F., Liu, K-M., Yokawa, K., Yasuko, S., Hazin, F., Rosa, D., Lino, P.G. 2017. A revision of the shortfin mako shark catch-at-size in the Atlantic using observer data. *Collect. Vol. Sci. Pap. ICCAT*, 74(4): 1562-1578.

Coelho, R., Fernandez-Carvalho, J., Lino, P.G., Santos, M.N., 2012a. An overview of the hooking mortality of elasmobranchs caught in a swordfish pelagic longline fishery in the Atlantic Ocean. *Aquat. Living Resour.* 25: 311–319.

Coelho, R., Mejuto, J., Domingo, A., Yokawa, K., Liu, K-M., Cortés, E., Romanov, E., da Silva, C., Hazin, F., Arocha, F., Mwilima, A.M., Bach, P., Ortiz de Zarate, V., Roche, W., Lino, P.G., García-Cortés, B., Ramos-Cartelle, A.M., Forselledo, R., Mas, F., Ohshimo, S., Courtney, D., Sabarros, P.S., Perez, B., Wogerbauer, C., Tsai, W-P., Carvalho, F., Santos, M.N. 2018. Distribution patterns and population structure of the blue shark (*Prionace glauca*) in the Atlantic and Indian Oceans. *Fish Fish.*, 19: 90–106.

Coelho, R., Santos, M.N., Amorim, S., 2012b. Effects of Hook and Bait on Targeted and Bycatch Fishes in an Equatorial Atlantic Pelagic Longline Fishery. Bull. Mar. Sci. 88: 449–467.

Coelho, R., Yokawa, K., Liu, K-M., Romanov, E., da Silva, C., Bach, P., Lino, P.G., Ohshimo, S., Tsai, W-P., Santos, M.N. 2015b. Distribution patterns of sizes and sex-ratios of blue shark in the Indian Ocean. 11th Working Party on Ecosystems and Bycatch, 7-11 September 2015, Olhão, Portugal. IOTC Document IOTC–2015–WPEB11–22. 22 pp.

Collen, B., Dulvy, N. K., Gaston, K. J., Gärdenfors, U., Keith, D. A., Punt, A. E., Regan, H. M., Böhm, M., Hedges, S., Seddon, M. and Butchart, S. H. M., Hilton-taylor, C., Hoffmann, M., Bachman, S. P., Akçakaya, H. R. 2016. Clarifying misconceptions of extinction risk assessment with the IUCN Red List. *Biol. Lett.*, 12:20150843.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Santos, M.N., Ribera, M., Simpfendorfer, C. 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquat. Living Resour.*, 23: 25–34.

Cortés, E., Domingo, A., Miller, P., Forselledo, R., Mas, F., Arocha, F., Campana, S., Coelho, R., Da Silva, C., Holtzhausen, H., Keene, K., Lucena, F., Ramirez, K., Santos, M.N., Semba-Murakami, Y., Yokawa, K. 2015. Expanded ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Collect. Vol. Sci. Pap. ICCAT*, 71: 2637-2688.

Cortés, E., Neer, J.A. 2006. Preliminary reassessment of the validity of the 5% fin to carcass weight ratio for sharks*. Collect. Vol. Sci. Pap. ICCAT*. 59:1025–1036.

Godin, A.C., Wimmer, T., Wang, J.H., Worm, B. 2013. No effect from rare-earth metal deterrent on shark bycatch in a commercial pelagic longline trial. *Fish. Res.*, 143: 131–135.

Dagorn, L., Filmalter, J.D., Forget, F., Amandè, M.J., Hall, M.A., Williams, P., Murua, H., Ariz, J., Chavance, P., Bez, N. 2012. Targeting bigger schools can reduce ecosystem impacts of fisheries. *Can. J. Fish. Aquat. Sci.* 69: 1463–1467.

Dagorn, L., Holland, K.N., Restrepo, V., Moreno, G. 2013. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? *Fish Fish.* 14: 391–415.

Davies, T.K., Mees, C.C., Milner-Gulland, E.J. 2014. The past, present and future use of drifting fish aggregating devices (FADs) in the Indian Ocean. *Mar. Policy* 45: 163–170.

Davis, B., Worm, B. 2013. The International Plan of Action for Sharks: How does national implementation measure up? *Mar. Policy*, 38: 312–320.

De Oliveira, J.A.A., Carpi, P., Walker, N.D., Fischer, S., Earl, T.J., Davie, S. 2017. DRuMFISH: Data-limited methods review. http://drumfish.org/WP2.

Duffy, L., Lennert-Cody, C., Vogel, N., Boster, J., Marrow, J. 2016. Description of reported catch for non-target species: Does sufficient data exist to produce a comprehensive ecological risk assessment?. 7th Meeting of the Scientific Advisoty Committee of the IATTC, 9-13 May 2016, La Jolla, California. IATTC document SAC-07-INF C(d): 20 pp.

Dunn, D.C., Boustany, A.M., Halpin, P.N. 2011. Spatio-temporal management of fisheries to reduce by-catch and increase fishing selectivity. *Fish Fish.*, 12: 110–119.

Eddy, C., Brill, R., Bernal, D. 2016. Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. *Fish. Res.* 174: 109–117.

Ellis, J. R., McCully Phillips, S. R. and Poisson, F. 2017. A review of capture and post-release mortality of elasmobranchs. *J. Fish Biol.*, 90: 653–722.

Epperly, S.P., Watson, J.W., Foster, D.G., Shah, A.K. 2012. Anatomical hooking location and condition of animals captured with pelagic longlines: the Grand Banks experiments 2002-2003. *Bull. Mar. Sci.*, 88: 513–527.

Erickson, D.L., Berkeley, S.A., 2008. Methods to Reduce Bycatch Mortality in Longline Fisheries. 462–471 pp. In Camhi, M.D., Pikitch, E.K., Babcock, E.A. (Eds.), Sharks of the Open Ocean. Blackwell Publishing Ltd.

Espmark, Å.M., Midling, K.Ø., Nilsson, J., Humborstad, O.-B., 2016. Effects of Pumping Height and Repeated Pumping in Atlantic Salmon Salmo salar. *Nat. Resour*. 7: 377-383.

EU. 2018. Council Regulation (EU) 2018/120 of 23 January 2018 fixing for 2018 the fishing opportunities for certain fish stocks and groups of fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, and amending Regulation (EU) 2017/127. Official Journal of the European Union L27, 1–168.

FAO. 2000. FAO Marine Resources Service. Fisheries management. 1. Conservation and management of sharks. FAO Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 1. Rome, FAO. 2000. 37p.

Feekings, J.P., Krag, L.A., Malta, T.A., Lund, H.S., Eliasen, S., Ulrich, C., Mortensen, L.O. 2016. Industry-led fishing gear selectivity improvements. How can we increase flexibility and ownership over the gears used whole ensuring an effective introduction of the new EU Common Fisheries Policy? Presented at the ICES-FAO Working Group on Fishing Technology and Fish Behaviour, Mérida, Mexico.

Fernandez-Carvalho, J., Coelho, R., Mejuto, J., Cortés, E., Domingo, A., Yokawa, K., Liu, K. M., García-Cortés, B., Forselledo, R., Ohshimo, S., Ramos-Cartelle, A. 2015. Pan-Atlantic distribution patterns and reproductive biology of the bigeye thresher, *Alopias superciliosus. Rev. Fish Biol. Fisher.*, 25: 551–568.

Fernandez-Carvalho, J., Coelho, R., Santos, M.N., Amorim, S. 2015. Effects of hook and bait in a tropical northeast Atlantic pelagic longline fishery: Part II—Target, bycatch and discard fishes. *Fish. Res.*, 164: 312–321.

Ferrari, L.D., Kotas, J.E. 2013. Hook selectivity as a mitigating measure in the catches of the stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) (Elasmobranchii, Dasyatidae). *J. Appl. Ichthyol.*, 29: 769–774.

Filmalter, J.D., Capello, M., Deneubourg, J.-L., Cowley, P.D., Dagorn, L. 2013. Looking behind the curtain: quantifying massive shark mortality in fish aggregating devices. *Front. Ecol. Environ*. 11: 291–296.

Fischer, J., Erikstein, K., D’Offay, B., Guggisberg, S., Barone, M. 2012. Review of the Implementation of the International Plan of Action for the Conservation and Management of Sharks. FAO Fisheries and Aquaculture Circular No. 1076. Rome, FAO. 120 pp.

Fishteck. 2015. Shark guard stage 1 commercial sea trials. Final Report.

Fitzgerald, W.J. 2004. Milkfish aquaculture in the Pacific: potential for the tuna longline fishery bait market. Aquaculture Technical Papers. Secretariat of the Pacific Community, Noumea, New Caledonia.

Fletcher, R. 1978. On the restructuring of the Pella-Tomlinson system. *Fish. Bull.*, 76: 515–521.

Forney, K.A., Kobayashi, D.R., Johnston, D.W., Marchetti, J.A., Marsik, M.G. 2011. What's the catch? Patterns of cetacean bycatch and depredation in Hawaii-based pelagic longline fisheries. *Mar. Ecol.*, 32: 380–391.

Foster, D.G., Epperly, S.P., Shah, A.K., Watson, J.W. 2012. Evaluation of hook and bait type on the catch rates in the Western North Atlantic Ocean pelagic longline fishery. *Bull. Mar. Sci.* 88: 529–545.

Fowler, S., Séret, B., 2010. Shark fins in Europe: implications for reforming the EU finning Ban. European Elasmobranch Association/IUCN Shark Specialist Group. 49 pp.

Fowler, S.L., Cavanagh, R.D., Camhi, M., Burgess, G.H., Cailliet, G.M., Fordham, S.V., Simpfendorfer, C.A., Musick, J.A. (Eds.) 2005. Sharks, Rays and Chimaeras: The Status of the Chondrichthyan Fishes. Status Survey. IUCN/SSC Shark Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. x + 461 pp.

Francis, M.P. 2006. Morphometric minefields—towards a measurement standard for chondrichthyan fishes. *Environ. Biol. Fishes*, 77: 407–421.

Francis, M.P., Griggs, L.H., Baird, S.J. 2001. Pelagic shark bycatch in the New Zealand tuna longline fishery. *Mar. Freshw. Res.* 52: 165–178.

Frick, L.H., Walker, T.I., Reina, R.D. 2012. Immediate and delayed effects of gill-net capture on acid-base balance and intramuscular lactate concentration of gummy sharks, *Mustelus antarcticus*. *Comp. Biochem. Physiol. A. Mol. Integr. Physiol*. 162: 88–93.

Froese, R., Demirel, N., Coro, G., Kleisner, K. M., Winker, H. 2017. Estimating fisheries reference points from catch and resilience. *Fish Fish.*, 18(3): 506-526.

Gallagher, A.J., Kyne, P.M., Hammerschlag, N. 2012. Ecological risk assessment and its application to elasmobranch conservation and management. *J. Fish Biol.*, 80: 1727–1748.

Garcia, D., Sánchez, S., Prellezo, R., Urtizberea, A., Andrés, M. 2017. FLBEIA: A simulation model to conduct Bio-Economic evaluation of fisheries management strategies. *SoftwareX*, 6: 141-147.

García, D., Urtizberea, A., Diez, G., Gil, J., Marchal, P. 2013. Bio-economic management strategy evaluation of deepwater stocks using the FLBEIA model. *Aquat. Living Resour.*, 26: 365-379.

Gibson, C., Valenti, S.V., Fordham, S.V., Fowler, S.L. 2008. The Conservation of Northeast Atlantic Chondrichthyans: Report of the IUCN Shark Specialist Group

Northeast Atlantic Red List Workshop. IUCN Species Survival Commission Shark Specialist Group. Newbury, UK. viii + 76pp.

Gilman, E. 2011. Bycatch governance and best practice mitigation technology in global tuna fisheries. *Mar. Policy*, 35: 590–609.

Gilman, E., Brothers, N., Kobayashi, D.R. 2007. Comparison of three seabird bycatch avoidance methods in Hawaii-based pelagic longline fisheries. *Fish. Sci*., 73: 208–201.

Gilman, E., Chaloupka, M., Read, A., Dalzell, P., Holetschek, J., Curtice, C. 2012. Hawaii longline tuna fishery temporal trends in standardized catch rates and length distributions and effects on pelagic and seamount ecosystems. *Aquat. Conserv. Mar. Freshw. Ecosyst*., 22: 446–488.

Gilman, E., Clarke, S., Brothers, N., Alfaro-Shigueto, J., Mandelman, J., Mangel, J., Petersen, S., Piovano, S., Thomson, N., Dalzell, P., Donoso, M., Goren, M., Werner, T. 2008. Shark interactions in pelagic longline fisheries. *Mar. Policy*, 32: 1–18.

Gilman, E.L., Dalzell, P., Martin, S. 2006. Fleet communication to abate fisheries bycatch. *Mar. Policy*, 30: 360–366.

Gless, J., Salmon, M., Wyneken, J. 2008. Behavioral responses of juvenile leatherbacks *Dermochelys coriacea* to lights used in the longline fishery. *Endanger. Species Res*., 5: 239–247.

Godin, A.C., Carlson, J.K., Burgener, V. 2012. The Effect of Circle Hooks on Shark Catchability and At-Vessel Mortality Rates in Longlines Fisheries. *Bull. Mar. Sci*., 88: 469–483.

Graves, J.E., Horodysky, A.Z. 2008. Does Hook Choice Matter? Effects of Three Circle Hook Models on Postrelease Survival of White Marlin. *North Am. J. Fish. Manag*., 28: 471–480.

Graves, J.E., Horodysky, A.Z., Kerstetter, D.W. 2012. Incorporating Circle Hooks Into Atlantic Pelagic Fisheries: Case Studies from the Commercial Tuna/Swordfish Longline and Recreational Billfish Fisheries. *Bull. Mar. Sci*., 88: 411–422.

Guida, L., Dapp, D.R., Huveneers, C.P.M., Walker, T.I., Reina, R.D. 2017. Evaluating time-depth recorders as a tool to measure the behaviour of sharks captured on longlines. *J. Exp. Mar. Biol. Ecol.,* 497: 120–126.

Hall, M., Roman, M. 2013. Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO Fisheries and Aquaculture Technical Paper No. 568 . FAO, Rome. 249 pp.

Hareide, N.R., Carlson, J.K., Clarke, M., Clarke, S., Ellis, J.R., Fordham, S.V., Fowler, S., Pinho, M., Polti, S., Raymakers, C., Serena, F., Séret, B., 2007. European Shark Fisheries: A Preliminary Investigation into Fisheries, Conversion Factors, Trade Products, Markets and Management Measures. European Elasmobranch Association.

Hazin, H.G., Hazin, F.H.V., Travassos, P., Erzini, K. 2005. Effect of light-sticks and electrolume attractors on surface-longline catches of swordfish (*Xiphias gladius*, Linnaeus, 1959) in the southwest equatorial Atlantic. *Fish. Res.*, 72: 271–277.

Herrera M., Pierre L. 2011. Review of the statistical data available for the bycatch species. 7th Working Party on Ecosystems and Bycatch, 24-27 October 2011, Maldives. IOTC document IOTC-2011-WPEB07-08: 18 pp.

Hindmarsh, S. 2007. A review of fin-weight ratios for pelagic sharks. 3rd Regular Session of the Scientific Committee of WCPFC, 13-24 August 2007, Honolulu, United States of America. WCPFC document WPCFC-SC3-EB SWG/ WP-4: 17pp.

Hinton, M., Maunder, M.N., Vogel, N., Olson, R., Lennert-Cody, C., Aires-da-Silva, A., Hall, M. 2014. Stock status indicators for fisheries of the eastern Pacific Ocean. 5th IATTC Scientific Advisory Committee Meeting, 12-16 May 2014, La Jolla, California. IATTC document SAC-05-11c: 26 pp.

Hovgård, H., Lassen, H. 2000. Manual on estimation of selectivity for gillnet and longline gears in abundance surveys. FAO Fisheries and Aquaculture Technical Paper No. 397. Rome, FAO. 84 pp.

Hueter, R.E., Manire, C.A., Tyminski, J.P., Hoenig, J.M., Hepworth, D.A. 2006. Assessing Mortality of Released or Discarded Fish Using a Logistic Model of Relative Survival Derived from Tagging Data. *Trans. Am. Fish. Soc.,* 135: 500–508.

Hutchinson, M.R., Itano, D.G., Muir, J.A., Holland, K.N. 2015. Post-release survival of juvenile silky sharks captured in a tropical tuna purse seine fishery. *Mar. Ecol. Prog. Ser*. 521: 143–154.

Huveneers, C., Rogers, P.J., Semmens, J.M., Beckmann, C., Kock, A.A., Page, B., Goldsworthy, S.D. 2013. Effects of an Electric Field on White Sharks: In Situ Testing of an Electric Deterrent. *PLoS ONE*, 8(5): e62730.

ICES. 2012. ICES Implementation of Advice for Data-limited Stocks in 2012 in its 2012 Advice. ICES CM 2012/ACOM 68: 42 pp.

ICES. 2014. Report of the Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE IV), 27–31 October 2014, Lisbon, Portugal. ICES CM 2014/ACOM:54: 223 pp.

ICES. 2015. Report of the Fifth Workshop on the Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE V), 5–9 October 2015, Lisbon, Portugal. ICES CM 2015/ACOM:56; 157 pp.

ICES. 2017. Report of the ICES Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for stocks in categories 3-6 (WKLIFEVI), 3-7 October 2016, Lisbon, Portugal. ICES CM 2017/ACOM:59: 106 pp.

IOTC. 2015. Report of the Eleventh Session of the IOTC Working Party on Ecosystems and Bycatch. 11-17 September 2015. Olhão, Portugal. IOTC–2015–WPEB11–R[E]: 117 pp.

IOTC. 2016a. Review of the statistical data available for bycatch species. 12th Working Party on Ecosystems and Bycatch, 12-16 November 2016, Victoria, Seychelles. IOTC document IOTC–2016–WPEB12–07: 39pp.

IOTC. 2016b. Report on IOTC data collection and Statistics. IOTC–2016–WPDCS12–07_Rev1: 24 pp.

IOTC. 2016c. Report of the 12th Session of the IOTC Working Party on Data Collection and Statistics. 28-30 November, Victoria, Seychelles. IOTC document IOTC–2016–WPDCS12–R[E]: 37pp.

ISC. 2014. Stock assessment and future projection of blue shark in the North Pacific Ocean. *14th Meeting of the ISC*, 16-21 July 2014, Taipei, Chinese-Taipei. ISC document ISC14/SHARKWG Annex 13: 195 pp.

ISC. 2015. Indicator-based analysis of the status of shortfin mako shark in the North Pacific Ocean. *15th Meeting of the ISC*, 15–20 July 2017, Kona, Hawaii, U.S.A. ISC document ISC15/SHARKWG Annex 12: 33 pp.

ISC. 2017. Stock assessment and future projection of blue shark in the North Pacific Ocean through 2015. *17th Meeting of the ISC*, 12–17 July 2017, Vancouver, Canada. ISC document ISC17/SHARKWG Annex 13: 96 pp.

ISSF. 2015. Non-Entangling FADs [WWW Document]. Int. Seaf. Sustain. Found. URL https://iss-foundation.org/knowledge-tools/guides-best-practices/non-entangling-fads/

Itano, D., Muir, J., Hutchinson, M., Leroy, B. 2012. Development and testing of a release panel for sharks and non-target finfish in purse seine gear. 8th Regular Session of the Scientific Committee of WCPFC, 7-15 August 2012, Busan, Republic of Korea. WCPFC document WCPFC-SC8-2012/EB-WP-14: 7 pp.

IUCN. 2012. IUCN Red List Categories and Criteria: Version 3.1. Second edition. Gland, Switzerland and Cambridge, UK: IUCN. iv + 32 pp.

IUCN. 2017. Guidelines for Using the IUCN Red List Categories and Criteria. Version 13. Prepared by the Standards and Petitions Subcommittee. Available from http://www.iucnredlist.org/technical-documents/red-list-documents

James, K.C., Lewison, R.L., Dillingham, P.W., Curtis, K.A., Moore, J.E. 2016. Drivers of retention and discards of elasmobranch non-target catch. *Environ. Conserv*. 43: 3–12.

Jardim, E., Millar, C. P., Mosqueira, I., Scott, F., Osio, G. C., Ferretti, M., Alzorriz, N., Orio, A. 2015. What if stock assessment is as simple as a linear model? The a4a initiative. *ICES J. Mar. Sci.*, 72: 232-236.

Jiao, Y., Cortes E., Andrews, K., Guo, F. 2011. Poor-data and data-poor species stock assessment using a Bayesian hierarchical approach. *Ecol. Appl.*, 21: 2691-2708.

Jordan, L.K., Mandelman, J.W., McComb, D.M., Fordham, S.V., Carlson, J.K., Werner, T.B. 2013. Linking sensory biology and fisheries bycatch reduction in elasmobranch fishes: a review with new directions for research. *Conserv. Physiol.,* 1: 1–20.

Kaimmer, S., Stoner, A.W. 2008. Field investigation of rare-earth metal as a deterrent to spiny dogfish in the Pacific halibut fishery. *Fish. Res.*, 94: 43–47.

Kaplan, I.C., Cox, S.P., Kitchell, J.F. 2007. Circle Hooks for Pacific Longliners: Not a Panacea for Marlin and Shark Bycatch, but Part of the Solution. *Trans. Am. Fish. Soc*., 136: 392–401.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J.-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M. A., Poos, J. J., Scott, F., Scott, R. D. 2007. FLR: an open-source framework for the evaluation and development of management strategies. *ICES J. Mar. Sci.*, 64: 640-646.

Kyne, P.M., Carlson, J.K., Ebert, D.A., Fordham, S.V., Bizzarro, J.J., Graham, R.T., Kulka, D.W., Tewes, E.E., Harrison, L.R., Dulvy, N.K. (eds). 2012. The Conservation Status of North American, Central American, and Caribbean Chondrichthyans. IUCN Species Survival Commission Shark Specialist Group, Vancouver, Canada. Vi + 148 pp.

Lack, M., Sant, G., Burgener, M., Okes, N. 2014. Development of a Rapid Management-Risk Assessment Method for Fish Species through its Application to Sharks: Framework and Results. Report to the Department of Environment, Food and Rural Affairs. Defra Contract No. MB0123.

Last, P.R., White, W.T., Carvalho, M.R., Séret, B., Stehmann, M.F.W., Naylor, G.J.P. 2016. Rays of the World. CSIRO Publishing, Australia. 790 pp.

Lewison, R.L., Crowder, L.B., Wallace, B.P., Moore, J.E., Cox, T., Zydelis, R., McDonald, S., DiMatteo, A., Dunn, D.C., Kot, C.Y., Bjorkland, R., Kelez, S., Soykan, C., Stewart, K.R., Sims, M., Boustany, A., Read, A.J., Halpin, P., Nichols, W.J., Safina, C. 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. *Proc. Natl. Acad. Sci.* 111: 5271–5276.

Lezama-Ochoa, N., Murua, H., Chust, G., Van Loon, E., Ruiz, J., Hall, M., Chavance, P., Delgado De Molina, A., Villarino, E. 2016. Present and Future Potential Habitat Distribution of *Carcharhinus falciformis* and *Canthidermis maculata* By-Catch Species in the Tropical Tuna Purse-Seine Fishery under Climate Change. *Front. Mar. Sci*. 3:34.

Løkkeborg, S. 1990. Rate of release of potential feeding attractants from natural and artificial bait. *Fish. Res*., 8: 253–261.

Løkkeborg, S. 1991. Fishing experiments with an alternative longline bait using surplus fish products. *Fish. Res.*, 12: 43–56.

Løkkeborg, S. 2011. Best practices to mitigate seabird bycatch in longline, trawl and gillnet fisheries—efficiency and practical applicability. *Mar. Ecol. Prog. Ser*., 435: 285–303.

Løkkeborg, S., Johannessen, T. 1992. The importance of chemical stimuli in bait fishing — fishing trials with pre-soaked bait. *Fish. Res*., 14: 21–29.

Løkkeborg, S., Pina, T. 1997. Effects of setting time, setting direction and soak time on longline catch rates. *Fish. Res.*, 32: 213–222.

Løkkeborg, S., Siikavuopio, S.I., Humborstad, O.-B., Utne-Palm, A.C., Ferter, K. 2014. Towards more efficient longline fisheries: fish feeding behaviour, bait characteristics and development of alternative baits. *Rev. Fish Biol. Fish*., 24: 985–1003.

Lopez, J., Alvarez-Berastegui, D., Soto, M., Murua, H. 2016. Modelling the oceanic habitats of Silky shark (*Carcharhinus falciformis*), implications for conservation and management. Sharks species group intersessional meeting, 25-29 April 2016, Madeira, Portugal. ICCAT document SCRS/2016/175: 18 pp.

Lopez, J., Ferarios, J.M., Santiago, J., Alvarez, O.G., Moreno, G., Murua, H. 2016. Evaluating potential biodegradable twines for use in the tropical tuna fishery. 12th Regular Session of the Scientific Committee of the WCPFC, 3-11 August 2016, Bali, Indonesia. WCPFC document WCPFC-S12-2016/EB_IP-11: 11 pp.

Lopez, J., Goñi, N., Arregi, I., Ruiz, J., Krug, I., Murua, H., Murua, J., Santiago, J. 2017. Main results of the Spanish Best Practices program: evolution of the use of Non-entangling FADs, interaction with entangled animals, and fauna release operations. 19th Working Party on Tropical Tunas, 17-22 October 2017, Mahé, Seychelles. IOTC document IOTC-2017-WPTT19-17: 7 pp.

Mace, G. M., Collar, N. J., Gaston, K. J., Hilton-Taylor, C., Akçakaya, H. R., Leader-Williams, N., Milner-Gulland, E. J., Stuart, S. N. 2008. Quantification of extinction risk: IUCN's system for classifying threatened species. *Conserv. Biol.*, 22: 1424–1442.

Marshall, H., Skomal, G., Ross, P.G., Bernal, D. 2015. At-vessel and post-release mortality of the dusky (*Carcharhinus obscurus*) and sandbar (*C. plumbeus*) sharks after longline capture. *Fish. Res.* 172: 373–384.

Martell, S., Froese, R. 2013. A simple method for estimating MSY from catch and resilience. *Fish Fish.*, 14: 504-514.

Maunder, M. N. 2012. A length based meta-population stock assessment model: application to skipjack tuna in the eastern Pacific Ocean. 3rd IATTC Scientific Advisory Committee Meeting, 15-18 May 2012, La Jolla, California. IATTC document SAC-03-INF A.

Maunder, M.N., Harley, S.J. 2005. Status of skipjack tuna in the eastern Pacific Ocean in 2003 and outlook for 2004. *Inter-Amer. Trop. Tuna Comm.*, Stock Asses. Rep. 5:109-167.

McAllister, M. K., Babcock, E. A. 2003. Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): a user’s guide. Available from www.iccat.int.

McAuley, R.B., Simpfendorfer, C.A., Wright, I.W. 2007. Gillnet mesh selectivity of the sandbar shark (*Carcharhinus plumbeus*): implications for fisheries management. *ICES J. Mar. Sci.* 64: 1702–1709.

McCully Phillips, S. R., Scott, F., Ellis, J. R. 2015. Having confidence in Productivity Susceptibility Analyses: A method for underpinning scientific advice on skate stocks? *Fish. Res.*, 171: 87–100.

McCully, S.R., Scott, F., Ellis, J.R., Pilling, G.M. 2012. Productivity and susceptibility analysis: application and suitability for data poor assessment of elasmobranchs in northern European Seas. *Collect. Vol. Sci. Pap. ICCAT*, 69: 1679–1698.

McCutcheon, S.M., Kajiura, S.M. 2013. Electrochemical properties of lanthanide metals in relation to their application as shark repellents. *Fish. Res.*, 147: 47–54.

McGrath, S., Butcher, P., Broadhurst, M., Cairns, S. 2011. Reviewing hook degradation to promote ejection after ingestion by marine fish. *Mar. Freshw. Res*., 62: 1237–1247.

Megalofonou, P., Yannopoulos, C., Damalas, D., De Metrio, G., Deflorio, M., De la Serna, J.M., Macias, D. 2005. Incidental catch and estimated discards of pelagic sharks from the swordfish and tuna fisheries in the Mediterranean Sea. *Fish. Bull*. 103: 620–634.

Mejuto, J., Autón, U., Quintans, M. 2005. Visual acuity and olfactory sensitivity in the swordfish, *Xiphias gladius*, for the detection of prey during field experiments using the surface longline gear with different bait types. *Collect. Vol. Sci. Pap. ICCAT,* 58: 1501–1510.

Mejuto, J., Garcia-Cortés, B., Ramos-Cartelle, A., 2008. Trials with different hook and bait types in the configuration of the surface longline gear used by the Spanish swordfish (*Xiphias gladius*) fishery in the Pacific Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 64: 1793–1830.

Meyer, C.G., Holland, K.N., Papastamatiou, Y.P. 2005. Sharks can detect changes in the geomagnetic field. *J. R. Soc. Interface*, 2: 129–130.

Meyer, R., Miller, R.B. 1999. BUGS in Bayesian stock assessment. *Can. J. Fish. Aquat. Sci.*, 56: 1078-1086.

Micheli, F., De Leo, G., Butner, C., Martone, R. G., Shester, G. 2014. A risk-based framework for assessing the cumulative impact of multiple fisheries. *Biol. Cons.*, 176: 224-235.

Millar, C. P., Jardim, E., Scott, F., Osio, G. C., Mosqueira, I., Alzorriz, N. 2015. Model averaging to streamline the stock assessment process. *ICES J. Mar. Sci.*, 72: 93-98

Monk, M. H., He, X., Budrick, J. 2017. Status of the California Scorpionfish (*Scorpaena guttata*) Off Southern California in 2017. Pacific Fishery Management Council, Portland, OR.

Moreno, G., Restrepo, V., Dagorn, L., Hall, M., Murua, H., Sancristobal, I., Grande, M., Lecouls, S., Santiago, J. 2016. Workshop on the use of biodegradable fish aggregating devices (FADs).ISSF Technical Report No. 2016– 18A. International Seafood Sustainability Foundation, Washigton D.C., USA.

Morgan, A., Burgess, G. 2007. At-Vessel Fishing Mortality for Six Species of Sharks Caught in the Northwest Atlantic and Gulf of Mexico. *Gulf Caribb. Res.* 19: 123–129.

Moyes, C.D., Fragoso, N., Musyl, M.K., Brill, R.W., 2006. Predicting Postrelease Survival in Large Pelagic Fish. *Trans. Am. Fish. Soc*. 135: 1389–1397.

MSC. 2014. MSC Fisheries Certification Requirements and Guidance. Version 2.0, 1st October, 2014. https://www.msc.org/documents/scheme-documents/fisheries-certification-scheme-documents/fisheries-certification-requirements-version-2.0

Murua, H., Abascal, F.J., Amande, J., Ariz, J., Bach, P., Chavance, P., Coelho, R., Korta, M., Poisson, F., Santos, M.N., Seret, B. 2013a. EUPOA-Sharks: Provision of scientific advice for the purpose of the implementation of the EUPOA sharks. Studies for Carrying out the Common Fisheries Policy; Reference: MARE/2010/11. Final Report. European Commission. 443 pp.

Murua, H., Chavance P., Amande J., Poisson F., Korta M., Santos M. N. , Abascal F. J., Ariz J., Bach P., Coelho R., Seret B. 2013b. EU project for the Provision of Scientific Advice for the Purpose of the implementation of the EUPOA sharks: a brief overview of the results for ICCAT. Sharks species group intersessional meeting, 25-26 September 2013, Madrid, Spain. ICCAT document SCRS/2013/165.

Murua H., Santos M. N., Chavance P., Amande J., Abascal F. J., Ariz J., Bach P., Korta M., Poisson F., Coelho R., Seret B. 2013c. EU project for the Provision of Scientific Advice for the Purpose of the implementation of the EUPOA sharks: a brief overview of the results for Indian Ocean. 9th Working Group on Ecosystems and Bycatch, 12-16 September 2013, La Réunion, France. IOTC document IOTC–2013–WPEB09–19: 21pp.

Murua, H., Coelho, R., Santos, M.S., Arrizabalaga, H., Yokawa, K., Romanov, E., Zhu, J.F., Kim, Z.G., Bach, P., Chavance, P., Delgado de Molina, A., Ruiz, J. 2012. Preliminary Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC). 8th Working Party on Ecosystems and Bycatch, 17 September 2012, South Africa. IOTC Document IOTC–2012–WPEB08–31: 16pp.

Murua, H., Moreno, G., Hall, M.A., Itano, D.G., Dagorn, L., Restrepo, V.R. 2014. ISSF Skipper Workshops: Collaboration between scientists and fishing industry to mitigate bycatch in tuna FAD fisheries. ISSF Technical Report No. 2014– 06. International Seafood Sustainability Foundation, Washington, D.C., USA.

Murua, H., Moreno, G., Restrepo, V. 2017. Progress on the Adoption of Non-Entangling Drifting Fish Aggregating Devices in Tuna Purse Seine Fleets. *Collect. Vol. Sci. Pap. ICCAT,* 73: 958–973.

Nieto, A., Ralph, G.M., Comeros-Raynal, M.T., Kemp, J., García Criado, M., Allen, D.J., Dulvy, N.K., Walls, R.H.L., Russell, B., Pollard, D., García, S., Craig, M., Collette, B.B., Pollom, R., Biscoito, M., Labbish Chao, N., Abella, A., Afonso, P., Álvarez, H., Carpenter, K.E., Clò, S., Cook, R., Costa, M.J., Delgado, J., Dureuil, M., Ellis, J.R., Farrell, E.D., Fernandes, P., Florin, A-B., Fordham, S., Fowler, S., Gil de Sola, L., Gil Herrera, J., Goodpaster, A., Harvey, M., Heessen, H., Herler, J., Jung, A., Karmovskaya, E., Keskin, C., Knudsen, S.W., Kobyliansky, S., Kovačić, M., Lawson, J.M., Lorance, P., McCully Phillips, S., Munroe, T., Nedreaas, K., Nielsen, J., Papaconstantinou, C., Polidoro, B., Pollock, C.M., Rijnsdorp, A.D., Sayer, C., Scott, J., Serena, F., Smith-Vaniz, W.F., Soldo, A., Stump, E., Williams, J.T. 2015. European Red List of marine fishes. Luxembourg: Publications Office of the European Union. Iv + 81 pp.

NMFS. 2008. Report of the U.S. Longline Bycatch Reduction Assessment and Planning Workshop (No. NOAA Tech. Memo. NMFS-OPR-41). National Marine Fisheries Service, U.S. Dep. Commerce.

NMFS. 2008. Report of the U.S. Longline Bycatch Reduction Assessment and Planning Workshop. No. NOAA Tech. Memo. NMFS-OPR-41. National Marine Fisheries Service, U.S. Dep. Commerce.

O'Connell, C.P., Abel, D.C., Stroud, E.M., Rice, P.H. 2011. Analysis of permanent magnets as elasmobranch bycatch reduction devices in hook-and-line and longline trials. *Fish. Bull*., 109: 394–401.

O'Connell, C.P., He, P. 2014. A large scale field analysis examining the effect of magnetically-treated baits and barriers on teleost and elasmobranch behaviour. *Ocean Coast. Manag*., 96: 130–137.

O'Connell, C.P., Stroud, E.M., He, P. 2012. The emerging field of electrosensory and semiochemical shark repellents: Mechanisms of detection, overview of past studies, and future directions. *Ocean Coast. Manag*., 97: 2-11.

de Oliveira, T.F., da Silva, A.L.M., de Moura, R.A., Bagattini, R., de Oliveira, A.A.F., de Medeiros, M.H.G., Di Mascio, P., de Arruda Campos, I.P., Barretto, F.P., Bechara, E.J.H., Loureiro, A.P. 2014. Luminescent threat: toxicity of light stick attractors used in pelagic fishery. *Sci. Rep.*, 4: 53-59.

Pacheco, J.C., Kerstetter, D.W., Hazin, F.H., Hazin, H., Segundo, R.S.S.L., Graves, J.E., Carvalho, F., Travassos, P.E. 2011. A comparison of circle hook and J hook performance in a western equatorial Atlantic Ocean pelagic longline fishery. *Fish. Res.*, 107: 39–45.

Patrick, W.S., Spencer, P., Ormseth, O., Cope, J. Field, J., Kobayashi, D., Gedamke, T., Cortés, E., Bigelow, K., Overholtz, W., Link, J., Lawson, P. 2009. Use of productivity and susceptibility indices to determine stock vulnerability, with example applications to six U.S. fisheries. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-101: 90 p.

Patterson, H.M., Tudman, M.J. 2009. Chondrichthyan guide for fisheries managers. A practical guide for mitigating chondrichthyan bycatch. Bureau of Rural Sciences and Australian Fisheries Management Authority, Canberra.

Pedersen, M.W.,Berg, C.W. 2017. A stochastic surplus production model in continuous time. *Fish Fish.*, 18: 226-243.

Pella, J.J., Tomlinson, P.K. 1969. A generalized stock production model. *Bulletin of the Inter-American Tropical Tuna Commission 13*: 421–458.

Pelletier, D., Ferraris, J. 2000. A multivariate approach for defining fishing tactics from commercial catch and effort data. *Can. J. Fish. Aquat. Sci.*, 57: 51–65.

Piovano, S., Clò, S., Giacoma, C. 2010. Reducing longline bycatch: The larger the hook, the fewer the stingrays. *Biol. Conserv*., 143: 261–264.

Piovano, S., Swimmer, Y., Giacoma, C. 2009. Are circle hooks effective in reducing incidental captures of loggerhead sea turtles in a Mediterranean longline fishery? *Aquat. Conserv. Mar. Freshw. Ecosyst*., 19: 779–785.

Poisson, F., Crespo, F. A., Ellis, J. R., Chavance, P., Pascal, B., Santos, M. N., Séret, B., Korta, M., Coelho, R., Ariz, J., Murua, H. 2016. Technical mitigation measures for sharks and rays in tuna and tuna-like fisheries: turning possibility into reality. *Aquat. Living Resour.*, 29 (402): 45 pp.

Poisson, F., Filmalter, J.D., Vernet, A., Dagorn, L. 2014a. Mortality rate of silky sharks (*Carcharhinus falciformis*) caught in the tropical tuna purse seine fishery in the Indian Ocean. *Can. J. Fish. Aquat. Sci.* 71: 795–798.

Poisson, F., Gaertner, J.C., Taquet, M., Durbec, J.-P., Bigelow, K. 2010. Effects of lunar cycle and fishing operations on longline-caught pelagic fish: fishing performance, capture time, and survival of fish. *Fish. Bull*., 108: 268–281.

Poisson, F., Séret, B., Vernet, A.-L., Goujon, M., Dagorn, L. 2014b. Collaborative research: Development of a manual on elasmobranch handling and release best practices in tropical tuna purse-seine fisheries. *Mar. Policy* 44: 312–320.

Prager, M. H. 1992. ASPIC: A Surplus-Production Model Incorporating Covariates. *Collect. Vol. Sci. Pap. ICCAT,* 28: 218–229.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus-production model. U. S. *Fish. Bull.*, 92: 374-389.

Prellezo, R., Carmona, I., García, D. 2016. The bad, the good and the very good of the landing obligation implementation in the Bay of Biscay: A case study of Basque trawlers. *Fish. Res.*, 181: 172-185.

Prince, E.D., Snodgrass, D., Orbesen, E.S., Hoolihan, J.P., Serafy, J.E., Schratwieser, J.E. 2007. Circle hooks, 'J' hooks and drop-back time: a hook performance study of the south Florida recreational live-bait fishery for sailfish, *Istiophorus platypterus*. *Fish. Manag. Ecol*., 14: 173–182.

Punt, A. E. 2015. Strategic management decision-making in a complex world: quantifying, understanding, and using trade-offs. *ICES J.Mar. Sci.*, 74: 499–510.

Punt, A.E., Smith, D.C., Smith, A.D.M. 2011. Among-stock comparisons for improving stock assessments of data-poor stocks: the "Robin Hood" approach. *ICES J.Mar. Sci.*, 68: 972–981.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Read, A.J. 2007. Do circle hooks reduce the mortality of sea turtles in pelagic longlines? A review of recent experiments. *Biol. Conserv*., 135: 155–169.

Regan, T. J., Burgman, M. A., McCarthy, M. A., Master, L. L., Keith, D. A., Mace, G. M., Andelman, S. J. 2005. The consistency of extinction risk classification protocols. *Conserv. Biol.*, 19: 1969–1977.

Restrepo, V., Dagorn, L., Itano, D., Justel-Rubio, A., Forget, F., Filmalter, J. 2014. A summary of bycatch issues and ISSF mitigation initiatives to-date in purse seine fisheries, with emphasis on FADs. ISSF Technical Report No. 2014–11. International Seafood Sustainability Foundation, Washigton D.C., USA.

Rice, J. C. Legacè, È. 2007. When control rules collide: a comparison of fisheries management reference points and IUCN criteria for assessing risk of extinction. *ICES J. Mar. Sci.*, 64: 718–722.

Rice, J., Harley, S. 2013. Updated assessment of silky sharks in the Western and Central Pacific Ocean. 9th Regular Meeting of the Scientific Committee of the WCPFC, 6-14 August 2013, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC9-2013/ SA-WP-03: 71 pp.

Rice, J.C., Legacè, È. 2007. When control rules collide: a comparison of fisheries management reference points and IUCN criteria for assessing risk of extinction. *ICES J. Mar. Sci.*, 64: 718–722.

Rice, P.H., Serafy, J.E., Snodgrass, D., Prince, E.D. 2012. Performance of non-offset and 10 offset 18/0 circle hooks in the United States pelagic longline fishery. *Bull. Mar. Sci*., 88: 571–587.

Richards, P.M., Epperly, S.P., Watson, J.W., Foster, D.G., Bergmann, C.E., Beideman, N.R. 2012. Can circle hook offset combined with baiting technique affect catch and bycatch in pelagic longline fisheries? *Bull. Mar. Sci.*, 88: 589–603.

Rigg, D.P., Peverell, S.C., Hearndon, M., Seymour, J.E. 2009. Do elasmobranch reactions to magnetic fields in water show promise for bycatch mitigation? *Mar. Freshw. Res*., 60: 942–948.

Robbins, W.D., Peddemors, V.M., Kennelly, S.J. 2011. Assessment of permanent magnets and electropositive metals to reduce the line-based capture of Galapagos sharks, *Carcharhinus galapagensis*. *Fish. Res*. 109: 100–106.

Román-Verdesoto, M., Hall, M. 2014. Updated summary regarding hammerhead sharks caught in the tuna fisheries in the Eastern Pacific Ocean. 5th Meeting of the Scientific Advisory Committee of the IATTC, 12-16 May 2014, La Jolla, California. IATTC document SAC-05-03b: 2 pp.

Sales, G., Giffoni, B.B., Fiedler, F.N., Azevedo, V.G., Kotas, J.E., Swimmer, Y., Bugoni, L. 2010. Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. *Aquat. Conserv. Mar. Freshw. Ecosyst*., 20: 428–436.

Sancristobal, I., Martinez, U., Boyra, G., Muir, J., Moreno, G., Restrepo, V., 2017. ISSF bycatch reduction research cruise on the F/V Mar de Sergio in 2016. *Collect. Vol. Sci. Pap. ICCAT.* 73: 3152–3162.

Santos, M.N., Lino, P.G., Coelho, R., 2017. Effects of leader material on catches of shallow pelagic longline fisheries in the southwest Indian Ocean. *Fish. Bull*. 115: 219–232.9

Schaefer, K.M., Fuller, D.W., 2011. An overview of the 2011 ISSF/IATCC research cruise for investigating potential solutions for reducing fishing mortality of undesirable sizes of bigeye and yellowfin tunas and sharks in purse-seine sets on drifting FADs. 7th Regular Session of the Scientific Committe of the WCPFC, 9-17 August 2011, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC7-2011/EB-WP-13: 5pp.

Schaefer, M. 1954. Some aspects of the dynamics of populations important to the management of the commercial Marine fisheries. *Bulletin of the Inter-American Tropical Tuna Commission*, 1: 27-56.

Schaefer, M. B. 1957. A study of the dynamics of fishery for yellowfin tuna in the Eastern Tropical Pacific Ocean. *Bulletin of the Inter-American Tropical Tuna Commission*, 2: 247-285.

Scott, F., Jardim, E., Millar, C. P., Cervino, S. 2016. An Applied Framework for Incorporating Multiple Sources of Uncertainty in Fisheries Stock Assessments. *PLoS ONE*, 11: e0154922.

Senina, I., Sibert, J., Lehodey, P. 2008. Parameter estimation for basin-scale ecosystem-linked population models of large pelagic predators: application to skipjack tuna. *Prog.in Oceanogr.*, 78: 319-335.

Senko, J., White, E.R., Heppell, S.S., Gerber, L.R. 2014. Comparing bycatch mitigation strategies for vulnerable marine megafauna: Mitigating marine megafauna bycatch. *Anim. Conserv.*, 17: 5–18.

Serafy, J.E., Cooke, S.J., Diaz, G.A., Graves, J.E., Hall, M., Shivji, M., Swimmer, Y. 2012. Circle hooks in commercial, recreational, and artisanal fisheries: research status and needs for improved conservation and management. *Bull. Mar. Sci*., 88: 371–391.

Serafy, J.E., Kerstetter, D.W., Rice, P.H. 2009. Can circle hook use benefit billfishes? *Fish Fish.*, 10: 132–142.

Sisneros, J.A., Nelson, D.R. 2001. Surfactants as chemical shark repellents: past, present, and future. pp. 117–130. In Tricas, T.C., Gruber, S.H. (Eds.), The behaviour and sensory biology of elasmobranch fishes: an anthology in memory of Donald Richard Nelson, Developments in Environmental Biology of Fishes. Springer Netherlands.

Southwood, A., Fritsches, K., Brill, R., Swimmer, Y. 2008. Sound, chemical, and light detection in sea turtles and pelagic fishes: sensory-based approaches to bycatch reduction in longline fisheries. *Endanger. Species Res*., 5: 225–238.

Stobutzki, I.C., Miller, M.J., Heales, D.S., Brewer, D.T. 2002. Sustainability of elasmobranchs caught as by-catch in a tropical prawn (shrimp) trawl fishery. *Fish. Bull.*, 100: 800–821.

Stokes, L.W., Epperly, S.P., McCarthy, K.J. 2012. Relationship between hook type and hooking location in sea turtles incidentally captured in the United States Atlantic pelagic longline fishery. *Bull. Mar. Sci.,* 88: 703–718.

Stoner, A.W., Kaimmer, S.M. 2008. Reducing elasmobranch bycatch: Laboratory investigation of rare earth metal and magnetic deterrents with spiny dogfish and Pacific halibut. *Fish. Res.*, 92: 162–168.

Stroud, E.M., O'Connell, C.P., Rice, P.H., Snow, N.H., Barnes, B.B., Elshaer, M.R., Hanson, J.E. 2013. Chemical shark repellent: Myth or fact? The effect of a shark necromone on shark feeding behaviour. *Ocean Coast. Manag*., 97: 50–57.

Swimmer, Y., Arauz, R., Higgins, B., McNaughton, L., McCracken, M., Ballestero, J., Brill, R. 2005. Food color and marine turtle feeding behavior: Can blue bait reduce turtle bycatch in commercial fisheries? *Mar. Ecol. Prog. Ser.*, 295: 273–278.

Swimmer, Y., Brill, R.W. 2006. Sea Turtle and Pelagic Fish Sensory Biology: Developing Techniques to Reduce Sea Turtle Bycatch in Longline Fisheries, NOAA Technical Memorandum NMFS-PIFSC-7.

Takeuchi, Y., Tremblay-Boyer, L., Pilling, M.G., Hampton, J. 2016. Assessment of blue shark in the southwestern Pacific. *12th Regular Meeting of the Scientific Committe of the WCPFC*, 3-11 August 2016, Bali, Indonesia. WCPFC document WCPFC-SC12-2016/SA-WP-08: 51 pp.

Tallack, S.M.L., Mandelman, J.W. 2009. Do rare-earth metals deter spiny dogfish? A feasibility study on the use of electropositive "mischmetal" to reduce the bycatch of *Squalus acanthias* by hook gear in the Gulf of Maine. *ICES J. Mar. Sci*., 66: 315–322.

Thorpe, T., Frierson, D. 2009. Bycatch mitigation assessment for sharks caught in coastal anchored gillnets. *Fish. Res*. 98: 102–112.

Tolotti, M.T., Filmalter, J.D., Bach, P., Travassos, P., Seret, B., Dagorn, L. 2015. Banning is not enough: The complexities of oceanic shark management by tuna regional fisheries management organizations. *Glob. Ecol. Conserv*., 4: 1–7.

Tryggvadóttir, S., Jónsson, G., Jónsdóttir, R., Ólafsdóttir, G. 2002. Artificial bait alternatives, mainly based on fish waste. Project report to EU No. 09–02. Icelandic Fisheries Laboratories.

Walsh, W.A., Bigelow, K.A., Sender, K.L. 2009. Decreases in shark catches and mortality in the Hawaii-based longline fishery as documented by fishery observers. *Mar. Coast. Fish. Dyn. Manag. Ecosyst. Sci.*, 1: 270–282.

Wang, J.H., Boles, L.C., Higgins, B., Lohmann, K.J. 2007. Behavioral responses of sea turtles to lightsticks used in longline fisheries. *Anim. Conserv*., 10: 176–182.

Wang, J.H., Fisler, S., Swimmer, Y., 2010. Developing visual deterrents to reduce sea turtle bycatch in gillnet fisheries. *Mar. Ecol. Prog. Ser.,* 408: 241–250.

Ward, P., Epe, S., Kreutz, D., Lawrence, E., Robins, C., Sands, A. 2009. The effects of circle hooks on bycatch and target catches in Australia's pelagic longline fishery. *Fish. Res.*, 97: 253–262.

Ward, P., Myers, R.A. 2007. Bait loss and its potential effects on fishing power in pelagic longline fisheries. *Fish. Res*., 86: 69–76.

Watson, J., Kerstetter, D.W. 2006. Pelagic longline fishing gear: a brief history and review of research efforts to improve selectivity. *Mar. Technol. Soc. J*., 40: 6–11.

Watson, J.T., Bigelow, K.A. 2014. Trade-offs among catch, bycatch, and landed value in the American Samoa longline fishery. *Conserv. Biol*., 28(4): 1012-1022.

Watson, J.W., Epperly, S.P., Shah, A.K., Foster, D.G. 2005. Fishing methods to reduce sea turtle mortality associated with pelagic longlines. *Can. J. Fish. Aquat. Sci*., 62: 965–981.

WCPFC. 2017b. Pacific-wide sustainability risk assessment of bigeye thresher shark (*Alopias superciliosus*). 13th Regular Session of the Scientific Committe of the WCPFC, 9-17 August 2017, Rarotonga, Cook Islands. WCPFC document WCPFC-SC13-2017/SA-WP-11: 107 pp.

WCPFC. 2017c. Southern Hemisphere porbeagle shark (*Lamna nasus*) stock status assessment. 13th Regular Session of the Scientific Committe of the WCPFC, 9-17 August 2017, Rarotonga, Cook Islands. WCPFC document WCPFC-SC13-2017/SA-WP-12: 75 pp.

WCPFC. 2017a. Report of the Thirteenth Regular Session of the Scientific Committee. 9 - 17 August 2017, Rarotonga, Cook Islands. 281 pp.

Webb, G. J. 2008. The dilemma of accuracy in IUCN Red List categories, as exemplified by hawksbill turtles *Eretmochelys imbricata*. *Endanger. Species Res.*, 6: 161–172.

Webb, G.J., Carrillo, E. 2000. Risk of extinction and categories of endangerment: perspectives from long-lived reptiles. *Popul. Ecol.*, 42: 11–17.

Williams, P. 2016. Scientific data available to the Western and Central Pacific Fisheries Commission. 12th Regular Meeting of the Scientific Committe of the WCPFC, 3-11 August 2016, Bali, Indonesia. WCPFC document WCPFC-SC12-2016/ST WP-1: 31pp.

Wilson, J.A., Diaz, G.A. 2012. An overview of circle hook use and management measures in United States marine fisheries. *Bull. Mar. Sci*., 88: 771–788.

Yokota, K., Kiyota, M., Minami, H. 2006. Shark catch in a pelagic longline fishery: Comparison of circle and tuna hooks. *Fish. Res*., 81: 337–341.

Yokota, K., Kiyota, M., Okamura, H. 2009. Effect of bait species and color on sea turtle bycatch and fish catch in a pelagic longline fishery. *Fish. Res*., 97: 53–58.

Yokota, K., Mituhasi, T., Minami, H., Kiyota, M. 2012. Perspectives on the morphological elements of circle hooks and their performance in pelagic longline fisheries. *Bull. Mar. Sci*., 88: 623–629.

Zhou, S., Pascoe, S., Dowling, N., Haddon, M., Klaer, N., Larcombe, J., Smith, T., Thebaund, O., Vieira, S., Wayte, S. 2013. Quantitatively defining biological and economic reference points in data poor and data limited fisheries. Final Report on FRDC Project 2010/044. Canberra, Australia.

Zhou, S., Smith, A. D., Fuller, M. 2011. Quantitative ecological risk assessment for fishing effects on diverse data-poor non-target species in a multi-sector and multi-gear fishery. *Fish. Res.,* 112: 168-178.

APPENDIX I: LIST OF ACRONYMS

Table I.1. List of acronyms used in the report.

Acronym	Name
ABNJ	Areas Beyond National Jurisdictions
AIDCP	Agreement on the International Dolphin Conservation Program
A-SCALA	Age-Structured Catch at Length Analysis
ASPIC	A Stock Production Model Incorporating Covariates
ASPM	Age Structured Production Model
AVM	At-vessl mortality
AZTI	AZTI-Tecnalia
BB	Baitboat
BMIS	Bycatch Mitigation Information System
B_{MSY}	Biomass at Maximum Sustainable Yield
BSH	Blue shark (*Prionace glauca*)
BSK	Basking shark (*Cetorhinus maximus*)
BSP	Bayesian Surplus Production Model
BSSP	Bayesian State Space Surplus Production Model
BW	Body weight
CA	Consequence Analysis
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CE	Catch and effort
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CFASPM	Catch-Free Age-Structured Production Model
CFP	Common Fisheries Policy
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CKMR	Close-kin mark-recapture
CMM	Conservation and Management Measure
CMS	Convention on the Conservation of Migratory Species of Wild Animals
COM	Comoros
CPC	Contracting Party
CPUE	Catch Per Unit of Effort
CR	Critically Endangered
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVX	Carcharhiniformes
CWZ	*Carcharhinus* sharks *nei*
CXX	Coastal Sharks nei
Data-deficient	DD
DFO	Department of Fisheries and Oceans Canada
DG MARE	Directorate-General for Maritime Affairs and Fisheries
DGX	Squalidae
DLMTool	Data-Limited Methods Toolkit
DLS	Data limited stocks
EAG	Eagle rays (Myliobatidae)

EASME	Executive Agency for Small and Medium-sized Enterprises
EMS	Electronic Monitoring Systems
EN	Endangered
EPO	Eastern Pacific Ocean
ERA	Ecological Risk Assessment
EU	European Union
EU.ESP	European Union - Spain
EUPOA	EU Plan of Action
FAD	Fish Aggregating Device
FAL	Silky shark (*Carcharhinus falciformis*)
FAO	Food and Agriculture Organization of the United Nations
FFA	Forum Fisheries Agency
FL	Fork length
F_{MSY}	Fishing mortality at Maximum Sustainable Yield
FW	Fin weight
GAG	Tope shark (*Galeorhinus galeus*)
GFCM	General Fisheries Commission for the Mediterranean
GN	Gillnet combined
GN-alb-tur	Gillnet albacore
GN-LL	Gillnet combined LL
GN-shark	Gillnet for sharks
GN-small	Gillnet small
GN-swo-it	Gillnet swordfish
GN-swo-tul	Gillnet swordfish moroc.
GN-swo-tur	Gillnet swordfish Turkey
HCR	Harvest control rule
HL	Handline
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
IDN	Indonesia
IEO	Instituto Español de Oceanografía
IFMPs	Integrated Fisheries Management Plans
IND	India
IO	Indian Ocean
IOTC	Indian Ocean Tuna Commission
IPMA	Instituto Português do Mar e da Atmosfera
IRD	Institut de Recherche pour le Développement
IRN	Iran
ISC	International Scientific Committee for tuna and tuna-like species in the North Pacific Ocean
ISSF	International Seafood Sustainability Foundation
IUCN	International Union for Conservation of Nature
JABBA	Just Another Bayesian Biomass Assessment
JPN	Japan
LKA	Sri Lanka

LL	Longline (others)
LL	Longline (bottom)
LL-bft	Longline for tunas
LL-jpn	Longline for tunas (jpn)
LL-shark	Longline for sharks
LL-swo	Longline for swordfish
LL-swo-ad	Longline for swordfish
LL-swo-albo	Longline for swordfish
LL-swo-gr	Longline for swordfish
LL-swo-ic	Longline for swordfish
LL-swo-li	Longline for swordfish
LL-swo-si	Longline for swordfish
LL-swo-sp	Longline for swordfish
LL-swo-ty	Longline for swordfish
LL-tuna-it	Longline for tunas
LL-tuna-malt	Longline for tunas
LL-tuna-tur	Longline for tunas
LMA	Longfin mako (*Isurus paucus*)
MAK	Mako sharks
MAN	Manta rays (Mobulidae)
MDG	Madagascar
MDV	Maldives
MIST	Maximum impact sustainable threshold
MoU Sharks	Memorandum of Understanding on the Conservation of Migratory Sharks
MP	Management procedure
MRAG	MRAG
MSC	Marine Stewardship Council
MSE	Management Strategy Evaluation
MSY	Maximum Sustainable Yield
NAFO	Northwest Atlantic Fisheries Organization
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
OCS	Oceanic whitetip shark (*Carcharhinus longimanus*)
OMN	Oman
OTH	Others
OTH_SHA	Shark and ray species other than the 18 species originally considered in the EUPOA project
OTH-frgn	Gillnet BFT France
OTH-shark	Others for sharks
PCL	Pre-caudal length
PLS	Pelagic stingray (*Pteroplatytrygon violacea*)
POR	Porbeagle (*Lamna nasus*)
PRM	Post-release mortality
PS	Purse seine combined
PSA	Productivity-Susceptibility Analysis
PS-bft	Purse seine - BFT

PSK	Crocodile shark (*Pseudocarcharias kamoharai*)
PSST	Purse seine: Small scale
PXX	Pelagic Sharks nei
QUL	*Squaliolus laticaudus*
r	intrinsic population growth rate
RA	Risk analysis
RBF	Risk Based Framework
RFMO	Regional Fisheries Management Organization
RHN	Whale shark (*Rhincodon typus*)
ROP	Regional Observer Programme
RSK	Requiem sharks nei (Carcharhinidae)
SEAFO	South East Atlantic Fisheries Organisation
SEAPODYM	Spatial Ecosystem and Population Dynamic Model
SHX	Squaliformes
SHXX	Selachimorpha (Pleurotremata)
SKH	Selachimorpha
SMA	Short fin mako (*Isurus oxyrinchus*)
SPC-OFP	Secretariat of the Pacific Community - Oceanic Fisheries Programme
SPN	Hammerhead sharks nei (*Sphyrna* sp.)
SPOR	Sport: Recreational fisheries (mostly rod and reel)
SPY	Bonnethead and hammerhead sharks
SRA	Stock Reduction Analysis
SS	Stock Synthesis
SSC	Species Survival Commission
SSG	Shark Specialist Group
SSI	Stock staus indicators
STD	Standardized
SURF	Surface fisheries unclassified
SYX	Scyliorhinidae
TAC	Total allowable cathc
THR	Thresher sharks nei (*Alopias* sp.)
TIG	Tiger shark (*Galeocerdo cuvier*)
TL	Total length
TN	Trammel net
TP	Trap net
TRAFFIC	The Wildlife Trade Monitoring Network
tuna-RFMO	tuna Regional Fisheries Management Organization
TW	Trawl
TWN	Taiwan
VU	Vulnerable
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western-Central Pacific Ocean
WPEB	Working Party on Ecosystems and Bycatch (IOTC)
WPO	Western Pacific Ocean

WSH	White shark (*Carcharodon carcharias*)
WT	Total weight
WUR/IMARES	Wageningen Marine Research
YEM	Yemen

APPENDIX II - SPECIES AND DISTRIBUTION CHECKLISTS

Table II.1: Taxonomic list of pelagic, oceanic and highly migratory elasmobranchs mentioned in the report, giving scientific name, common name (English, French, Spanish and Portuguese) and the FAO three-letter codes.

Family	Scientific name	English name	Spanish name	French name	Portuguese name	FAO
Rhincodontidae	*Rhincodon typus*	Whale shark	Tiburón ballena	Requin baleine	Tubarão-baleia	RHN
Odontaspididae	*Odontaspis noronhai*	Bigeye sand tiger	Solrayo ojigrande	Requin noronhai		ODH
Pseudocarchariidae	*Pseudocarcharias kamoharai*	Crocodile shark	Tiburón cocodrilo	Requin crocodile		PSK
Megachasmidae	*Megachasma pelagios*	Megamouth shark	Tiburón bocudo	Requin grande guele		LMP
Alopiidae	*Alopias pelagicus*	Pelagic thresher	Zorro pelágico	Renard pélagique	Tubarão-raposo-do-Índico	PTH
	Alopias superciliosus	Bigeye thresher	Zorro ojón	Renard à gros yeux	Tubarão-raposo-olhudo	BTH
	Alopias vulpinus	Common thresher	Zorro	Renard	Tubarão-raposo	ALV
Cetorhinidae	*Cetorhinus maximus*	Basking shark	Peregrino	Pèlerin	Tubarão-frade	BSK
Lamnidae	*Carcharodon carcharias*	White shark	Jaquetón blanco	Grand requin blanc	Tubarão-branco	WSH
	Isurus oxyrinchus	Shortfin mako	Marrajo dientuso	Taupe bleue	Tubarão-anequim	SMA
	Isurus paucus	Longfin mako	Marrajo carite	Petite taupe	Tubarão-anequim-de-gadanha	LMA
	Lamna ditropis	Salmon shark	Marrajo salmón	Requin-taupe saumon	Tubarão-sardo-do-Japão	LMD
	Lamna nasus	Porbeagle	Marrajo sardinero	Requin-taupe commun	Tubarão-sardo	POR
Carcharhinidae	*Carcharhinus falciformis*	Silky shark	Tiburón jaquetón	Requin soyeux	Tubarão-luzídio	FAL
	Carcharhinus galapagensis	Galapagos shark	Tiburón de Galápagos	Requin des Galapagos	Tubarão-dos-Galápagos	CCG

	Carcharhinus longimanus	Oceanic whitetip shark	Tiburón oceánico	Requin océanique	Tubarão-de-pontas-brancas	OCS
	Galeocerdo cuvier	Tiger shark	Tintorera tigre	Requin tigre commun	Tubarão-tigre	TIG
	Prionace glauca	Blue shark	Tiburón azul	Peau bleue	Tintureira	BSH
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead	Cornuda común	Requin-marteau halicorne	Tubarão-martelo-recortado	SPL
	Sphyrna mokarran	Great hammerhead	Cornuda gigante	Grand requin marteau	Tubarão-martelo-gigante	SPK
	Sphyrna zygaena	Smooth hammerhead	Cornuda cruz (Pez martillo)	Requin-marteau commun	Tubarão-martelo	SPZ
Dasyatidae	*Pteroplatytrygon violacea*	Pelagic stingray	Raya-látigo violeta	Pastenague violette	Uge-violeta	PLS
Mobulidae	*Mobula alfredi*	Alfred manta				RMA
	Mobula birostris	Manta ray	Manta gigante	Mante géante	Manta	RMB
	Mobula hypostoma	Lesser devil ray	Manta del Golfo	Mante diable		RMH
	Mobula kuhlii	Shortfin devil ray		Petit diable		RMK
	Mobula mobular	Giant devilray		Manta mobula	Jamanta	RMM
	Mobula munkiana	Munk's devil ray				RMU
	Mobula tarapacana	Chilean devilray			Manta-cornuda	RMT
	Mobula thurstoni	Smoothtail mobula				RMO

Notes: Recent taxonomic revisions have indicated that longhorned mobula (*Mobula eregoodootenkee*; RME) is a junior synonym of *Mobula kuhlii,* spinetail devilray (*Mobula japanica*, RMJ) a junior synonym of *Mobula mobular,* and lesser Guinean devil ray (Mobula rochebrunei, RMN) a junior synonym of *Mobula hypostoma;* The genus *Manta* seems to be no longer valid and species are now in genus *Mobula* (Last et al., 2016).

Table II.2: Taxonomic list of pelagic, oceanic and highly migratory elasmobranchs mentioned in the report, with occurrence by FAO area. Adapted from Compagno (1984) and Last et al. (2017). Symbols indicate presence (●), (potential) presence in the periphery of the area (○), presence uncertain (?) and absence (–).

Family	Scientific name	FAO code	Atlantic and Mediterranean							Indian		Pacific						Polar			
			21	27	31	34	37	41	47	51	57	61	67	71	77	81	87	18	48	58	88
Rhincodontidae	*Rhincodon typus*	RHN	●	–	●	●	–	●	●	●	●	●	–	●	●	?	●	–	–	–	–
Odontaspididae	*Odontaspis noronhai*	ODH				●		●		?								–	–	–	–
Pseudocarchariidae	*Pseudocarcharias kamoharai*	PSK				●			●	●	●	●		?	●			–	–	–	–
Megachasmidae	*Megachasma pelagios*	LMP				●		●		●	●	●		●	●			–	–	–	–
Alopiidae	*Alopias pelagicus*	PTH								●	●	●		●	●			–	–	–	–
	Alopias superciliosus	BTH	●	●	●	●	●	●	●	●	●	●		●	●	●		● ?	–	–	–
	Alopias vulpinus	ALV	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	● ?	–	–	–
Cetorhinidae	*Cetorhinus maximus*	BSK	●	●	●	●	●	●	●	?	●	●	●	–	●	●	●	?	–	–	–
Lamnidae	*Carcharodon carcharias*	WSH	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	–	–	–	–
	Isurus oxyrinchus	SMA	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	–	–	–	–
	Isurus paucus	LMA	●		●	●				●	?			●	●			–	–	–	–
	Lamna ditropis	LMD	–	–	–	–	–	–	–	–	–	●	●	–	●	–	–	?	–	–	–
	Lamna nasus	POR	●	●	●	●	●	●	●	●	●	–	–	–	–	●	●	–	○	○	?

Carcharhinidae	*Carcharhinus falciformis*	FAL	●	–	●	●	–	●		●	?	●		●	●	●	●	–	–	–	–
	Carcharhinus galapagensis	CCG		?	●	●			●	●				●	●	●	●	–	–	–	–
	Carcharhinus longimanus	OCS	●	●	●	●	?	●		●	●	●		●	●	●	●	–	–	–	–
	Galeocerdo cuvier	TIG	●	●	●	●		●		●	●	●		●	●	●	●	–	–	–	–
	Prionace glauca	BSH	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	–	–	–	–
Sphyrnidae	*Sphyrna lewini*	SPL	●		●			●		●	●	●		●	●		●	–	–	–	–
	Sphyrna mokarran	SPK			●	●	●	●	●	●	●	●		●	●	●	●	–	–	–	–
	Sphyrna zygaena	SPZ	●	●	●	●	●	●	●	●	●				●	●	●	–	–	–	–
Dasyatidae	*Pteroplatytrygon violacea*	PLS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	–	–	–	–
Mobulidae	*Mobula alfredi*	RMA				●				●	●	?		●	●		?	–	–	–	–
	Mobula birostris	RMB	●	●	●	●		●	●	●	●	●		●	●	●	●	–	–	–	–
	Mobula hypostoma	RMH			●	●		●	●									–	–	–	–
	Mobula kuhlii	RMK								●	●			●				–	–	–	–
	Mobula mobular	RMM		?		●	●	●	●	●	●	?		●	●	●	?	–	–	–	–
	Mobula munkiana	RMU													●	?		–	–	–	–
	Mobula tarapacana	RMT			●	●		?	?	●	●	●		●	?	?	?	–	–	–	–
	Mobula thurstoni	RMO				●		●		●	●	?		●	●		?	–	–	–	–

APPENDIX III – TASK 1

1. Historical catch reconstruction: "Low" estimation scenario

ICCAT

The estimated "potential" shark catches are 100,000 for the Low estimation scenarios (see methods on Task 1). This contrasts to the currently reported shark catches of around 80,000 t presently declared in ICCAT for the Atlantic Ocean (Figure III.1). Among the different *métiers* identified, longlines targeting sharks (LL-shark) is the most impacting with the majority of the total estimated studied shark species catches (Figure III.2). This is followed by general longline and other/unknown gears.

In terms of species, the shark with more estimated catches is blue shark with the majority of the catches, followed by shortfin mako. Those 2 species are mainly impacted by longline fisheries (LL-Sharks and LL). Other species with some relevance are hammerheads and then general Carcharhinidae sharks and other sharks that are mainly impacted by gillnets (Figure III.3).

In terms of fleets and *métiers*, in the Atlantic Ocean the impact on pelagic sharks is highly concentrated in just a few fisheries (Figure III.4). The EU longline fleets, particularly Spain followed by Portugal, are responsible for the majority of the catches, and the main captured species are blue shark and shortfin mako. Other important fleets and *métiers* that contribute to the overall shark catches are longlines from Brazil, Taiwan, Japan, Namibia and Senegal (Figure III.4).

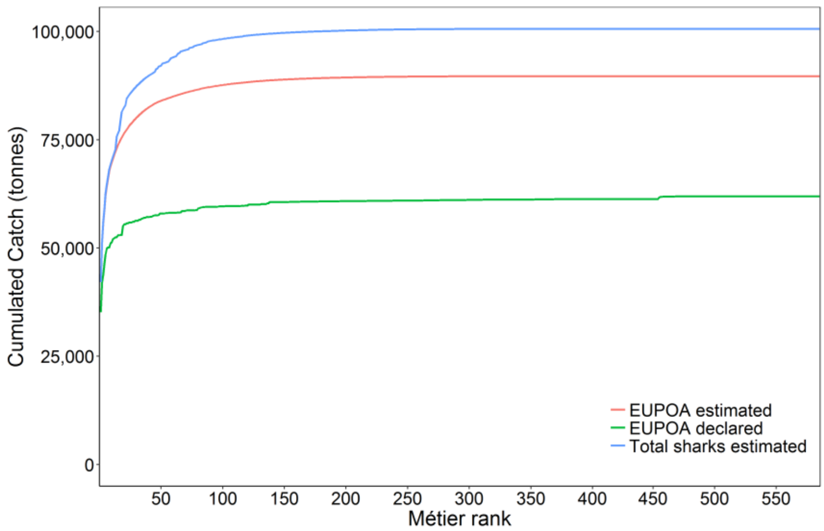


Figure III.1. Cumulative declared catches (tonnes) and "Low" estimation scenario reconstructed catches (tonnes), ranked by métier (from métier with higher estimated EUPOA catches to métier with lower estimated EUPOA catches). "EUPOA" refers to the 18 species originally considered in the EUPOA project and "Total sharks" refers to all shark species combined.

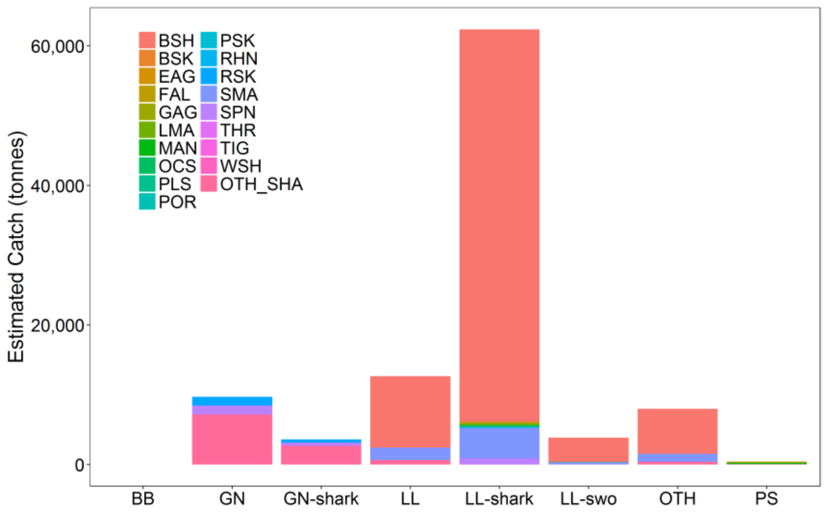


Figure III.2. Estimated catch (tonnes) by *métier* and by species in the Atlantic Ocean (ICCAT), for the "Low" scenario estimation. See Appendix I for acronyms list.

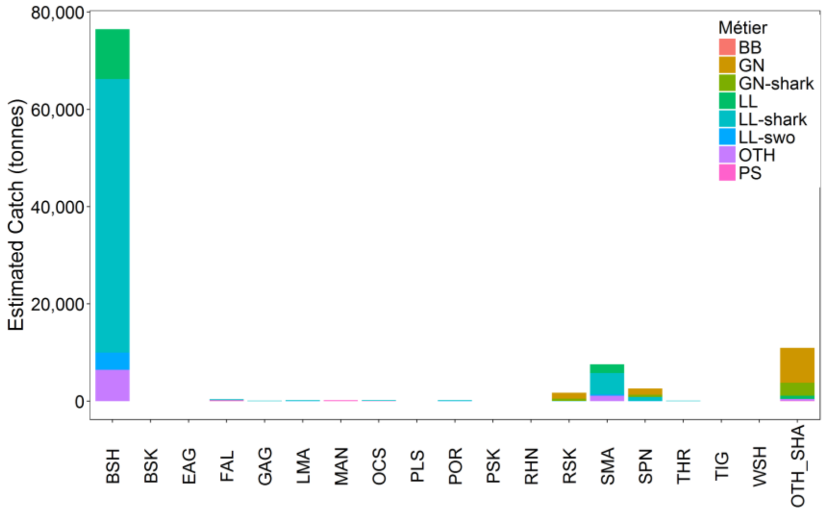


Figure III.3. Estimated catch (tonnes) of the EUPOA shark species and other sharks by *métier* in the Atlantic Ocean (ICCAT), for the "Low" estimation scenario. See Appendix I for acronyms list.

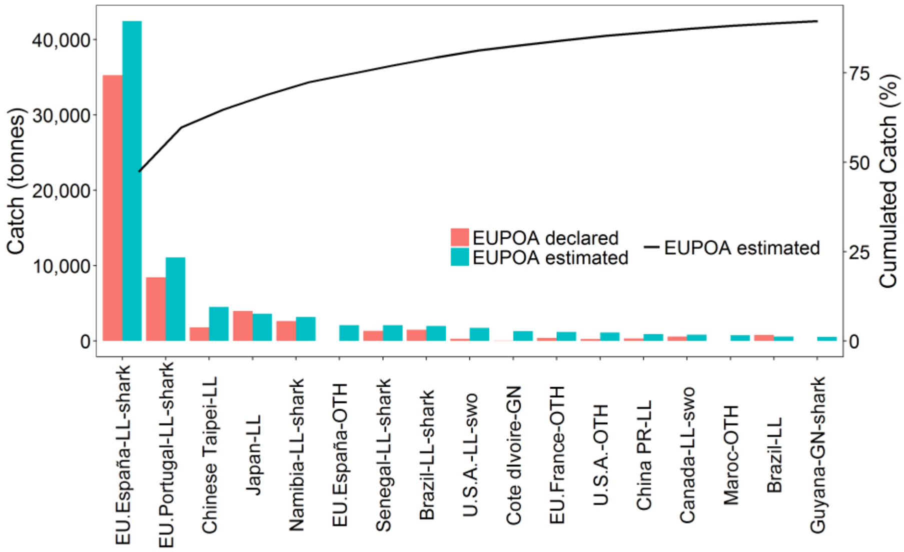


Figure III.4. Declared and estimated catch (tonnes) and cumulative percentage of estimated catch of EUPOA shark species for the main fisheries (flag and *métier*) responsible for catching pelagic sharks species in the Atlantic Ocean (EUPOA shark species), under the "Low" estimation scenario. See Appendix I for acronyms list.

ICCAT - Mediterranean

The estimated “potential” shark catches vary is 4,300t considering the Low estimation scenarios (see Task 1 methods). This contrasts to the currently reported shark catches of around 400-800t presently declared in ICCAT for the Mediterranean Sea (Figure III.5).

Among the identified different *métiers*, longlines targeting swordfish (LL-swo-albo) is the most impacting with the majority of the total estimated studied shark species catches (Figures III.6). This is followed by gillnets targeting swordfish (GN-swo-tul, GN-swo-it) and other types of longlines targeting swordfish and sharks (LL-swo-sp, LL-sharks).

In terms of species, the shark with more estimated catches is blue shark with the majority of the catches, followed by thresher sharks and shortfin mako. These 3 species are mainly impacted by longline fisheries (LL-swo-albo and LL-sharks) and gillnets targeting swordfish (GN-swo-tul). Other species with some relevance are the tope sharks followed by the pelagic stingray that are mainly impacted by longlines targeting sharks (LL-sharks) (Figures III.7).

In terms of fleets and *métiers*, in the Mediterranean Sea the impact on pelagic sharks is distributed by a few fisheries (Figures III.8). The Moroccan gillnet fleet, the EU longline fleets, particularly Spain, the Moroccan, Tunisian and Turkish longline fleets are the five fleets with most catches.

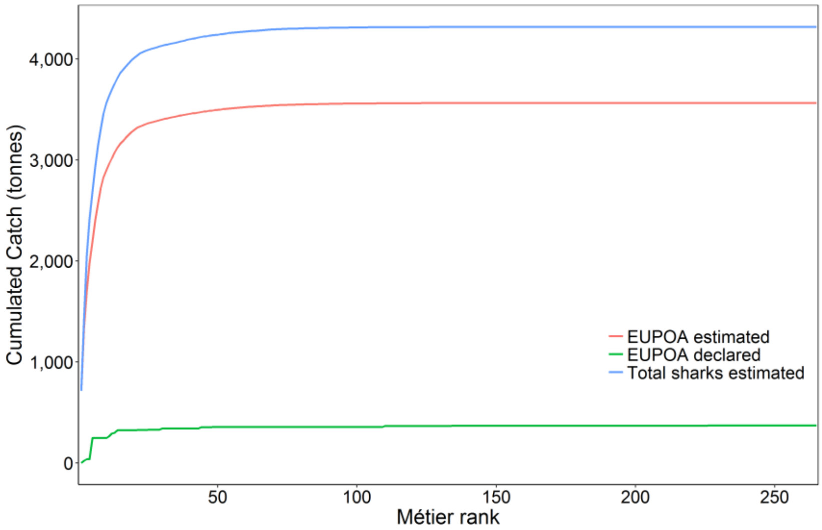


Figure III.5. Cumulative declared catches (tonnes) and "Low" estimation scenario reconstructed catches (tonnes), ranked by *métier* (from *métier* with higher estimated EUPOA catches to *métier* with lower estimated EUPOA catches). "EUPOA" refers to the 18 species originally considered in the EUPOA project and "Total sharks" refers to all shark species combined.

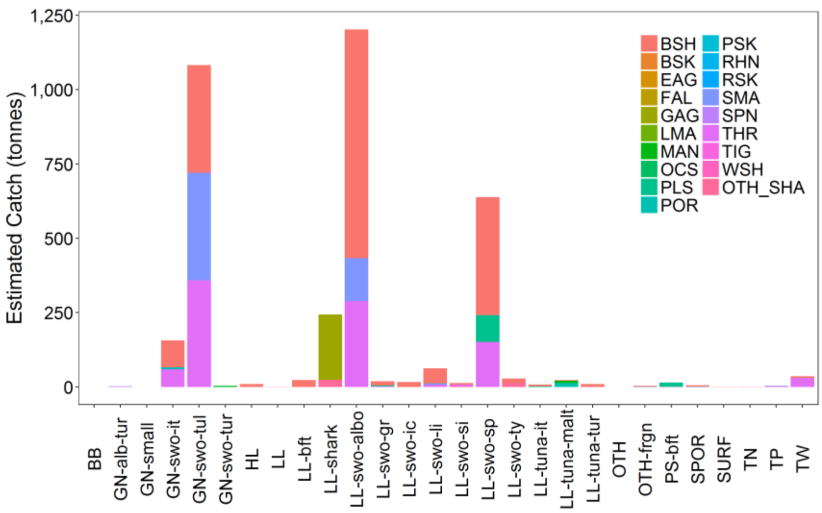


Figure III.6. Estimated catch (tonnes) by *métier* and by species in the Mediterranean Sea (ICCAT), for the "Low" scenario estimation. See Appendix I for acronyms list.

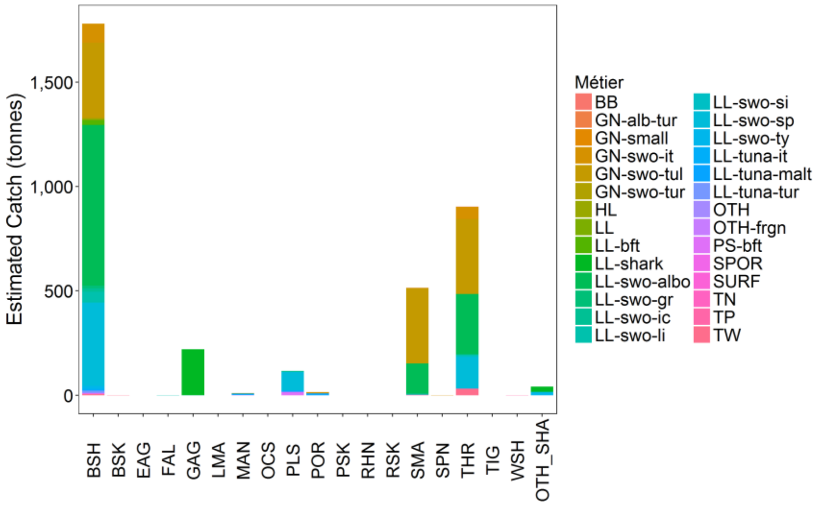


Figure III.7. Estimated catch (tonnes) of the EUPOA shark species and other sharks by *métier* in the Mediterranean Sea (ICCAT), for the "Low" estimation scenario. See Appendix I for acronyms list.

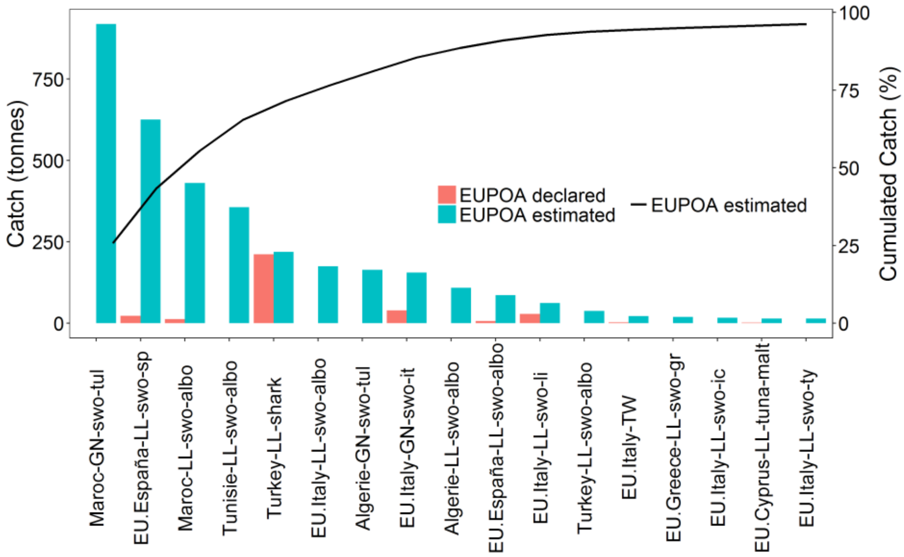


Figure III.8. Declared and estimated catch (tonnes) and cumulative percentage of estimated catch of EUPOA shark species for the main fisheries (flag and *métier*) responsible for catching pelagic sharks species in the Mediterranean (EUPOA shark species), under the "High" estimation scenario. See Appendix I for acronyms list.

IOTC

The estimated "potential" shark catches is around 130,000 t, for either the High and Low estimation scenarios (see methods). This contrasts to the currently reported shark catches of around 100,000 t presently declared in IOTC for the Indian Ocean (Figure III.9). Among the different *métiers* identified, gillnets combined with longlines (GN-LL) is the most impacting with the majority of the total estimated studied shark species catches (Figures III.10). This is followed by other/unknown gears (OTH), general longline (LL) and longlines targeting swordfish (LL-swo).

In terms of species, the five shark species with more estimated catches are blue shark, with the majority of the catches, followed by silky shark, thresher sharks, shortfin mako and hammerhead sharks. Blue shark and shortfin mako are mainly impacted by other/unknown gears (OTH) and longline fishery (LL). The other 3 species are mostly impacted by gillnet fisheries (GN-LL) (Figure III.11).

In terms of fleets and *métiers*, in the Indian Ocean the impact on pelagic sharks is highly concentrated in just a few fisheries (Figures III.12). The Sri Lanka gillnet combined with longlines fishery, the Iranian gillnet fishery, other Indonesian fisheries (not longlines, gillnets, baitboats and purse-seiners) and Taiwanese longliners accounts for around 50% of the catches.

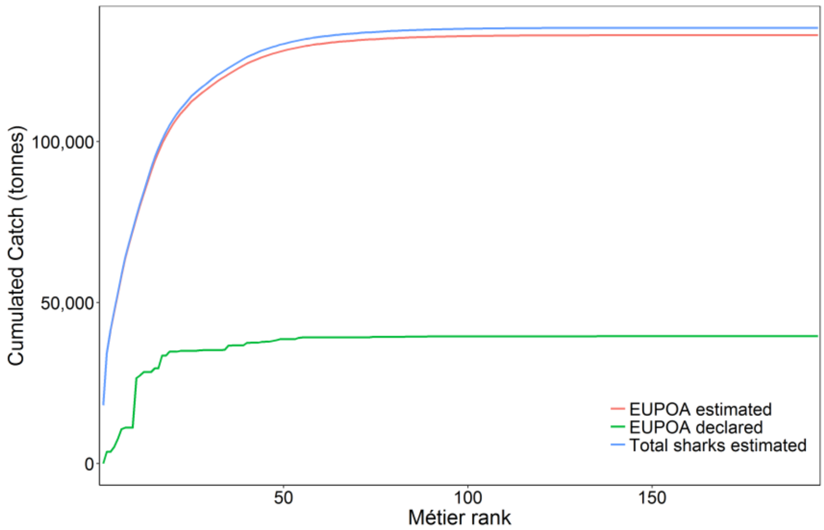


Figure III.9. Cumulative declared catches (tonnes) and "Low" estimation scenario reconstructed catches (tonnes), ranked by *métier* (from *métier* with higher estimated EUPOA catches to *métier* with lower estimated EUPOA catches). "EUPOA" refers to the 18 species originally considered in the EUPOA project and "Total sharks" refers to all shark species combined.

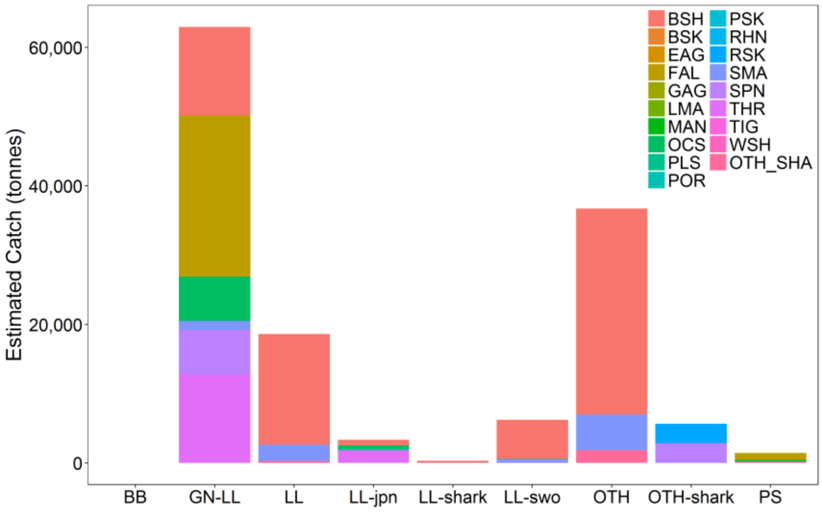


Figure III.10. Estimated catch (tonnes) by *métier* and by species in the Indian Ocean (IOTC), for the “Low” scenario estimation. See Appendix I for acronyms list.

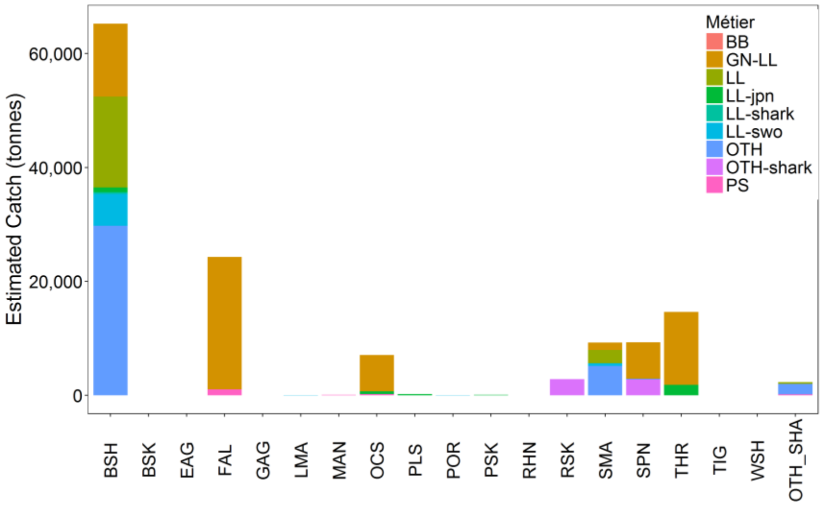


Figure III.11. Estimated catch (tonnes) of the EUPOA shark species and other sharks by *métier* in the Indian Ocean (IOTC), for the “Low” estimation scenario. See Appendix I for acronyms list.

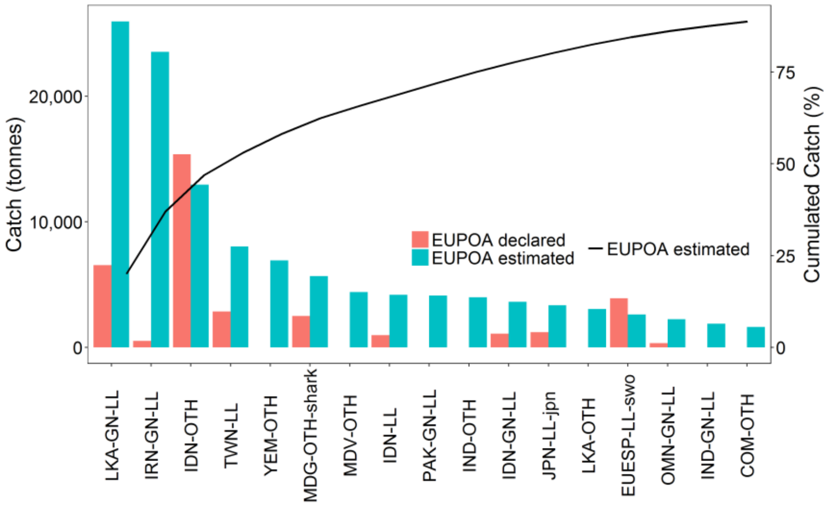


Figure III.12. Declared and estimated catch (tonnes) and cumulative percentage of estimated catch of EUPOA shark species for the main fisheries (flag and *métier*) responsible for catching pelagic sharks species in the Mediterranean (EUPOA shark species), under the "High" estimation scenario. See Appendix I for acronyms list.

2. Discard levels

Table III.1. Live discards (t) of the main shark species and stocks in the ICCAT convention area.

Species	Stock	Flag	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Blue shark	ATN	Canada										112.65
		Mexico									0.06	
		UK.Bermuda				1.56	1.334	1.665	0.408	0.26	0.18	0.54
	ATS	Brazil		327.223	12.64							
		EU.France										5.683
		South Africa								0.134	1.826	
	MED	EU.España										3.955
Blue shark total				**327.223**	**12.64**	**1.56**	**1.334**	**1.665**	**0.408**	**0.394**	**2.066**	**122.828**
Porbeagle	ATN	Canada										10.551
	ATS	EU.France										0.1
Porbeagle total												**10.651**
Shortfin mako	ATN	Canada										0.872
		Mexico	0.132	0.28	0.1	0.49	0.2	0.437	0.393		0.385	0.355
	ATS	Brazil		15.67	0.16							
		EU.France										0.307
Shortfin maki total			**0.132**	**15.95**	**0.26**	**0.49**	**0.2**	**0.437**	**0.393**		**0.385**	**1.534**

Table III.2. Purse Seine catch of sharks (t) in IATTC.

	BSHn	CCLn	FALn	OCSn	SEPNn	SKHn	SPLn	SPNn	SPZn	THRn	BSHmt	CCLmt	FALmt	OCSmt	SEPNmt	SKHmt	SPLmt	SPNmt	SPZmt	THRmt	TOTAL
1993	37	0	3149	6540	1024	1889	19	486	3	156	0	0	14.48	0	175.5	16.3	0	0	0	0	13509
1994	51	0	3189	12212	2641	3587	27	970	20	252	0	0	9100.3	0.9	139.67	29.32	1.81	2.3	0.9	0	32224
1995	212	0	4738	15586	4142	3599	56	874	50	180	0	0	28.87	29.18	90.4	12.92	0	0	0	0	29598
1996	100	0	6683	13693	5014	3213	35	1299	76	134	0	0	12.95	16.22	56.82	33.17	0	0	0	0	30366
1997	96	0	9643	19384	5339	3514	267	709	316	104	0	0	12.3	6.1	211.54	15.4	0	0	1.8	0	39619
1998	67	0	9320	16113	4597	1561	352	490	325	205	0	0	60.6	5.18	155.72	43.16	0	3.62	0	0	33298
1999	22	0	8374	14848	3658	2456	313	294	289	240	0	0	18.08	3.22	134.9	12.9	2.26	1.12	0.9	0	30667
2000	33	0	9094	3578	2215	1188	302	207	166	227	0	0	23.65	1.06	82.13	169.5	8	4	0	0	17298
2001	128	0	16017	2506	2126	1741	276	298	312	203	0	0	28.8	0	44.4	2.6	0	0	0	0	23683
2002	65	0	15347	1370	710	2069	893	617	369	411	0	0	49.35	0	6.15	3.5	3	1	0	0	21914
2003	15	0	15877	1599	438	1001	813	660	772	474	0	0	49.61	0	14.25	3.8	3	0	0	0	21720
2004	22	0	13885	832	188	1486	627	542	1089	592	0	0	60.85	0	13.08	1.9	0.25	2.5	0	0	19342
2005	19	3	22644	807	75	821	692	216	492	304	0	0	0	0	0	0	0	0	0	0	26073
2006	56	496	26054	614	158	1811	427	86	620	916	0	0	0	0	0	0	0	0	0	0	31238
2007	51	8	25201	1015	78	1856	338	47	354	381	0	0	0	0	0	0	0	0	0	0	29329
2008	81	129	31161	124	66	1209	431	119	258	281	0	0	0	0	0	0	0	0	0	0	33859
2009	103	654	23253	8	159	3846	304	109	322	180	0	0	0	0	0	0	0	0	0	0	28938
2010	76	53	26473	0	89	2994	302	58	417	211	0	0	0	0	0	0	0	0	0	0	30673
2011	100	116	20146	0	86	3016	431	223	667	269	0	0	0	0	0	0	0	0	0	0	25054
2012	256	78	12976	0	30	930	302	159	427	200	0	0	0	0	0	0	0	0	0	0	15358
2013	80	30	16145	0	34	1180	501	271	666	226	0	0	0	0	0	0	0	0	0	0	19133
2014	60	3	28163	0	81	2364	511	371	434	200	0	0	0	0	0	0	0	0	0	0	32187
2015	41	1	38038	0	116	3514	197	171	506	160	0	0	0	0	0	0	0	0	0	0	42744

Table III.3. Longline catch of sharks (t) in IATTC.

	BSHn	CCLn	FALn	MAKn	OCSn	RSKn	SKHn	SMAn	SPNn	THRn	BSHmt	CCLmt	FALmt	MAKmt	OCSmt	RSKmt	SKHmt	SMAmt	SPNmt	THRmt	TOTAL
1979	0	0	0	0	0	0	1393	0	0	0	0	0	0	0	0	0	16.76	0	0	0	1409.8
1980	0	0	0	0	0	0	2417	0	0	0	0	0	0	0	0	0	6.84	0	0	0	2423.8
1981	0	0	0	0	0	0	10877	0	0	0	0	0	0	0	0	0	119.42	0	0	0	10996
1982	0	0	0	0	0	0	12241	0	0	0	0	0	0	0	0	0	214.77	0	0	0	12456
1983	0	0	0	0	0	0	12873	0	0	0	0	0	0	0	0	0	98.44	0	0	81.67	13053
1984	0	0	0	0	0	0	9285	0	0	0	0	0	0	0	0	0	5.67	0	0	0	9290.7
1985	0	0	0	0	0	0	7805	0	0	0	3.25	0	0	2.14	0	0	18.22	0	0.15	0	7828.8
1986	0	0	0	0	0	0	19876	0	0	0	0	0	0	1.69	0	0	143.52	0	8.18	65.93	20095
1987	0	0	0	0	0	0	14873	0	0	0	0.29	0	0	6.95	0	0	362.62	0	6.83	126.69	15376
1988	0	0	0	0	0	0	13734	0	0	0	12.97	0	0	30.5	0	0	232.81	0	14.28	93.17	14118
1989	0	0	0	0	0	0	1624	0	0	0	0.3	0	0	13.07	0	0	77.63	0	0.01	3.86	1718.9
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.96	0	0	0	0.96
1991	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	49.7	0	0	0	52.7
1992	4	0	0	0	0	0	0	13	0	6	0	0	0	0	0	0	109.47	0	0	0	132.47
1993	114	0	0	0	0	0	0	22	0	1	0	0	0	0.06	0	0	190.79	0	0	0	327.85
1994	80	0	0	0	0	0	0	16	0	6	0	0	0	0.89	0	0	677.69	0	0	0	780.58
1995	1565	0	0	0	0	0	0	56	0	2	0	0	0	4.74	0	0	122.61	0	0	0	1750.4
1996	495	0	0	0	0	0	0	20	0	6	0	0	0	4.76	0	0	151.5	0	0	0	677.26
1997	530	0	0	0	0	0	0	14	0	1	0	0	0	7.9	0	0	165.66	0	0	0	718.56
1998	1917	0	0	0	0	0	0	61	0	7	0	0	0	8.05	0	0	168.15	0	0	0	2161.2
1999	3185	0	0	0	0	0	0	95	0	2	0	0	0	15.29	0	0	144.02	0	0	0	3441.3
2000	1646	0	0	0	0	0	0	54	0	1	0	0	0	24.396	0	0	292.52	0	0	0	2017.9
2001	2066	0	0	0	0	0	1	162	0	7	0	0	0	26.88	0	0	485.1	0	0	0	2748
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0.52	0	0	1269.6	0	0	0	1270.1
2003	0	0	0	0	0	0	0	0	0	0	0	0	0	30.65	0	0	34738	0	0	0	34769
2004	2252	0	0	209	3	0	31	0	0	45	0	0	0	18.32	0	0	1026	0	0	0	3584.3
2005	2979	0	0	246	2	0	11	0	0	52	0	0	0	15.87	0	0	735.54	0	0	0	4041.4
2006	475	0	0	79	0	0	9	0	0	42	0	0	0	14.617	0	0	978.78	0	0	0	1598.4
2007	4450	0	0	275	7	0	25	0	0	83	0	0	0	9.03	0	0	703.57	0	0	0	5552.6
2008	8692	0	0	757	10	0	31	0	0	311	333.66	0	0	5.53	0	0	388.21	85.19	0	0	10614
2009	4804	0	0	764	22	0	8	0	0	242	787.72	16.7	1522.3	9.31	279.89	0	571.48	62.24	0	2.03	9091.7
2010	34	0	0	241	0	0	16	0	0	13	434.67	0	1725.7	9.3	24.43	4.4	1238.6	48.83	0	0	3790
2011	45	0	0	131	0	0	0	0	0	11	833.43	60.87	1165.1	7.74	0	5.33	1552.4	113.83	0.7	3.7	3930
2012	25	0	0	141	0	0	0	0	0	6	10656	47.92	840.34	8.707	0	0	10751	407.6	11.06	2452.5	25348
2013	1	0	0	129	0	0	0	0	1	5	1383.6	0	722.91	54.89	0	11.8	1286.4	453.49	99.86	194.05	4343
2014	21215	0	0	0	0	0	0	3262	0	0	567.59	0	661.92	9.47	0	0	1001	305.7	54.44	186.35	27263
2015	19760	0	0	0	0	0	0	1977	0	0	782.99	0	396.48	4.6	0	0	769.49	182.85	9.23	116.78	23999

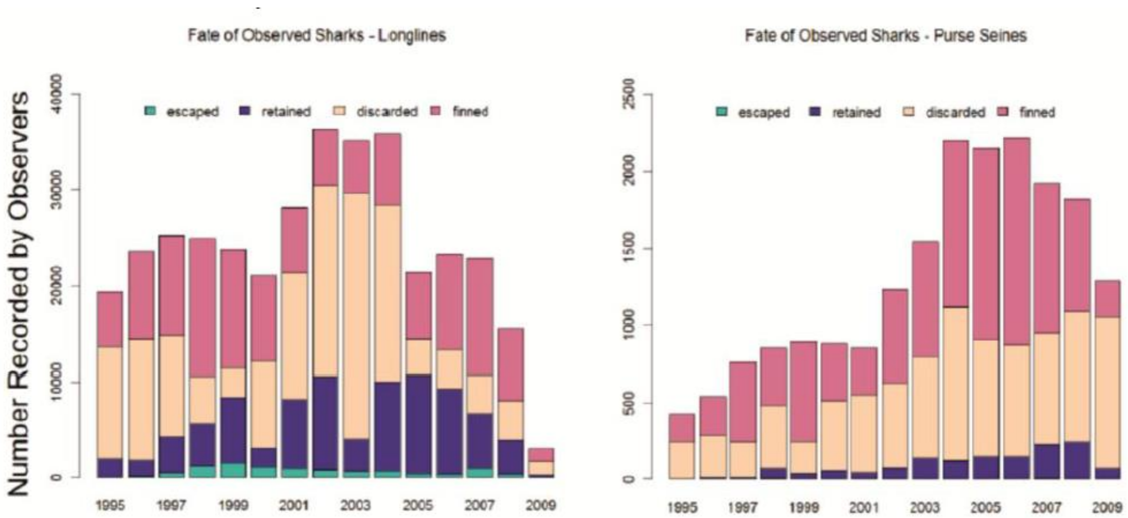


Figure III.13. Fate of observed shark in longline and purse seine in the WCPFC vs. year (Clarke, 2011[45]).

45 Clarke, S. 2011. A Status Snapshot of Key Shark Species in the Western and Central Pacific and Potential Management Option. 7th Regular Session of the Scientific Committe of the WCPFC, 6-14 August 2013, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC7-2011/EB-WP-04: 37pp.

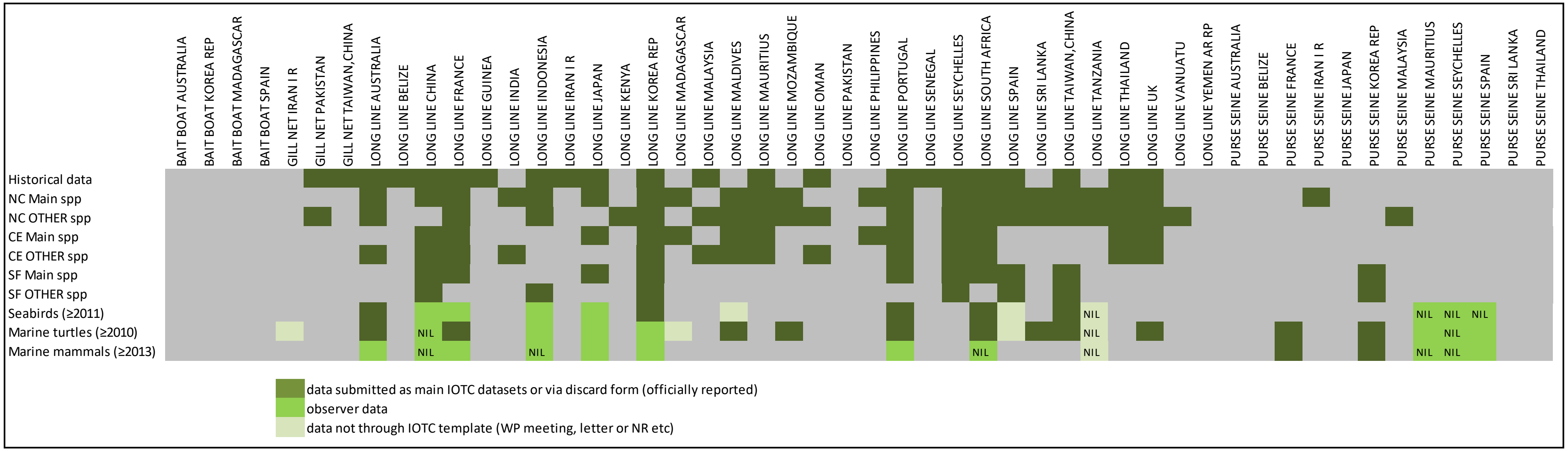


Figure III.14. Datasets provided by industrial fleets according to IOTC reporting requirements. Grey cells indicate which fleets have reported data for IOTC species, whereas green cells indicate which fleets have provided the bycatch data specified (Source: IOTC, 2016[46]).

[46] IOTC. 2016. Report on IOTC data collection and Statistics. IOTC–2016–WPDCS12–07_Rev1: 24 pp.

Table III.4. Discard levels as reported in IOTC (IOTC, 2016[35]).

Fleet	Gear type	Units	Catch (species or species group and numbers or kg of bycatch reported as recorded in column Units)
EU-France	Longline	# Fish	Albacore-82, Bigeye thresher-1, Bigeye tuna-219, Black Marlin-1, Blue Marlin-1, Blue shark-283, Brama-1, Carcharhinus sharks nei-8, Common dolphinfish-14, Dolphinfishes nei-29, Escolar-47, Green turtle-1, Hammerhead sharks nei-15, Long snouted lancetfish-141, Mako sharks-3, Oceanic whitetip shark-14, Oilfish-14, Olive ridley turtle-1, Pelagic stingray-503, Scalloped hammerhead-1, Short-billed spearfish-4, Shortfin mako-3, Silky shark-47, Silvertip shark-57, Skipjack tuna-11, Smooth hammerhead-2, Snake mackerel-158, Swordfish-532, True tunas nei-41, Wahoo-2, Yellowfin tuna-101
	Purse Seine	MT	Bigeye trevally-1, Bigeye tuna-20, Black Marlin-10, Blue Marlin-13, Blue sea chub-1, Common dolphinfish-78, Cottonmouth jack-1, Frigate and bullet tunas-2, Frigate tuna-26, Great barracuda-7, Kawakawa-1, Longfin batfish-1, Mackerel scad-118, Marlins and sailfish and spearfish nei-6, Ocean triggerfish-69, Oceanic whitetip shark-2, Rainbow runner-210, Sharks various nei-1, Silky shark-82, Skipjack tuna-67, Striped marlin-13, Tripletail-2, Tunas nei-2, Unicorn leatherjacket filefish-28, Wahoo-40, Yellowfin tuna-329
Australia	Longline	# Fish	Albacore-127, Bigeye tuna-909, Black Marlin-10, Blue shark-2315, Hammerhead sharks nei-91, Indo-Pacific sailfish-1, Mako sharks-361, Oceanic whitetip shark-11, Porbeagle-3, Shy Albatross-2, Skipjack tuna-7, Southern bluefin tuna-42, Striped marlin-14, Swordfish-172, Yellowfin tuna-90, Crocodile shark-2716, Flesh-footed shearwater-2, Indo-Pacific Blue Marlin-8, Mantas, devil rays nei-7, Petrels and shearwaters nei-5, Salvin's albatross-1, Shearwaters nei-1, Tiger shark-8, White-chinned Petrel-1
UK-OT			nil
Korea Rep	Longline	# Fish	Bigeye thresher-1, Blue Marlin-20, Blue shark-2156, Oceanic whitetip shark-2, Other non tuna-like fishes nei-519, Porbeagle-205, Sharks various nei-207, Shortfin mako-21, Southern bluefin tuna-161, Thresher sharks nei-1, Yellowfin tuna-5
	Purse Seine	kg	Black Marlin-4, Porbeagle-7, Skipjack tuna-8, Sliteye shark-3, Striped marlin-3, Yellowfin tuna-7
	Purse Seine	# Fish	Marine turtles-1, Oceanic whitetip shark-3, Olive ridley turtle-1, Spinner dolphin-2
Sri Lanka	Gillnet	# Fish	Bottlenose dolphin-16, Green turtle-25, Blue whale-7
	Longline	# Fish	Bigeye thresher-32, Green turtle-8
	Purse Seine	# Fish	Green turtle-45
South Africa	Longline (foreign flags)	# fish	Albacore-475, Bigeye thresher-6, Bigeye tuna-3706, Black Marlin-30, Black-browed Albatross-7, Blue Marlin-18, Blue shark-3295, Common dolphinfish-100, Indo-Pacific sailfish-5, Oceanic whitetip shark-4, Oilfish-586, Scalloped hammerhead-30, Short-billed spearfish-5, Shortfin mako-869, Shy Albatross-10, Silky shark-7, Skipjack tuna-89, Smooth hammerhead-2, Southern bluefin tuna-170, Striped marlin-3, Swordfish-235, Thresher Shark-83, Wahoo-32, Yellowfin tuna-14722, Crocodile shark-3, Tiger shark-1, White-chinned Petrel-127, Loggerhead turtle-11, Opah-97, Atlantic Yellow-nosed Albatross-42, Copper shark-8, Indian Yellow-nosed Albatross-46, Leatherback turtle-2, Pomfrets nei-168

	Longline (National flag)	# fish	Albacore-601, Bigeye thresher-3, Bigeye tuna-539, Black Marlin-6, Black-browed Albatross-2, Blue Marlin-11, Blue shark-5035, Common dolphinfish-163, Green turtle-1, Indo-Pacific sailfish-1, Oceanic whitetip shark-12, Oilfish-55, Porbeagle-8, Scalloped hammerhead-24, Short-billed spearfish-12, Shortfin mako-2038, Shy Albatross-14, Silky shark-80, Smooth hammerhead-2, Southern bluefin tuna-7, Striped marlin-2, Swordfish-557, Thresher Shark-40, Wahoo-3, Yellowfin tuna-521, Crocodile shark-11, Tiger shark-2, White-chinned Petrel-4, Loggerhead turtle-5, Opah-3, Wandering Albatross-2, Atlantic Yellow-nosed Albatross-2, Copper shark-97, Indian Yellow-nosed Albatross-11, Leatherback turtle-20, Pomfrets nei-14, Butterfly kingfish-2
Maldives	Longline	# fish	Albacore-82-Bigeye trevally-1, Bigeye thresher-1-Bigeye tuna-20, Bigeye tuna-219-Black Marlin-10, Black Marlin-1-Blue Marlin-13, Blue Marlin-1-Blue sea chub-1, Blue shark-283-Common dolphinfish-78, Brama-1-Cottonmouth jack-1, Carcharhinus sharks nei-8-Frigate and bullet tunas-2
Mauritius	Purse Seine	kg	Common dolphinfish-1390, Skipjack tuna-1775, Balistidae-745, Wahoo-100, Yellowfin tuna-35900, Other Species-9800
Mozambique	longline	# fish	Marine turtles-3
China	longline	# fish	Hammerhead sharks nei-106, Longfin mako-199, Oceanic whitetip shark-2154, Porbeagle-13, Silky shark-319, Thresher sharks nei-248
Taiwan,China	longline	# fish	Black-browed Albatross-1, Green turtle-1, Shy Albatross-4, Sooty albatross-7, Yellow-nosed albatross-9

3. Length Frequency

Table III.5. ICCAT-SCRS catalogue on statistics (Task-I and Task-II) for blue shark (BSH) for the North Atlantic stock. The catalogue is detailed by major fishery (flag/gear combinations ranked by order of importance) and year (1995 to 2017). Only the most important fisheries (representing ±97.5% of Task-I total catch) are shown. For each data series, Task I (DSet= "t1", in tonnes) is visualised against its equivalent Task II availability (DSet= "t2") scheme. The Task-II colour scheme, has a concatenation of characters ("a"= T2CE exists; "b"= T2SZ exists; "c"= CAS exists) that represents the Task-II data availability in the ICCAT-DB.

				T1 Total		8468	7395	29283	26763	26172	28174	21709	20066	23005	21742	22359	23217	26927	30723	35198	37178	38083	36778	37058	41840	44925			
Species	**Stock**	**Status**	**FlagName**	**GearGrp**	**DSet**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	Rank	%	%cum
BSH	ATN	CP	EU.España	LL	t1			24497	22504	21811	24112	17362	15666	15975	17314	15006	15464	17038	20788	24465	26094	27988	28666	28562	29041	30078	1	72.0%	72%
BSH	ATN	CP	EU.España	LL	t2			-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	b	b	b	1		
BSH	ATN	CP	EU.Portugal	LL	t1	4722	4843	2630	2440	2227	2081	2110	2265	5642	1751	4026	4337	5283	6164	6248	8256	6508	3725	3694	2994	3808	2	14.6%	87%
BSH	ATN	CP	EU.Portugal	LL	t2	a	a	a	a	a	a	a	a	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	2		
BSH	ATN	CP	Japan	LL	t1	1145	618	489	340	357	273	350	386	558	1035	1729	1434	1921	2531	2007	1763	1227	2437	1808	8532	9629	3	6.9%	93%
BSH	ATN	CP	Japan	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	ab	ab	ab	a	a	a	a	3		
BSH	ATN	CP	Canada	LL	t1	1494	528	831	612	547	624	581	836	346	965	1134	977	843	0	0	0	0	1	0	1	5	4	1.8%	95%
BSH	ATN	CP	Canada	LL	t2	-1	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	4		
BSH	ATN	CP	Belize	LL	t1															114	461	1039	903	1216	392	4	5	0.7%	96%
BSH	ATN	CP	Belize	LL	t2															ab	ab	ab	ab	a	a	a	5		
BSH	ATN	NCC	Chinese Taipei	LL	t1	167	132	203	246	384	165	59		171	206	240	588	292	110	73	99	148	107	123	104	185	6	0.6%	97%
BSH	ATN	NCC	Chinese Taipei	LL	t2	-1	-1	-1	-1	-1	-1	-1		ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	6		
BSH	ATN	CP	Panama	LL	t1					9							254	892	613	1575				289	153		7	0.6%	97%
BSH	ATN	CP	Panama	LL	t2					-1							a	a	a	a				a	a		7		
BSH	ATN	CP	U.S.A.	LL	t1	622	607	181	172	96	137	105	68	55	70	68	47	54	137	106	176	232	123	114	142	83	8	0.6%	98%
BSH	ATN	CP	U.S.A.	LL	t2	-1	-1	-1	-1	-1	-1	b	c	-1	b	b	b	b	b	ab	ab	ab	ab	ab	ab	ab	8		
BSH	ATN	CP	EU.France	UN	t1	266	278	213	163	399	395	207	221	57	95	120	99	50	46	30	3	6	0	0	105		9	0.5%	98%
BSH	ATN	CP	EU.France	UN	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	a		9		
BSH	ATN	CP	China PR	LL	t1							185	104	148				367	109	88	53	109	98	327		1	10	0.3%	99%
BSH	ATN	CP	China PR	LL	t2							-1	-1	-1				a	a	a	a	a	a	a		ab	10		

Table III.6. ICCAT-SCRS catalogue on statistics (Task-I and Task-II) <u>for blue shark (BSH) for the South Atlantic stock</u>. The catalogue is detailed by major fishery (flag/gear combinations ranked by order of importance) and year (1995 to 2017). Only the most important fisheries (representing ±97.5% of Task-I total catch) are shown. For each data series, Task I (DSet= "t1", in tonnes) is visualised against its equivalent Task II availability (DSet= "t2") scheme. The Task-II colour scheme, has a concatenation of characters ("a"= T2CE exists; "b"= T2SZ exists; "c"= CAS exists) that represents the Task-II data availability in the ICCAT-DB.

				T1 Total		3108	4252	10145	8797	10829	12444	14043	12682	14967	14438	20642	20493	23487	23097	23459	27799	35069	26421	19682	29980	25235			
Species	**Stock**	**Status**	**FlagName**	**GearGrp**	**DSet**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	Rank	%	%cum
BSH	ATS	CP	EU.España	LL	t1			5272	5574	7173	6951	7743	5368	6626	7366	6410	8724	8942	9615	13099	13953	16978	14348	10473	11447	10133	1	46.2%	46%
BSH	ATS	CP	EU.España	LL	t2			-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	b	b	b	b	b	1		
BSH	ATS	CP	EU.Portugal	LL	t1	847	867	1336	876	1110	2134	2562	2324	1841	1863	3184	2751	4493	4866	5358	6338	7642	2424	1646	1622	2420	2	15.4%	62%
BSH	ATS	CP	EU.Portugal	LL	t2	-1	-1	a	a	a	a	a	a	a	a	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	a	2		
BSH	ATS	CP	Namibia	LL	t1					0			2213	2316	1906	6616	3536	3419	1829	207	2351	2633	1176	1147	2471	2137	3	8.9%	71%
BSH	ATS	CP	Namibia	LL	t2					-1			a	-1	ab	ab	ab	ab	ab	ab	ab	ab	a	ab	a	a	3		
BSH	ATS	CP	Brazil	LL	t1		743	1103		179	1683	2173	1966	2160	1568	2520	2533	2309	1625	1268	1500	1913	1607	1008	2548	2080	4	8.5%	79%
BSH	ATS	CP	Brazil	LL	t2		-1	a		-1	ab	a	a	a	a	ab	a	ab	a	ab	ab	ab	ab	a	a	a	4		
BSH	ATS	NCC	Chinese Taipei	LL	t1	1767	1952	1737	1559	1496	1353	665		521	800	866	1805	2177	1843	1356	1625	2142	2074	2257	2219	1357	5	8.3%	87%
BSH	ATS	NCC	Chinese Taipei	LL	t2	-1	-1	-1	-1	-1	-1	-1		ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	5		
BSH	ATS	CP	Japan	LL	t1	437	425	506	510	536	221	182	343	331	209	236	525	896	1789	981	1161	1483	3060	2255	7085	5582	6	7.5%	95%
BSH	ATS	CP	Japan	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	ab	ab	ab	a	a	a	a	6		
BSH	ATS	CP	Uruguay	LL	t1	57	259	180	248	118	81	66	85	480	462	376	232	337	359	942	208	725	433	130			7	1.5%	96%
BSH	ATS	CP	Uruguay	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	ab	ab	ab	ab	b	ab	ab	ab			7		
BSH	ATS	CP	South Africa	LL	t1				23	21		82	63	232	128	154	90	82	126	119	112	317	158	179	525	487	8	0.8%	97%
BSH	ATS	CP	South Africa	LL	t2				-1	-1	ab	a	ab	ab	ab	ab	ab	ab	ab	ab	ab	a	ab	ab	ab	-1	8		
BSH	ATS	CP	China PR	LL	t1							565	316	452				585	40	109	41	131	84	64	48	20	9	0.6%	98%
BSH	ATS	CP	China PR	LL	t2							-1	-1	-1				a	a	a	a	a	a	a	ab	a	9		
BSH	ATS	CP	Belize	LL	t1										37	259		236	109		273	243	483	234	171	105	10	0.6%	98%
BSH	ATS	CP	Belize	LL	t2										a	a	a	a	a		ab	ab	ab	a	a	a	10		
BSH	ATS	CP	Ghana	GN	t1																				1583	385	11	0.5%	99%
BSH	ATS	CP	Ghana	GN	t2																				a	a	11		

Table III.7. ICCAT-SCRS catalogue on statistics (Task-I and Task-II) for blue shark (BSH) for the Mediterranean stock. The catalogue is detailed by major fishery (flag/gear combinations ranked by order of importance) and year (1995 to 2017). Only the most important fisheries (representing ±97.5% of Task-I total catch) are shown. For each data series, Task I (DSet= "t1", in tonnes) is visualised against its equivalent Task II availability (DSet= "t2") scheme. The Task-II colour scheme, has a concatenation of characters ("a"= T2CE exists; "b"= T2SZ exists; "c"= CAS exists) that represents the Task-II data availability in the ICCAT-DB.

				T1 Total		8	2	150	63	22	45	47	17	11	125	72	178	50	81	185	216	40	42	100	235	71			
Species	Stock	Status	FlagName	GearGrp	DSet	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Rank	%	%cum
BSH	MED	CP	EU.España	LL	t1			146	59	20	31	6	3	3	4	8	61	3	2	7	48	38	39	37	53	65	1	36.0%	36%
BSH	MED	CP	EU.España	LL	t2			-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	a	-1	a	ab	ab	ab	1		
BSH	MED	CP	EU.Italy	UN	t1										67		95				165			3	44		2	21.3%	57%
BSH	MED	CP	EU.Italy	UN	t2										-1		-1				-1			-1	-1		2		
BSH	MED	CP	EU.Italy	LL	t1										32	1		44	75	9				25	129		3	17.9%	75%
BSH	MED	CP	EU.Italy	LL	t2										-1	-1		-1	-1	-1				-1	-1		3		
BSH	MED	CP	EU.Italy	GN	t1										12			2		166							4	10.2%	85%
BSH	MED	CP	EU.Italy	GN	t2										-1			-1		-1							4		
BSH	MED	CP	EU.Portugal	LL	t1				2		5	41	14	3		56	22				2						5	8.1%	93%
BSH	MED	CP	EU.Portugal	LL	t2				-1		-1	-1	a	a	a	a	a				a						5		
BSH	MED	CP	EU.Italy	TW	t1														0	1				29			6	1.7%	95%
BSH	MED	CP	EU.Italy	TW	t2														-1	-1				-1			6		
BSH	MED	CP	EU.Cyprus	LL	t1						9			3	6	5											7	1.3%	97%
BSH	MED	CP	EU.Cyprus	LL	t2						a			a	a	a											7		
BSH	MED	CP	EU.Malta	LL	t1													1	1	2	1	1	2	2	4	5	8	1.1%	98%
BSH	MED	CP	EU.Malta	LL	t2					a	a					a		a	ab	ab	ab	ab	abc	ab	abc	a	8		
BSH	MED	CP	Japan	LL	t1	7	1	1						1	1	2			2	0							9	0.9%	99%
BSH	MED	CP	Japan	LL	t2	-1	-1	-1						-1	-1	-1			-1	a							9		
BSH	MED	CP	EU.Malta	UN	t1	1	1	2	2	2	1	1	1	0		0	0										10	0.7%	99%
BSH	MED	CP	EU.Malta	UN	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1		-1	-1										10		

Table III.8. ICCAT-SCRS catalogue on statistics (Task-I and Task-II) for <u>shortfin mako shark (SMA) for the North Atlantic stock</u>. The catalogue is detailed by major fishery (flag/gear combinations ranked by order of importance) and year (1995 to 2017). Only the most important fisheries (representing ±97.5% of Task-I total catch) are shown. For each data series, Task I (DSet= "t1", in tonnes) is visualised against its equivalent Task II availability (DSet= "t2") scheme. The Task-II colour scheme, has a concatenation of characters ("a"= T2CE exists; "b"= T2SZ exists; "c"= CAS exists) that represents the Task-II data availability in the ICCAT-DB.

				T1 Total		5347	5346	3580	3879	2791	2592	2682	3416	3923	3864	3479	3378	4083	3566	4116	4188	3771	4478	3646	2906	3227			
Species	**Stock**	**Status**	**FlagName**	**GearGrp**	**DSet**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	Rank	%	%cum
SMA	ATN	CP	EU.España	LL	t1	2209	3294	2416	2223	2051	1561	1684	2047	2068	2088	1751	1918	1816	1895	2216	2091	1667	2308	1509	1481	1362	1	53.2%	53%
SMA	ATN	CP	EU.España	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	b	b	b	1		
SMA	ATN	CP	EU.Portugal	LL	t1	657	691	354	307	327	318	378	415	1249	399	1109	951	1540	1033	1169	1432	1045	1023	817	209	213	2	20.0%	73%
SMA	ATN	CP	EU.Portugal	LL	t2	a	a	a	a	a	a	a	a	a	a	a	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	2		
SMA	ATN	CP	Japan	LL	t1	592	790	258	892	120	138	105	438	267	572			82	131	98	116	53	56	33	69	47	3	6.2%	79%
SMA	ATN	CP	Japan	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			-1	-1	ab	ab	ab	a	a	a	a	3		
SMA	ATN	CP	U.S.A.	LL	t1	310	234	242	195	89	164	181	167	141	188	187	129	222	197	221	226	213	198	190	207	341	4	5.4%	85%
SMA	ATN	CP	U.S.A.	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	b	b	b	b	b	b	ab	ab	ab	ab	ab	ab	ab	4		
SMA	ATN	CP	U.S.A.	SP	t1	1422	232	164	148	69	290	214	248														5	3.6%	88%
SMA	ATN	CP	U.S.A.	SP	t2	-1	-1	-1	-1	-1	-1	-1	-1														5		
SMA	ATN	CP	Maroc	LL	t1																	390	380	616	580	807	6	3.5%	92%
SMA	ATN	CP	Maroc	LL	t2																	-1	a	a	-1	a	6		
SMA	ATN	CP	U.S.A.	RR	t1		0	0	0	0	1	0	0	0	333	282	257	158	156	163	168	178	229	219	201	190	7	3.2%	95%
SMA	ATN	CP	U.S.A.	RR	t2		-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	7		
SMA	ATN	CP	Canada	LL	t1	93	56	99	55	54	59	60	61	63	69	74	64	64	39	50	39	37	28	35	53	84	8	1.6%	97%
SMA	ATN	CP	Canada	LL	t2	-1	a	a	a	a	a	a	-1	a	a	a	-1	-1	-1	a	abc	ab	ab	ab	ab	ab	8		
SMA	ATN	NCC	Chinese Taipei	LL	t1	21	16	25	31	48	21	7		84	57	19	30	25	23	11	14	13	15	8	6	11	9	0.6%	97%
SMA	ATN	NCC	Chinese Taipei	LL	t2	-1	-1	-1	-1	-1	-1	-1		ab	ab	ab	ab	ab	ab	a	ab	ab	ab	ab	ab	ab	9		
SMA	ATN	CP	Belize	LL	t1															23	28	69	114	99	1	1	10	0.4%	98%
SMA	ATN	CP	Belize	LL	t2															ab	ab	ab	ab	-1	-1	-1	10		
SMA	ATN	CP	Venezuela	LL	t1	4	12	3	1	2	2	20	16	22	58	20	6	11	2	35	22	18	24	6	7	7	11	0.4%	98%
SMA	ATN	CP	Venezuela	LL	t2	b	b	b	b	b	b	b	b	b	ab	a	ab	ab	ab	ab	ab	a	ab	a	a	a	11		

Table III.9. ICCAT-SCRS catalogue on statistics (Task-I and Task-II) for shortfin mako shark (SMA) for the South Atlantic stock. The catalogue is detailed by major fishery (flag/gear combinations ranked by order of importance) and year (1995 to 2017). Only the most important fisheries (representing ±97.5% of Task-I total catch) are shown. For each data series, Task I (DSet= "t1", in tonnes) is visualised against its equivalent Task II availability (DSet= "t2") scheme. The Task-II colour scheme, has a concatenation of characters ("a"= T2CE exists; "b"= T2SZ exists; "c"= CAS exists) that represents the Task-II data availability in the ICCAT-DB.

				T1 Total		3060	2461	2213	1793	1549	2555	2050	1957	3779	2398	3115	2938	2850	1881	2063	2486	3258	2905	2001	3271	2686			
Species	**Stock**	**Status**	**FlagName**	**GearGrp**	**DSet**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	Rank	%	%cum
SMA	ATS	CP	EU.España	LL	t1	1084	1482	1356	984	861	1090	1235	811	1158	703	584	664	654	628	922	1192	1535	1207	1083	1077	862	1	39.7%	40%
SMA	ATS	CP	EU.España	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	b	b	b	b	b	1		
SMA	ATS	CP	Namibia	LL	t1					1			459	375	509	1415	1243	1002	295	23	306	328	554	9	950	661	2	15.3%	55%
SMA	ATS	CP	Namibia	LL	t2					-1			a	-1	ab	ab	ab	ab	ab	ab	ab	ab	a	ab	a	a	2		
SMA	ATS	CP	EU.Portugal	LL	t1	92	94	165	116	119	388	140	56	625	13	242	493	375	321	502	336	409	176	132	127	158	3	9.5%	65%
SMA	ATS	CP	EU.Portugal	LL	t2	-1	-1	a	a	a	a	a	a	a	a	a	ab	ab	ab	ab	ab	ab	ab	ab	ab	a	3		
SMA	ATS	CP	Japan	LL	t1	1617	514	244	267	151	264	56	133	118	398			72	115	108	103	132	291	114	181	110	4	9.4%	74%
SMA	ATS	CP	Japan	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1			-1	-1	ab	ab	ab	a	a	a	a	4		
SMA	ATS	CP	Brazil	LL	t1		83	190		27	219	409	226	283	177	426	183	152	121	92	128	179	193	80	256	120	5	6.7%	81%
SMA	ATS	CP	Brazil	LL	t2		-1	-1		-1	ab	a	a	a	a	ab	a	-1	a	a	a	-1	a	-1	-1	a	5		
SMA	ATS	NCC	Chinese Taipei	LL	t1	166	183	163	146	141	127	63		626	121	128	138	211	124	117	144	204	158	157	159	114	6	6.4%	87%
SMA	ATS	NCC	Chinese Taipei	LL	t2	-1	-1	-1	-1	-1	-1	-1		ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	ab	6		
SMA	ATS	CP	South Africa	LL	t1	46	36	29	168	66	103	68	12	115	101	111	86	224	137	146	152	218	108	250	476	613	7	6.1%	93%
SMA	ATS	CP	South Africa	LL	t2	-1	-1	-1	-1	-1	ab	a	ab	ab	ab	ab	ab	ab	ab	ab	ab	a	ab	ab	ab	ab	7		
SMA	ATS	CP	China PR	LL	t1	23	27	19	74	126	305	22	208	260				77	6	24	32	29	8	9	9	5	8	2.4%	95%
SMA	ATS	CP	China PR	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1				a	a	a	a	a	a	a	a	a	8		
SMA	ATS	CP	Uruguay	LL	t1	17	26	20	23	21	35	40	38	188	249	146	68	36	41	106	23	76	36	1			9	2.2%	98%
SMA	ATS	CP	Uruguay	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	ab	ab	ab	a	-1	ab	ab	ab			9		
SMA	ATS	CP	Belize	LL	t1											38		17	2		32	59	78	88	1	15	10	0.6%	98%
SMA	ATS	CP	Belize	LL	t2											-1		a	a		ab	ab	ab	-1	-1	a	10		

Table III.10. ICCAT-SCRS catalogue on statistics (Task-I and Task-II) for porbeagle (POR) for the North Atlantic stock. The catalogue is detailed by major fishery (flag/gear combinations ranked by order of importance) and year (1995 to 2017). Only the most important fisheries (representing ±97.5% of Task-I total catch) are shown. For each data series, Task I (DSet= "t1", in tonnes) is visualised against its equivalent Task II availability (DSet= "t2") scheme. The Task-II colour scheme, has a concatenation of characters ("a"= T2CE exists; "b"= T2SZ exists; "c"= CAS exists) that represents the Task-II data availability in the ICCAT-DB.

Species	Stock	Status	FlagName	GearGrp	DSet	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Rank	%	%cum
				T1 Total		2136	1556	1833	1451	1393	1457	507	838	604	725	539	470	512	524	421	119	68	111	156	86	79			
POR	ATN	CP	Canada	LL	t1	1351	1045	1322	1055	956	899		223	130	220	191	184	83	115	50	65	22	29	16	8	3	1	51.1%	51%
POR	ATN	CP	Canada	LL	t2	-1	a	a	a	a	a	a	a	a	a	a	a	a	a	a	abc	ab	ab	ab	ab	ab	1		
POR	ATN	CP	EU.France	UN	t1	565	267	315	219	240	410	361	461	303	194	276	194	83	83	153							2	26.5%	78%
POR	ATN	CP	EU.France	UN	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1							2		
POR	ATN	CP	EU.France	LL	t1										185			271	184	46		1	0				3	4.4%	82%
POR	ATN	CP	EU.France	LL	t2										-1			-1	-1	-1		-1	-1				3		
POR	ATN	CP	EU.Denmark	UN	t1	86	72	69	85	107	73	76	42								0		2				4	3.9%	86%
POR	ATN	CP	EU.Denmark	UN	t2	-1	-1	-1	-1	-1	-1	-1	-1								a		a				4		
POR	ATN	CP	EU.España	LL	t1	19	41	25	25	18	13	24	54	27	11	14	34	8	41	77		0					5	2.8%	89%
POR	ATN	CP	EU.España	LL	t2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1		-1					5		
POR	ATN	CP	Japan	LL	t1		5	4										12	10	13	13	14	49	98	57	23	6	1.9%	91%
POR	ATN	CP	Japan	LL	t2		-1	-1										-1	-1	ab	ab	ab	a	a	a	a	6		
POR	ATN	CP	Norway	UN	t1	26	28	17	27	32	22			19			1	8	9	6	12	11	17				7	1.5%	92%
POR	ATN	CP	Norway	UN	t2	-1	-1	-1	-1	-1	-1			-1			-1	-1	-1	-1	-1	-1	-1				7		
POR	ATN	CP	U.S.A.	LL	t1	35	78	56	9	0	1	0	1	0	1	0	0	0	0	0	3	2	0	2	7	35	8	1.5%	94%
POR	ATN	CP	U.S.A.	LL	t2	-1	-1	-1	-1	-1	-1	-1	b	b	b	b	b	b	b	ab	ab	ab	ab	ab	ab	ab	8		
POR	ATN	CP	EU.Portugal	LL	t1					0	7	4	10	101	50	14	6	0	3	17	7	0	0				9	1.4%	95%
POR	ATN	CP	EU.Portugal	LL	t2					-1	-1	-1	a	a	a	a	a	a	a	a	a	a	a			ab	9		
POR	ATN	CP	Canada	GN	t1	2	4	8	11	6	2	7	12	11	10	10	6	10	8	11	18	7	2	0	1	1	10	1.0%	96%
POR	ATN	CP	Canada	GN	t2	a	a	a	a	a	a	a	a	a	a	a	a	a	a	a	ac	a	a	a	a	a	10		
POR	ATN	NCO	Faroe Islands	UN	t1	44	8	9	7	10																	11	0.5%	96%
POR	ATN	NCO	Faroe Islands	UN	t2	-1	-1	-1	-1	-1																	11		
POR	ATN	CP	EU.Ireland	UN	t1					8	2	6	3	11	18		4	8	7		0						12	0.4%	97%
POR	ATN	CP	EU.Ireland	UN	t2					-1	-1	-1	-1	-1	-1		-1	-1	-1		-1						12		
POR	ATN	CP	EU.France	TW	t1										24				22	14		1	3				13	0.4%	97%
POR	ATN	CP	EU.France	TW	t2										-1				-1	-1		-1	-1				13		
POR	ATN	CP	Norway	GN	t1							6	3			8	26	1	2	2				8			14	0.4%	98%
POR	ATN	CP	Norway	GN	t2							-1	-1			-1	-1	-1	-1	-1				-1			14		
POR	ATN	CP	U.S.A.	RR	t1																	8	4	27	7	9	15	0.4%	98%
POR	ATN	CP	U.S.A.	RR	t2																	-1	-1	-1	-1	-1	15		

Table III.11. ICCAT-SCRS catalogue on statistics (Task-I and Task-II) for porbeagle (POR) for the South Atlantic stock. The catalogue is detailed by major fishery (flag/gear combinations ranked by order of importance) and year (1995 to 2017). Only the most important fisheries (representing ±97.5% of Task-I total catch) are shown. For each data series, Task I (DSet= "t1", in tonnes) is visualised against its equivalent Task II availability (DSet= "t2") scheme. The Task-II colour scheme, has a concatenation of characters ("a"= T2CE exists; "b"= T2SZ exists; "c"= CAS exists) that represents the Task-II data availability in the ICCAT-DB.

Species	Stock	Status	FlagName	GearGrp	DSet	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Rank	%	%cum
				T1 Total		3	3	26	17	10	11	1	11	43	17	31	37	13	85	62	16	21	37	29	71	42			
POR	ATS	CP	Japan	LL	t1		3	14										5	41	34	8	7	25	15	46	32	1	39.2%	39%
POR	ATS	CP	Japan	LL	t2		-1	-1										-1	-1	a	a	a	a	a	a	a	1		
POR	ATS	CP	Uruguay	LL	t1	3		5	14	3	4		8	34	8	28	34	3	40	14	6	12	12				2	39.1%	78%
POR	ATS	CP	Uruguay	LL	t2	-1		-1	-1	-1	-1		-1	-1	-1	-1	a	a	b	a	-1	ab	ab	b			2		
POR	ATS	CP	EU.España	LL	t1			2	2	2	7	1	2	9	4	0	3	5	4	13							3	9.1%	87%
POR	ATS	CP	EU.España	LL	t2			-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1							3		
POR	ATS	CP	Ghana	PS	t1																				25		4	4.3%	92%
POR	ATS	CP	Ghana	PS	t2																				-1		4		
POR	ATS	CP	Korea Rep.	LL	t1																			14			5	2.3%	94%
POR	ATS	CP	Korea Rep.	LL	t2																			abc			5		
POR	ATS	CP	Senegal	LL	t1																					11	6	1.8%	96%
POR	ATS	CP	Senegal	LL	t2																					a	6		
POR	ATS	NCO	Benin	SU	t1			4	0	4																	7	1.4%	97%
POR	ATS	NCO	Benin	SU	t2			-1	-1	-1																	7		
POR	ATS	CP	EU.Portugal	LL	t1										4	2											8	1.2%	98%
POR	ATS	CP	EU.Portugal	LL	t2									a	a	a										a	8		
POR	ATS	NCC	Chinese Taipei	LL	t1																2	0	0	1	0	0	9	0.6%	99%
POR	ATS	NCC	Chinese Taipei	LL	t2																a	-1	a	a	a	-1	9		
POR	ATS	CP	Brazil	LL	t1																	2					10	0.3%	99%
POR	ATS	CP	Brazil	LL	t2									a					a			-1				a	10		

Table III.12. WCPFC data catalogue on longline statistics (annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data) for blue shark.

		FISHERY		ANNUAL CATCH ESTIMATES			AGGREGATE DATA			OPERATIONAL DATA			LENGTH DATA		
GEAR	FLAG	FROM	TO	FROM	TO	AVG. CATCH	FROM	TO	CATCH RECS	FROM	TO	CATCH RECS	FROM	TO	SAMPLES
L	AU	1985	2016	1991	2016	346	1991	2016	2,536	1991	2016	40,163	1981	2015	4,197
L	BZ	1995	2013	2010	2013	4	2010	2013	24						
L	CK	1994	2016	2002	2016	21	2002	2016	345	2002	2016	3,186	1995	2015	11
L	CN	1988	2016	2008	2016	444	2008	2016	2,516				1993	2016	5,192
L	ES	2004	2016	2004	2016	1,401	2004	2016	1,353	2004	2016	16,660	2009	2011	1,195
L	FJ	1989	2016	2006	2016	247	2006	2016	522	2006	2016	4,303	1995	2016	3,836
L	FM	1991	2016	2009	2016	218	2012	2016	386	2012	2016	3,209	1994	2016	1,130
L	ID	1978	2016		2016	0									
L	JP	1960	2016	1994	2016	13,315	1994	2016	11,013				1979	2016	60,441
L	KI	1995	2016	2010	2016	17	2012	2016	45	2012	2016	104	2008	2015	9
L	KR	1960	2016	2010	2016	98	2010	2016	1,349				1991	2016	1,631
L	MH	1992	2016	2009	2016	18	2015	2016	63	2015	2016	460	2008	2008	41
L	NC	1983	2016	1996	2016	33	1996	2016	95	1996	2016	734	1996	2016	756
L	NR	2000	2004			0									
L	NU	2005	2010			0									
L	NZ	1987	2016	1989	2016	599	1989	2016	1,707	1989	2016	44,544	1994	2015	15,204
L	PF	1990	2016	2009	2016	111	2014	2016	286	2014	2016	6,254	1997	2016	523
L	PG	1993	2016	1998	2016	18	1998	2015	111	1998	2015	985	1996	2014	844
L	PH	1970	2014	2013	2014	0									
L	PT	2011	2016	2011	2016	204	2014	2015	7						
L	PW	1992	2004			0							2000	2000	12
L	SB	1973	2015	2010	2016	24	2010	2016	93	2013	2016	56	1996	2013	465
L	SN	2005	2007	2006	2007	116	2006	2007	65						
L	TO	1982	2016	2002	2016	8	2007	2016	18	2002	2016	92	1995	2016	740
L	TV	2011	2016		2016	0									
L	TW	1960	2016	1997	2016	4,924	1997	2016	3,995				1993	2016	11,131
L	US-AS	1988	2016	1996	2016	209	1996	2016	1,055	2012	2015	76	2002	2002	2
L	US-GU	2015	2016		2016	0									
L	US-HW	1960	2016	1990	2016	2,485	1990	2016	4,373						
L	US-MC	1991	2000		2014	0							2003	2014	5
L	US-MP	2013	2016	2013	2016	46	2013	2013	13						
L	VN	2000	2016		2016	0									
L	VU	1995	2016	2009	2016	1,120	2009	2016	1,136	2009	2016	9,453	2009	2016	491
L	WF	2011	2011			0									
L	WS	1993	2016	2007	2016	20	2007	2016	134	2007	2016	887	1998	2016	16

Table III.13. WCPFC data catalogue on longline statistics (annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data) for mako sharks.

		FISHERY		ANNUAL CATCH ESTIMATES			AGGREGATE DATA			OPERATIONAL DATA			LENGTH DATA		
GEAR	FLAG	FROM	TO	FROM	TO	AVG. CATCH	FROM	TO	CATCH RECS	FROM	TO	CATCH RECS	FROM	TO	SAMPLES
L	AU	1985	2016	1981	2016	55	1986	2016	2,623	1986	2016	32,681	1981	2015	5,294
L	BZ	1995	2013	2004	2013	0	2004	2013	27						
L	CK	1994	2016	2002	2016	4	2002	2016	418	2002	2016	1,493	2002	2016	101
L	CN	1988	2016	1996	2016	62	2002	2016	2,604				1996	2016	1,465
L	ES	2004	2016	2004	2016	463	2004	2016	889	2004	2016	8,606			
L	FJ	1989	2016	1994	2016	47	1997	2016	1,220	1997	2016	9,742	1994	2016	2,935
L	FM	1991	2016	1996	2016	27	2003	2016	190	2003	2016	827	1996	2016	210
L	ID	1978	2016		2016	0									
L	JP	1960	2016	1985	2016	413	1994	2016	8,933				1985	2016	9,206
L	KI	1995	2016	2008	2016	1				2016	2016	1	2008	2016	28
L	KR	1960	2016	1991	2016	2	2010	2016	389				1991	2016	693
L	MH	1992	2016	2004	2016	1	2004	2016	43	2004	2016	131	2008	2008	12
L	NC	1983	2016	1992	2016	22	1998	2016	404	1998	2016	2,226	1992	2016	717
L	NR	2000	2004			0									
L	NU	2005	2010	2005	2007	0	2005	2007	13	2005	2007	29			
L	NZ	1987	2016	1991	2016	178	1991	2016	1,479	1991	2016	22,452	1992	2015	6,089
L	PF	1990	2016	1993	2016	36	1993	2016	1,359	1993	2016	6,175	1997	2016	812
L	PG	1993	2016	1996	2016	25	1997	2015	14	1997	2015	33	1996	2014	787
L	PH	1970	2014		2014	0									
L	PT	2011	2016	2011	2016	110	2014	2015	7						
L	PW	1992	2004	2000	2000	0							2000	2000	5
L	SB	1973	2015	1997	2015	1	2015	2015	2	2015	2015	2	1997	2013	535
L	SN	2005	2007	2006	2007	50	2006	2007	67						
L	TO	1982	2016	1995	2016	7	2002	2016	225	2002	2016	1,147	1995	2016	692
L	TV	2011	2016	2016	2016	0							2016	2016	10
L	TW	1960	2016	1993	2016	349	1995	2016	3,083				1993	2016	4,433
L	US-AS	1988	2016	1996	2016	17	1996	2016	860	2003	2012	31	2002	2014	733
L	US-GU	2015	2016		2016	0									
L	US-HW	1960	2016	1990	2016	131	1990	2016	3,609				1994	2016	24,633
L	US-MC	1991	2000	2014	2014	0							2014	2014	2
L	US-MP	2013	2016	2013	2016	4	2013	2013	13						
L	VN	2000	2016		2016	0									
L	VU	1995	2016	2002	2016	328	2002	2016	1,303	2002	2016	6,572	2009	2016	512
L	WF	2011	2011			0									
L	WS	1993	2016	1998	2016	8	1998	2016	61	1998	2016	153	2000	2016	12

Table III.14. WCPFC data catalogue on longline statistics (annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data) for porbeagle.

GEAR	FLAG	FISHERY		ANNUAL CATCH ESTIMATES			AGGREGATE DATA			OPERATIONAL DATA			LENGTH DATA		
		FROM	TO	FROM	TO	AVG. CATCH	FROM	TO	CATCH RECS	FROM	TO	CATCH RECS	FROM	TO	SAMPLES
L	AU	1985	2016	1990	2016	9	1991	2016	339	1991	2016	4,261	1990	2014	83
L	BZ	1995	2013		2013	0									
L	CK	1994	2016	2015	2016	0	2015	2016	7	2015	2016	9			
L	CN	1988	2016	2016	2016	1	2015	2016	21						
L	ES	2004	2016	2004	2016	264	2004	2013	786	2004	2013	8,057			
L	FJ	1989	2016	2012	2016	2	2012	2016	104	2012	2016	359			
L	FM	1991	2016	2014	2016	2	2015	2016	56	2014	2016	180			
L	ID	1978	2016		2016	0									
L	JP	1960	2016	1988	2016	588	1994	2016	3,308				1988	2015	18,697
L	KI	1995	2016	2016	2016	0	2016	2016	3	2016	2016	4			
L	KR	1960	2016	1991	2016	4	2010	2014	351				1991	1991	5
L	MH	1992	2016	2016	2016	2	2016	2016	24	2016	2016	84			
L	NC	1983	2016	2015	2016	0	2015	2016	3	2015	2016	3			
L	NR	2000	2004			0									
L	NU	2005	2010			0									
L	NZ	1987	2016	1992	2016	67	1993	2016	777	1993	2016	9,714	1992	2015	6,225
L	PF	1990	2016		2016	0									
L	PG	1993	2016	2015	2016	0	2015	2015	1	2015	2015	1			
L	PH	1970	2014		2014	0									
L	PT	2011	2016		2016	0									
L	PW	1992	2004			0									
L	SB	1973	2015	2013	2015	0									
L	SN	2005	2007			0									
L	TO	1982	2016		2016	0									
L	TV	2011	2016		2016	0									
L	TW	1960	2016		2016	0									
L	US-AS	1988	2016		2016	0									
L	US-GU	2015	2016		2016	0									
L	US-HW	1960	2016		2016	0									
L	US-MC	1991	2000			0									
L	US-MP	2013	2016		2016	0									
L	VN	2000	2016		2016	0									
L	VU	1995	2016		2016	0									
L	WF	2011	2011			0									
L	WS	1993	2016	2016	2016	0	2016	2016	1	2016	2016	1			

Table III.15. WCPFC data catalogue on longline statistics (annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data) for oceanic whitetip.

GEAR	FLAG	FISHERY		ANNUAL CATCH ESTIMATES			AGGREGATE DATA			OPERATIONAL DATA			LENGTH DATA		
		FROM	TO	FROM	TO	AVG. CATCH	FROM	TO	CATCH RECS	FROM	TO	CATCH RECS	FROM	TO	SAMPLES
L	AU	1985	2016	1989	2016	16	1997	2016	1,464	1997	2016	7,421	1989	2015	622
L	BZ	1995	2013		2013	0									
L	CK	1994	2016	1996	2016	2	2011	2016	192	2011	2016	940	1996	2015	105
L	CN	1988	2016	1993	2016	27	2009	2016	636				1993	2016	3,169
L	ES	2004	2016	2007	2016	1	2007	2008	4	2007	2008	17			
L	FJ	1989	2016	1994	2016	15	2011	2016	129	2011	2016	725	1994	2016	2,473
L	FM	1991	2016	1996	2016	36	2012	2016	124	2012	2016	475	1996	2016	334
L	ID	1978	2016	2013	2016	0									
L	JP	1960	2016	1987	2016	19	2008	2012	927				1987	2016	839
L	KI	1995	2016	2008	2016	5	2016	2016	4	2016	2016	8	2008	2015	10
L	KR	1960	2016	1992	2016	1	2010	2016	210				1992	2016	1,271
L	MH	1992	2016	2008	2016	6	2016	2016	15	2016	2016	21	2008	2009	17
L	NC	1983	2016	1992	2016	1	2010	2016	34	2010	2016	66	1992	2016	248
L	NR	2000	2004			0									
L	NU	2005	2010			0									
L	NZ	1987	2016	1996	2016	1	2001	2015	13	2001	2015	69	1996	2010	26
L	PF	1990	2016	1997	2016	24	2014	2016	257	2014	2016	4,706	1997	2016	997
L	PG	1993	2016	1999	2016	11	2013	2015	35	2013	2015	102	1999	2014	5,246
L	PH	1970	2014		2014	0									
L	PT	2011	2016		2016	0									
L	PW	1992	2004	2000	2000	0							2000	2000	1
L	SB	1973	2015	1996	2015	3	2010	2014	15				1996	2013	1,207
L	SN	2005	2007			0									
L	TO	1982	2016	1995	2016	4	2007	2016	11	2007	2016	44	1995	2016	1,084
L	TV	2011	2016	2011	2016	0	2011	2012	2	2011	2012	2	2016	2016	11
L	TW	1960	2016	1993	2016	22	2008	2012	1,198				1993	2016	5,391
L	US-AS	1988	2016	2001	2016	44	2001	2016	743				2002	2016	974
L	US-GU	2015	2016		2016	0									
L	US-HW	1960	2016	1994	2016	34	2000	2016	1,518				1994	2016	9,067
L	US-MC	1991	2000			0									
L	US-MP	2013	2016	2013	2016	0	2013	2013	5						
L	VN	2000	2016		2016	0									
L	VU	1995	2016	2009	2016	296	2012	2014	8	2012	2014	21	2009	2016	356
L	WF	2011	2011			0									
L	WS	1993	2016	1998	2016	0	2007	2016	67	2007	2016	167	1998	2016	34

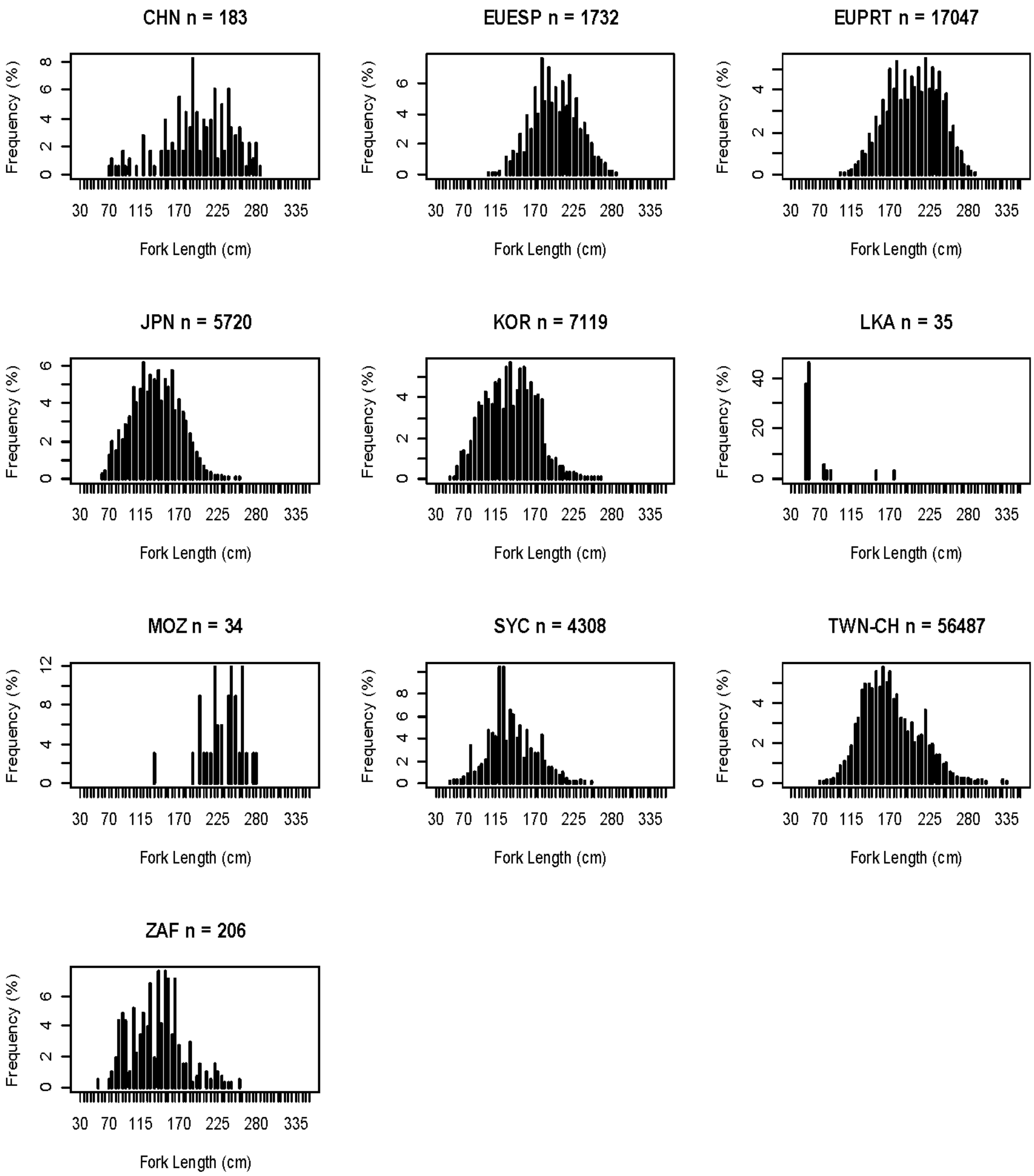
Table III.16. WCPFC data catalogue on longline statistics (annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data) for silky shark.

		FISHERY		ANNUAL CATCH ESTIMATES			AGGREGATE DATA			OPERATIONAL DATA			LENGTH DATA		
GEAR	FLAG	FROM	TO	FROM	TO	AVG. CATCH	FROM	TO	CATCH RECS	FROM	TO	CATCH RECS	FROM	TO	SAMPLES
L	AU	1985	2016	2001	2016	2	2001	2016	218	2001	2016	558	2001	2015	386
L	BZ	1995	2013		2013	0									
L	CK	1994	2016	2007	2016	9	2012	2016	136	2012	2016	601	2007	2016	328
L	CN	1988	2016	1995	2016	5	2015	2016	375				1995	2016	9,578
L	ES	2004	2016	2005	2016	2	2005	2013	78	2005	2013	219			
L	FJ	1989	2016	1995	2016	42	2011	2016	168	2011	2016	678	1995	2016	3,838
L	FM	1991	2016	1995	2016	62	2014	2016	200	2014	2016	1,418	1995	2016	1,738
L	ID	1978	2016		2016	0									
L	JP	1960	2016	1995	2016	3							1979	2016	715
L	KI	1995	2016	2008	2016	1	2016	2016	4	2016	2016	9	2008	2015	8
L	KR	1960	2016	1998	2016	10	2012	2016	285				1998	2016	6,330
L	MH	1992	2016	2008	2016	5	2015	2016	28	2015	2016	101	2008	2014	82
L	NC	1983	2016	1996	2016	3	2010	2016	60	2010	2016	211	1996	2016	476
L	NR	2000	2004			0									
L	NU	2005	2010			0									
L	NZ	1987	2016	2004	2016	0	2014	2015	7	2014	2015	68	2004	2007	3
L	PF	1990	2016	1997	2016	7	2014	2016	160	2014	2016	813	1997	2016	502
L	PG	1993	2016	1996	2016	104	2013	2014	44	2013	2014	837	1996	2014	175,658
L	PH	1970	2014	2013	2014	0									
L	PT	2011	2016		2016	0									
L	PW	1992	2004	2000	2000	0							2000	2000	3
L	SB	1973	2015	1996	2015	19	2010	2015	54	2014	2015	14	1996	2013	2,096
L	SN	2005	2007			0									
L	TO	1982	2016	1998	2016	3	2014	2016	15	2014	2016	37	1998	2016	394
L	TV	2011	2016	2016	2016	0							2016	2016	42
L	TW	1960	2016	1995	2016	190	2008	2014	2,731				1995	2016	30,643
L	US-AS	1988	2016	2002	2016	8	2002	2016	276				2002	2016	2,927
L	US-GU	2015	2016		2016	0									
L	US-HW	1960	2016	1994	2016	6	2000	2016	286				1994	2016	5,939
L	US-MC	1991	2000			0									
L	US-MP	2013	2016	2013	2016	0	2013	2013	1						
L	VN	2000	2016		2016	0									
L	VU	1995	2016	2009	2016	413	2011	2016	148	2011	2016	1,574	2009	2016	2,697
L	WF	2011	2011			0									
L	WS	1993	2016	1998	2016	12	1998	2016	61	1998	2016	161	2000	2015	14

Table III.17. WCPFC data catalogue on longline statistics (annual catch estimates, aggregated catch and effort data, operational catch and effort data and aggregated size data) for silky shark.

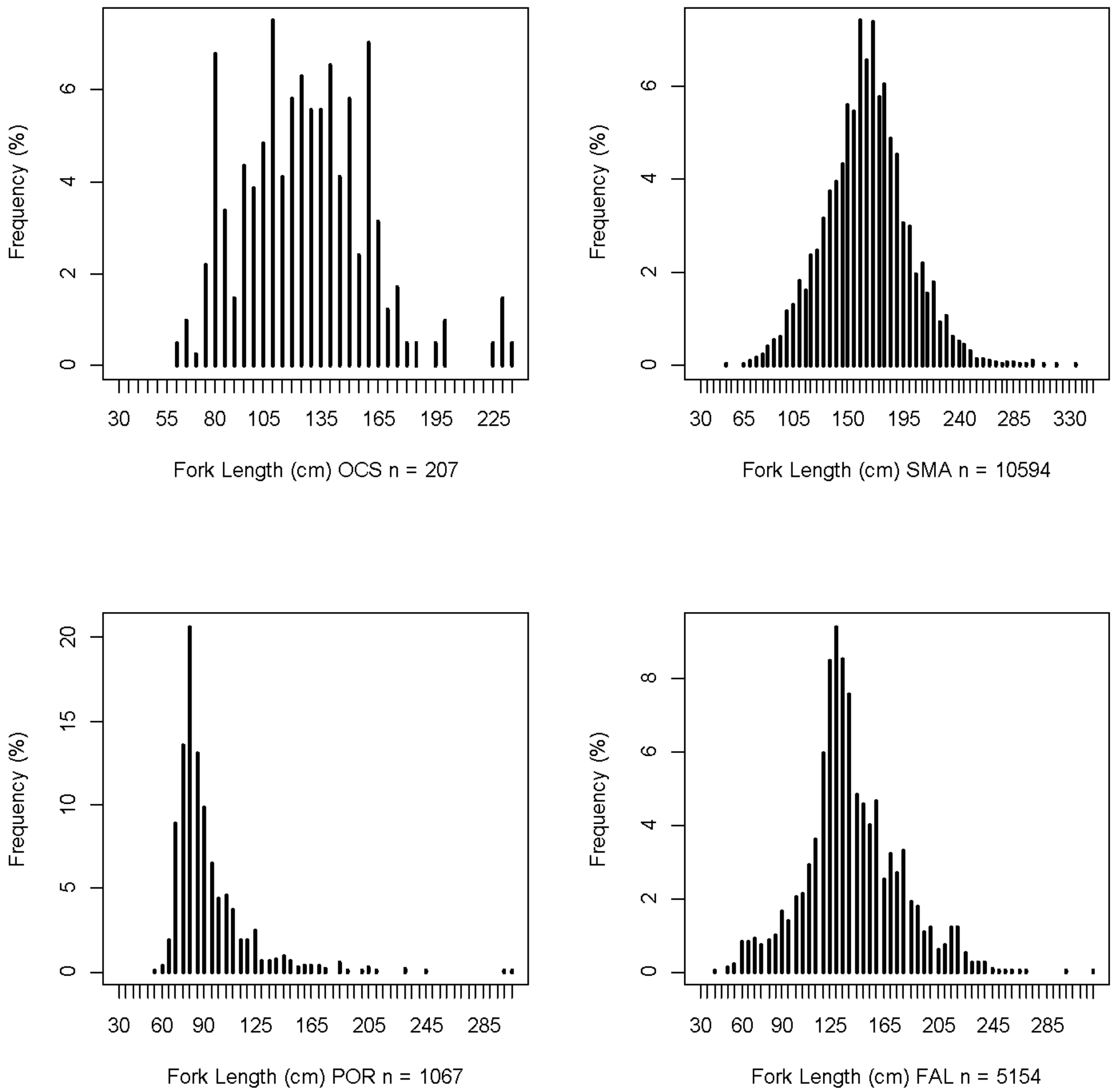
		FISHERY		ANNUAL CATCH ESTIMATES			AGGREGATE DATA			OPERATIONAL DATA			LENGTH DATA		
GEAR	FLAG	FROM	TO	FROM	TO	AVG. CATCH	FROM	TO	CATCH RECS	FROM	TO	CATCH RECS	FROM	TO	SAMPLES
L	AU	1985	2016	1988	2016	15	2007	2016	430	1996	2016	2,403	1988	2015	662
L	BZ	1995	2013		2013	0									
L	CK	1994	2016	1995	2016	0	2011	2016	57	2011	2016	111	1995	2016	17
L	CN	1988	2016	1993	2016	3	2015	2016	155				1993	2016	6,805
L	ES	2004	2016	2006	2016	1	2006	2008	25	2006	2009	76			
L	FJ	1989	2016	1995	2016	1	2002	2016	59	2002	2016	161	1995	2016	485
L	FM	1991	2016	1994	2016	10	2013	2016	45	2013	2016	90	1994	2016	1,082
L	ID	1978	2016		2016	0									
L	JP	1960	2016	1988	2016	47	2008	2016	1,376				1988	2016	2,200
L	KI	1995	2016	2008	2016	0	2014	2016	5	2014	2016	16	2008	2016	14
L	KR	1960	2016	1991	2016	18	2010	2016	966				1991	2016	759
L	MH	1992	2016	2008	2016	0							2008	2008	32
L	NC	1983	2016	1996	2016	0	2010	2016	33	2010	2016	64	1996	2016	150
L	NR	2000	2004			0									
L	NU	2005	2010			0									
L	NZ	1987	2016	1991	2016	25	2007	2015	149	1991	2015	2,555	1992	2015	494
L	PF	1990	2016	1993	2016	2				2014	2016	530	1993	2016	208
L	PG	1993	2016	1997	2016	0	1997	2014	2	1997	2014	2	1999	2014	1,465
L	PH	1970	2014		2014	0									
L	PT	2011	2016		2016	0									
L	PW	1992	2004			0									
L	SB	1973	2015	1997	2015	0	2015	2015	1	2015	2015	7	1997	2012	224
L	SN	2005	2007			0									
L	TO	1982	2016	1995	2016	0	2014	2016	4	2014	2016	5	1995	2014	113
L	TV	2011	2016	2016	2016	0							2016	2016	6
L	TW	1960	2016	1993	2016	221	2008	2016	1,465				1993	2016	1,628
L	US-AS	1988	2016	1997	2016	46	1997	2016	805				2002	2016	445
L	US-GU	2015	2016		2016	0									
L	US-HW	1960	2016	1990	2016	340	1990	2016	3,256				1994	2016	32,707
L	US-MC	1991	2000			0									
L	US-MP	2013	2016	2013	2016	6	2013	2013	12						
L	VN	2000	2016		2016	0									
L	VU	1995	2016	2009	2016	69	2013	2013	1	2013	2013	2	2009	2016	94
L	WF	2011	2011			0									
L	WS	1993	2016	1998	2016	26	1998	2016	110	1998	2016	591	2001	2015	7

Figure III.15. IOTC fork length frequency distributions (%) of blue shark derived from the samples reported for the longline fleets of China (CHN), Spain (EUESP), Portugal (EUPRT), Japan (JPN), Korea (KOR), Sri Lanka (LKA), Mozambique (MOZ) Seychelles (SYC), Taiwan.China (TWN-CHN) and South Africa (ZAF) between 2005 and 2015 in 5 cm length classes (Source: IOTC, 2017[47]).



[47] IOTC. 2017. Review of the statistical data available for bycatch species. IOTC–2017–WPEB13–07: 43 pp.

Figure III.16. IOTC fork length frequency distributions (%) for oceanic whitetip shark (OCS), shortfin mako shark (SMA), porbeagle shark (POR) and silky shark (FAL) between 2005 and 2015. Size frequency data is aggregated across all fleets and all years given the more limited amount of data available for these species (Source: IOTC, 2017[36]).



4. Biological tables

Table III.17. Biological parameters for pelagic thresher (PTH, *Alopias pelagicus*)

Alopias pelagicus *Nakamura, 1935* *Pelagic thresher* *FAO code: PTH*	Atlantic Ocean	Ref.	Mediter-ranean Sea	Ref.	Indian Ocean	Ref.	West Pacific	Ref.	East Pacific	Ref.
AGE & GROWTH										
L∞ for female in cm					L∞=362 TL	10	L∞=197 PCL	4		
K for female /year					k=0.13	10	k=0.09	4		
to for female in years						10	t_0=-7.67	4		
L∞ for male in cm					L∞=336 TL	10	L∞=182 PCL	4		
K for male /year					k=0.10	10	k=0.12	4		
to for male in years					Lo=151	10	t_0=-5.48	4		
Longevity in years					25-30 estim. 20-24 obs. male 24-28 obs. female	1-10	20 estim. male 29 estim. female 14 obs. male 16 obs. female	3-4	20 estim. male 29 estim. female	3
Maximum size TL in cm					365 383	1-24 3-5	383	3-4-5	383	3-5
Common size (FL) in cm					120 - 190	1				
Maximum weight in kg										
REPRODUCTION										
Female maturity size in cm					282-292 TL 145-150 SL 280-290 TL	3 24 25	282-292 TL	4	282-292 TL 151 PCL	3-8
Female maturity age in years					8-9 13 8-9 (50%)	1 10 24	8-9	4		
Male maturity size in cm					267-276 TL 220-270 TL 140-145 SL 240-275 TL	3 23 24 25	267-276 TL	4	267-276 TL 144 PCL	3 8
Male maturity age in years					7-8 10 7-8 (50%)	1 10 24	7-8	4		

Birth size TL in cm					130-160 TL up to 190 TL 158-190 TL 130-140 TL	3 24 25	130-160 TL up to 190 TL 158-190 TL 136-142 TL	3 4 8	130-160 TL up to 190 TL	3
Sex ratio					1/1	3	1/1	4	1/1	3
Mode of development					Ovoviviparous	1-2-3	Ovoviviparous	2-3	Ovoviviparous	2-3
Gestation period in months					<12	24			9	8
Spawning & mating periods										
Fecundity: number of embryos per litter					2-4 2 2	1 3 24	2	4	2	3 - 8
Nursery ground										
CONVERSION FACTORS										
Length / Weight relationships					$TW=0.001*10^{-4}*FL^{2.15243}$ for males & females	1-24	$W=4.61*10^{-5}*TL^{2.494}$ female $W=3.98*10^{-5}*TL^{2.52}$ males $W+2.5610^{-4}*PCL^{2.511}$ (Lui unpub.)	4-6		
Wet weight / dressed weight ratio										
TL / FL					TL=2*TL	5	TL=2*TL	5	TL=2*TL	5
TL/PCL										
Fins / carcass ratios										
Stables isotopes N^{15} & C^{14}										
POPULATION DYNAMICS										
Stock delineation/range							evidence of separation between East s & West Pac.	19-21	evidence of separation between East s & West Pac.	19-21
Natural mortality							0.151 0.132	15 16		
Stepness										

Intrinsic rate of increase (λ or r) ($year^{-1}$)							r=0.041 λ=1.049 λ=1.056-1.066 r=0.055-0.064	15 17 20		
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level										

References

1 – IOTC. 2015. Status of the Indian Ocean pelagic thresher shark (PTH: *Alopias pelagicus*). IOTC 18th Scientific Committe, 23-27 November 2015, Bali, Indonesia. IOTC document IOTC–2015–SC18–ES23: 6 pp.

2- Reardon, M., Márquez, F., Trejo, T., Clarke S.C. 2009. *Alopias pelagicus*. In IUCN Red List of Threatened Species. http://www.iucnredlist.org/.

3 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Volume 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Species Catalogue for Fishery Purposes. No 1. Vol. 2. FAO, Rome (Italy). 269 pp.

4 – Liu, K.-M., Chen, C.-T., Liao, T.-H., Joung, S.-J. 1999. Age, growth, and reproduction of the pelagic thresher shark, *Alopias pelagicus* in the Northwestern Pacific. Copeia, 1999, 68-74.

5 – Fishbase. 2017. *Alopias pelagicus*. http://www.fishbase.org/summary/Alopias-pelagicus.html.

6 – Tsai, W-P., Liu, K-M., Joung, S-J. 2010. Demographic analysis of the pelagic thresher shark, *Alopias pelagicus*, in the north-western Pacific using a stochastic stage-based model. *Mar. & Freshw. Res.*, 59: 575-586.

7 – Carpenter, K.E., Niem, V.H. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome. 716 pp.

8 - Romero-Caicedo, A.F., Galván-Magaña, F., Martínez-Ortiz, J., 2014. Reproduction of the pelagic thresher shark *Alopias pelagicus* in the equatorial Pacific. *J. Mar. Biol. Assoc. UK*, 94(7): 1501–1507.

9 – Cadwallader, H.F., Turner, J.R. Oliver, S.P. 2015. Cleaner wrasse forage on ectoparasitic digeneans (phylum Platyhelminthes) that infect pelagic thresher sharks (*Alopias pelagicus*). *Mar. Biodiv.*, 45: 613-614.

10 – Drew, M., White, W.T., Dharmadi, Harry, A.V., Huveneers, C. 2015. Age, growth and maturity of the pelagic thresher *Alopias pelagicus* and the scalloped hammerhead *Sphyrna lewini*. *J. Fish Biol.*, 86: 333-354.

11 – Varghese, S.P., Somvanshi, V.S., Dalvi, R.S. 2014. Diet composition, feeding niche partitioning and trophic organisation of large pelagic predatory fishes in the eastern Arabian Sea. *Hydrobiol.*, 736: 99-114.

12 - Polo-Silva, C., Newsome, S., Galván-Magaña, F., Grijalba-Bendeck, M., Sanjuan-Muñoz, A. 2013. Trophic shift in the diet of the pelagic thresher shark based on stomach contents and stable isotope analyses. *Mar. Biol. Res.*, 9(10): 958-971.

13 - Galván-Magaña, F., Polo-Silva, C., Hernández-Aguilar, S.B., Sandoval-Londoño, A., Ochoa-Díaz, M.R., Aguilar-Castro, N., Castañeda-Suárez, D., Chavez-Costa, A.C., Baigorrí-Santacruz, Á., Torres-Rojas, Y.E., Abitia-Cárdenas, L. 2013. Shark predation on cephalopods in the Mexican and Ecuadorian Pacific Ocean. *Deep-Sea Res. II*, 95: 52-62.

14 – Kiszka, J.J., Aubail, A., Hussey, N.E., Heithaus, M.R., Caurant, F., Bustamante, P. 2015. Plasticity of trophic interactions among sharks from the oceanic south-western Indian Ocean revealed by stable isotope and mercury analyses. *Deep-Sea Res. I*, 96: 49-58.

15 – Chen P., Yuan W., 2006. Demographic analysis based on the growth parameter of sharks. *Fish. Res.*, 78: 374-379.

16 – Liu, K.-M., Chang, Y.-T., Ni, I.-H., Jin C.-B. 2004. Spawning per recruit analysis of the pelagic thresher shark, *Alopias pelagicus*, in the eastern Taiwan waters. *Fish. Res.*, 82: 56-64.

17 – Liu, K.-M., Chin, C.-P., Chen, C.-H., Chang J.-H. 2015. Estimating Finite Rate of Population Increase for Sharks Based on Vital Parameters. PLoS ONE 10(11): e0143008.

18 - Polo-Silva, C., Redón, L., Galván-Maganã, F. 2009. Descripción de la dieta de los tiburones zorro (*Alopias pelagicus*) y (*Alopias superciliosus*) durante la época lluviosa en aguas ecuatorianas. *Pan-Am. J. Aquatic Sci.*, 4(4): 556-571.

19 – Trejo, T. 2005. Global phylogeography of thresher sharks (*Alopias* spp.) inferred from mitochondrial DNA control region sequences: a thesis. *Capstone Projects and Theses*, Paper 90: 91 p.

20 – Mollet, H.F., Caillet, G.M. 2002. Comparative population demography of elasmobranchs using life history tables, Leslie matrices and stage-based matrix models. *Mar. & Freshw. Res.*, 53: 503-516.

21 – Cardeñosa, D., Hyde, J., Caballero, S. 2014. Genetic Diversity and Population Structure of the Pelagic Thresher Shark (*Alopias pelagicus*) in the Pacific Ocean: evidence for two evolutionarily significant units. PLoS ONE 9(10):e110193.

22 – Weigmann, S. 2016. Annotated checklist of the living sharks, batoids and chimaeras (Chondrichthyes) of the world, with a focus on biogeographical diversity. *J. Fish Biol.*, 88:837-1037.

23 - Dharmadi, Fahmi, Wiadnyana, N. 2013. Biological aspects and catch fluctuation of the Pelagic Thresher Shark, *Alopias pelagicus* from the Indian Ocean. Proceedings of the Design Symposium on Conservation of Ecosystem, the 12th SEASTAR2000 workshop, 2013: 77-85.

24 – IOTC. 2012. Résumé exécutif: Requin-renard pélagique (*Alopias pelagicus*) dans l'Océan Indien.15th Scientific Committee, 10-15 December 2015, Victoria, Seychelles. IOTC document IOTC-2012-SC15-32(F): 6 pp.

25 – IOTC. 2016. Requin-renard pélagique: informations complémentaires. IOTC, groupe de travail sur les écosystèmes et prises accessoires. Mise à jour, décembre 2016, 5 pp.

Table III.18. Biological parameters for bigeye thresher (BTH, *Alopias superciliosus*).

Alopias superciliosus (Lowe, 1839**)** Bigeye thresher FAO code: BTH	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L_{∞} for female in cm	L_{∞} =284	23					L_{∞}= 224.6	9		
K for female /year	k=0.06	23					k=0.09	9		
to for female in years	L_0=109	23					t_0= -4.21	9		
L_{∞} for male in cm	L_{∞}=246	23					L_{∞}= 218.8	9		
K for male /year	k=0.09	23					k=0.088	9		
to for male in years	L_0=108 cm	23					t_0= -4.24	9		
Longevity in years	observed: 20- 25	2 24	observed: 20	2	observed: 20	2	observed.: 19 (male) observed.: 20 (fem.) estimated: 20-21		observed: 20	2
Maximum size TL in cm	488 461 460.7	2-3 12 15- 16	488 461 460.7	2- 3 12 15 - 16	488 461 460.7 461	2- 3 12 15 - 16 23	488 461 460.7	2- 3 12 15 - 16	488 461 460.7	2- 3 12 15 - 16
Common size (FL) in cm										
Maximum weight in kg	363.8	2-3	363.8	2- 3	363.8	2- 3	363.8	2- 3	363.8	2- 3
REPRODUCTION										
Female maturity size in cm	294-355 350 206.9 FL 208.6 FL	8 13 14 25	294-355	8	332-355 294-355 310 TL	1- 23 8 25	294-355 332-341.1	8 10	294-355	8
Female maturity age in years	12-13	8	12-13	8	12-13	8- 23	12-13 12.3-13.4	8 10	12-13	8
Male maturity size in cm	279-300 290-300 159.74 FL 276 159.2	8 13 14 15 25	279-300	8	270-300 279-300 263 TL	1 8 25	279-300 270.1-287.6 TL	8 10	279-300	8
Male maturity age in years	9-10	8	9-10	8	9-10	8- 23	9-10 9-10	8 10	9-10	8
Birth size TL in cm	64-106 100-140 100-130 64-105	6 8 12 15 - 17 - 18	64-106 100-140 100-130 64-105	6 8 12 15 - 17 - 18	64-140 64-106 100-140 100-130 64-105 118-135 TL	1- 23 6 8 12 15 - 17 -	64-106 100-140 135-140 100-130 64-105	6 8 10 12 15 - 17 - 18	64-106 100-140 100-130 64-105	6 8 12 15 - 17 - 18

						18 25				
Sex ratio	1:1 1.52:1	8 14	1:1	8	1:1	8	1:1	8-10	1:1	8
Mode of development	Ovoviviparous	8-18	Ovoviviparous	8-18	Ovoviviparous	8-18 - 23	0voviviparous	8-18	Ovoviviparous	8-18
Gestation period in months	12	8-18	12	8	12	1- 8- 23	12	8	12	8
Spawning & mating periods										
Fecundity: number of embryos per litter	2-4 2 2-4	6 15 - 19 15	2-4	6-15	2 2-4	1- 26 6- 23	2-4 2	6 10	2-4	6
Nursery ground	Strait of Gibraltar	8								
CONVERSION FACTORS										
Length / Weight relationships	W=9.1069*10^{-6}*TL$^{3.0802}$ W=1.02*10^{-5}*TL$^{2.78}$ (females) W=3.73*10^{-5}*TL$^{2.57}$ (males) W=0.1825*10^{-5}*TL$^{3.448534}$	7- 8 8 20 - 19	W=1.02*10^{-5}*TL$^{2.78}$ (females) W=3.73*10^{-5}*TL$^{2.57}$ (males)	8	PT=0.155*10^{-4}*FL$^{2.97883}$ W=1.02*10^{-5}*TL$^{2.78}$ (females) W=3.73*10^{-5}*TL$^{2.57}$ (males)	1- 23 8	W=1.02*10^{-5}*TL$^{2.78}$ (females) W=3.73*10^{-5}*TL$^{L2.57}$ (males)	8	W=1.02*10^{-5}*TL$^{2.78}$ (females) W=3.73*10^{-5}*TL$^{2.57}$ (males)	8
Wet weight / dressed weight ratio										
TL / FL	LF=0.5598*TL+17.666 TL=1.775*FL-13.007	7- 8 11	LF=0.5598*TL+17.666	8	LF=0.5598*TL+17.666	8	TL=13.3.1.69*FL (females) TL=26.3+1.56*FL (males) LF=0.5598*TL+17.666	9 8	LF=0.5598*TL+17.666	8
TL/PCL							TL=15.3+1.81*PCL (females) TL=15.1+1.76*PCL (males)	9		
Fins / carcass ratios										
Stables isotopes N^{15} & C^{14}										
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) (year^{-}										

[1])										
Intrinsic rebound potential ($r_{z(MSY)}$)					0.002-0.009	23				
Trophic level	4.2	5	4.2	5	4.2	5	4.2	5	4.2	5

References

1 - IOTC, 2011. Etat de la ressource du requin-renard à gros yeux (*Alopias superciliosus*). 14th Scientific Committee, 12-17 December 2011, Victoria, Seychelles. IOTC document IOTC-2011-SC14-31.

2 - Fishbase. 2017. *Alopias supercilosus*. https://www.fishbase.de/summary/Alopias-superciliosus

3 – IGFA. 2001. Database of IGFA. Angling records until 2001. Fort Lauderdale: IGFA.

4 – Bowman, R., Stillwell, C., Michaels, W., Grosslein, M. 2000. Food of northwest Atlantic fishes and two common species of squid. *NOAA Tech. Memo. NMFS-NE,* 155: 138 Pp.

5 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci*., 56: 707-717.

6 – Compagno, L., 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1 - Hexanchiformes to Lamniformes. *FAO Fish. Synop.* 125(4/1): 1-249. Rome, FAO.

7 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

8 – Compagno, L., 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Volume 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Species Catalogue for Fishery Purposes. No 1. Vol. 2. Rome, FAO. 269 p.

9 – Liu, K.-M., Chiang, P.-J., Chen, C.-T. 1998. Age and growth estimates of the bigeye thresher shark, *Alopias superciliosus*, in northeastern Taiwan waters. *Fish. Bull.,* 96(3): 482-491.

10 – Chen, C.-T., Liu, K.-M. Chang, Y.-C. 1997 Reproductive biology of the bigeye thresher shark, *Alopias superciliosus* (Lowe, 1839) (Chondrichthyes: *Alopiidae*), in the northwestern Pacific*. Ichthyol. Res.*, 44(3): 227-235.

11 – Buencuerpo, V., Rios, S., Moron, J. 1998. Pelagic sharks associated with the swordfish, *Xiphias gladius*, fishery in the eastern North Atlantic Ocean and the strait of Gibraltar. *Fish. Bull.*, 96: 667–685.

12 – Gruber, S., Compagno, L. 1981. Taxonomic status and biology of the bigeye thresher, *Alopias superciliosus*. *Fish. Bull.,* 79: 617–640.

13 – Stillwell, C., Casey, J. 1976. Observations on the bigeye thresher shark, *Alopias superciliosus,* in the western North Atlantic. *Fish. Bull.,* 74: 221-225.

14 – Carvalho, J., Coelho, R., Amorim, S., Santos, M. N. 2011. Maturity of the Bigeye Thresher shark, *Alopias superciliosus*, in the Atlantic Ocean. 2011 Sharks Data Preparatory Meeting, 20-24 June 2011, Madrid, Spain. ICCAT document SCRS/2011/086.

15 – Moreno, J., Morón, J. 1992. Reproductive Biology of the Bigeye Thresher Shark, *Alopias superciliosus* (Lowe, 1839). *Aus. J. Mar. Freshw. Res*., 43: 77-86.

16 – Nakamura, H. 1935. On the two species of the thresher shark from Formosan waters. *Mem. Fac. Sci. Agri. Taihoku Imp. Univ.,* 1-6.

17 – Bigelow, H., Schroeder, W. 1948. Fishes of the western North Atlantic. 1. Lancelets, cyclostomes and sharks. *Mem. Sears Found. Mar. Res.:* 576 p.

18 – Gilmore, R. 1983. Observations on the embryos of the longfin mako, *Isurus paucus,* and the bigeye thresher, *Alopias superciliosus. Copeia*, 1983: 375-382.

19 - Guitart Manday, D. 1975. Las pesquerias pelagico-oceanicas de corto radio de accibn en la regibn Noroccidental de Cuba. *Academia de Ciencias de Cuba Serie Oceanolbgica*, 31: 26 p.

20 – Gruber, S., Compagno, L. 1981. Taxonomic status and biology of the bigeye thresher *Alopias superciliosus. Fish. Bull.*, 79: 617-40.

21 – Suk, S., Smith, S., Raon, D. 2009. Bioaccumulation of mercury in pelagic sharks from the northeast Pacific Ocean. *California COFI Report,* 5: 172-177.

22 – Smith, S., Rasmussen, R., Ramon, D., Cailliet, G. 2008. The biology and ecology of thresher sharks (Alopiidae). 60-68 Pp. In Camhi M., Pikitch E., Babcock E. (eds), Sharks of the open ocean: biology, fisheries and conservation. Blackwell Science.

23 – IOTC. 2014. Résumé exécutif : Requin-renard à gros yeux (*Alopias superciliosus*) dans l'Océan Indien. 17th Scientific Committee, 8-12 December 2014, Victoria, Seychelles. IOTC document IOTC-2014-SC17-ES22(F): 7 pp.

24 - Fernandez-Carvalho, J., Coelho, R., Cortes, E., Domingo, A., Yokawa, K., Liu, K.-L., Garcia-Cortes, B., Forselledo, R., Ohshimo, S., Ramos-Cartelle, A., Tsai, W.-P., Santos, M.N. 2015. Pan-Atlantic distribution patterns and reproductive biology of the bigeey thresher, *Alopias superciliosus*. *Rev. Fish Biol. Fisher.*, 25(3): 551-568.

25 – Verghese, S.P., Unnikrishnan, N., Deepak, K.G., Ayoob, A.E. 2017. Size, sex and reproductive biology of seven pelagic sharks in the esatern Arabian Sea. *J. Mar. Biol. Assoc. UK*, 97(1): 181-1.

Table III.19. Biological parameters for common thresher (ALV, *Alopias vulpinus*).

Alopias vulpinus (Bonnaterre, 1788) Thresher shark FAO code: ALV	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L∞ for female in cm	L∞=275.5 FL	23							L∞=636 L∞=465	3 4
K for female /year	k=0.09	23							k=0.158 k=0.129	3 4
t_o for female in years									t_0=1.021 t_0=-2.88	3 4
L∞ for male in cm	L∞=225.4 FL	23							L∞=492.7 L∞=465	3 4
K for male /year	k=0.17	23							k=0.215 k=0.129	3 4
t_o for male in years									t_0=1.416 t_0=-2.88	3 4
Longevity in years	45-50 estimated males 22 females 24	7 23 23	45-50 estimated	7	45-50 estimated	7	45-50 estimated	7	45-50 estimated 25 females	7 4
Maximum size TL in cm	760 610	1-3-7 3	760 610	1-3-7 3	760 610	1-3-7 3	760 610	1-3-7 3	760 610 573	1-3-7 3 3
Common size (FL) in cm										
Maximum weight in kg	348	1-2	348	1-2	348	1-2	348	1-2	348	1-2
REPRODUCTION										
Female maturity size in cm	226 FL 315-400 260-426.7 426.7 208-224 FL	5 7 9 17 22	315-400 260-426.7	7 9	315-400 260-426.7 260-330	7 9 11-12	315-400 260-426.7 315	7 9 16	315-400 260-426.7 260-315 303 315	7 9 3 4 4-16
Female maturity age in years	3-8 3-9	7 9	3-8 3-9	7 9	3-8 3-9	7 9	3-8 3-9	7 9	3-4 3-8 3-9 5.3	3 7 9 4
Male maturity size in cm	184 FL >152 260-426.7 181-198 FL	5 7 9 22	>252 260-426.7	7 9	>252 260-426.7	7 9	>252 260-426.7	7 9	333 >252 260-426.7 303	3 7 9 4

Male maturity age in years	3-8 3-7	7 9	3-8 3-7	7 9	3-8 3-7	7 9	3-8 3-7	7 9	7 3-8 3-7 4.8	3 7 9 4
Birth size TL in cm	117-150 114-160 100-158	3 7 9	117-150 114-160 100-158	3 7 9	117-150 114-160 100-158 149	3 7 9 11-12	117-150 114-160 100-158	3 7 9	158 estimated 117-150 114-160 100-158	3 3 7 9
Sex ratio										
Mode of development	ovoviviparous	6	ovoviviparous	6	ovoviviparous	6	ovoviviparous	6	ovoviviparous	6
Gestation period in months	9	9	9	9	9	9	9	9	9	9
Spawning & mating periods	Summer / Spring	9			Spring / Summer	10-11-12			Summer / Spring	7-9
Fecundity: number of embryos per litter	3-7	9-22	2-4	6-7	2-4	6-7	2-4	6-7	2-4 up to 6	6-7 7
Nursery ground	Apparently uses inshore nursery areas in temperate waters	7	Apparently uses inshore nursery areas in temperate waters	7	Apparently uses inshore nursery areas in temperate waters	7	Apparently uses inshore nursery areas in temperate waters	7	Apparently uses inshore nursery areas in temperate waters	7
CONVERSION FACTORS										
Length / Weight relationships	$W= 1.8821*10^{-4}*FL^{2.5188}$	5-7	$W= 1.8821*10^{-4}*FL^{2.5188}$ $W= 1.5*10^{-5}LT^{2.70}$	5-7 18	$W= 1.8821*10^{-4}*FL^{2.5188}$	5-7	$W= 1.8821*10^{-4}*FL^{2.5188}$	5-7	$W= 1.8821*10^{-4}*FL^{2.5188}$	5-7
Wet weight / dressed weight ratio										
TL / FL	FL=0.5474*TL+ 7.0262	5-7	FL=0.5474*TL+ 7.0262	5-7	FL=0.5474*TL+ 7.0262	5-7	FL=0.5474*TL+ 7.0262	5-7	FL=0.5474*TL+ 7.0262	5-7
TL/PCL										
Fins / carcass ratios	2.06	20								
Stables isotopes N15 & C14										
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)										
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.2	8	4.2	8	4.2	8	4.2	8	4.2	8

References

1 –Fishbase. 2017. *Alopias vulpinus*. http://www.fishbase.org/summary/Alopias-vulpinus.html

2 – IGFA. 2001. Database of IGFA angling records until 2001. IGFA, Fort Lauderdale, USA.

3 – Cailliet, G., Bedford, D. 1983. The biology of three pelagic sharks from California waters and their emerging fisheries: a review. *California Cooperative Oceanic Fisheries Investigations Reports*, 24: 57-69.

4 – Smith, S., Rasmussen, R., Ramon, D., Cailliet, G. 2008. The biology and ecology of thresher sharks (Alopiidae). 60-68 pp. In Camhi M., Pikitch E., Babcock E. (eds), Sharks of the open ocean: biology, fisheries and conservation. Blackwell Science.

5 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull*. 93: 412-418.

6 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1 - Hexanchiformes to Lamniformes. *FAO Fish. Synop.* 125(4/1):1-249. Rome, FAO.

7 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Volume 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). FAO Species Catalogue for Fishery Purposes. No 1, Vol. 2: 269 pp.

8 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

9 – Goldman, K., Baum, J., Cailliet, G., Cortés, E., Kohin, S., Macías, D., Megalofonou, P., Perez, M., Soldo, A., Trejo, T. 2009. *Alopias vulpinus*. In IUCN, 2011. IUCN Red List of Threatened Species.

10 – Gilmore, R. 1993: Reproductive biology of Lamnoid sharks. *Environ. Biol. Fishes,* 38: 95–114.

11 – Gubanov, Ye. P., 1972. On the biology of thresher shark (*Alopias vulpinus*) in the North-west Indian Ocean. *J. Ichthyol.,* 12: 591- 600.

12 – Gubanov Ye. P., 1978. The reproduction of some species of pelagic sharks from the equatorial zone of the Indian ocean. *J. Ichthyol.,* 18: 781-792.

13 – Suk, S., Smith, S., Raon, D. 2009. Bioaccumulation of mercury in pelagic sharks from the northeast Pacific Ocean. *California COFI Report,* 5: 172-177.

14 – Walker, T. 1988. Mercury concentrations in edible tissues of elasmobranchs, teleosts, crustaceans and mollusks from south-eastern Australian waters. Austr. *J. Mar. Freshwater Res*., 39: 39-49.

15 – Bowman, R., Stillwill, C., Michaels, W., Grosslein, M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dep Commer, *NOAA Tech Memo NMFS NE*, 155: 1- 137.

16 – Strasburg, D. 1958. Distribution, abundance, and habits of pelagic sharks in the central Pacific Ocean. *U.S. Fish. Bull.,* 58: 355- 361.

17 – Bigelow, H., Schroeder, W. 1948. Lancelets, cyclostomes, and sharks. Pp 98-177. In Tee-Van J., Breder C., Hildebrand, S., Parr S. & Schroeder W. (eds) Fishes of the Western North Atlantic, Part 1, *Mem. Sears Found. Mar. Res.*, Yale University, New Haven.

18 - De Metrio, G., Cacucci, M., Deflorio, M., Desnatis, S., Santamaria, N. 2000. Incidenza della pesca ai grandi pelagici sulle catture di squali. *Biol. Mar. Medit.*, 7(1): 334-345.

19 – Megalofonou, P., Yannopoulos, C., Damals, D., De metrio, G., Delflorio, M., De La Serna, J., Macias, D. 2005. Incidental catch and estimated discards of pelagic sharks from the swordfish and tuna fisheries in the Mediterranean Sea. *Fish. Bull.*, 103: 620-634.

20 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

21 – Rogers, P.J., Huveneers, C., Page, B., Hamer, D.J., Goldsworthy, S.D., Mitchell, J.G., Seuront, L. 2012. A quantitative comparison of the diets of sympatric pelagic sharks in gulf and shelf ecosystemsn off southern Australia. *ICES J. Mar. Sci..* 69 (8): 1382-1393.

22 – Natanson, L.J., Gervelis, B.J. 2013. The reproductive biology of the common thresher shark in the Western North Atlantic Ocean. *Trans. Amer. Fish. Soc.*, 142(6): 1546-1562.

23 - Gervelis B.J. & Natanson L.J., 2013. Age and Growth of the Common Thresher Shark in the Western North Atlantic Ocean. *Tans. Amer. Fish. Soc.*, 142(6): 1535-1545.

Table III.20. Biological parameters for silky shark (FAL, *Carcharhinus falciformis*).

Carcharhinus falciformis (Bibron in Müller & Henle, 1839) Silky shark FAO code: FAL	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L∞ for female in cm	L∞=291	5			L∞=320.4	13	L∞=332	6		
K for female /year	k=0.153	5			k=0.057	13	k=0.0838	6		
t_o for female in years	t_0=2.2	5					t_0=-2.761	6		
L∞ for male in cm	L∞=291	5			L∞=277.3	13	L∞=332	6		
K for male /year	k=0.153	5			k=0.079	13	k=0.0838	6		
t_o for male in years	t0=2.2	5					t0=-2.761	6		
Longevity	25	4	25	4	25 19-20	4 23	25 females 35.8 males 28.6	4 6 6	25	4
Maximum size TL in cm	350 305	2 15	350	2	350	2	350 256	2 6	350	2
Common size (FL) in cm										
Maximum weight in kg	346	3	346	3	346	1-3	346	1-3	346	1-3
REPRODUCTION										
Female maturity size in cm	>225 233 232-245	5 11 11-12			215.6	13	210-220 186 214 #200	6 11 11 18	186 180 (50%) 180	11 22 23
Female maturity age in years	7-9 12	5 11-12			15	13	9.2-10.2 6-7	6 11	6-7	11
Male maturity size in cm	210-220 221 225	5 11 11-12			207.6	13	212.5 200-206 238-250	6 11 11	200-206 182(50%) 190	11 22 23
Male maturity age in years	6-7 10	5 11-12			13	13	9.3 5-6	6 11	5-6	11
Birth size TL in cm	57-87 72 68-84 75-80	2 5 11 12	57-87	2	57-87 81.1	2 13	57-87 63.5-75.5 65-81	2 6 11	57-87 65-81	2 6-11
Sex ratio					1.05	13	1:1	6	48% females	21
Mode of development	viviparous	2	viviparous	2	viviparous	2	viviparous	2	viviparous	2
Gestation period in months	12	5-11-12							11-12	22
Spawning & mating periods	May-June	5			no period	11	no period	11	no period	11

Fecundity: number of embryos per litter	2-14 2-12	2 11-12	2-14	2	2-14	2-3	2-14 8-10 1-16 5-8 2-18	2 6 11 18 21	2-14 1-16 2-18 2-9	2 11 21 22
Nursery ground										
CONVERSION FACTORS										
Length / Weight relationships	$W=2.01*10^{-6}TL^{3.23}$ $W=1.5406*10^{-5}FL^{2.9221}$ $W=0.8782*10^{-5}TL^{3.091}$	5 7 9-16			$W=0.160*10^{-4}*FL^{2.91497}$	10	$W=2.92*10^{-6}TL^{3.15}$ $W=2.887*10^{-5}TL^{2.70}$	6 18		
Wet weight / dressed weight ratio										
TL / FL	TL=1.20*FL-1.16 FL=0.8388*TL-2.6510	5 7					TL=1.21*FL+3.64	6		
TL/PCL							TL=1.31*PCL+3.64 TL=2.08+1.32*PCL	6 11	TL=2.08+1.32*PCL	11
Fins / carcass ratios	FW/DW=2.5%	14	FW/DW=2.5%	14	FW/DW=2.5% FW/BW=2.02 % (1st set) FB/BW=4.67 %	14 19 19	FW/DW=2.5 %	14	FW/DW=2.5 %	14
Stables isotopes N^{15} & C^{14}					C^{13}/N^{15}=2.66-2.68	20				
POPULATION DYNAMICS										
Stock delineation/range							1 stock in Western Pacific	25	2 stocks in Eastern Pacific : North & South	25
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)										
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.2	8	4.2	8	4.2	8	4.2	8	4.2	8

References

1 - Fishbase. 2017. *Carcharhinus falciformis.* https://www.fishbase.de/summary/Carcharhinus-falciformis.

2 - Compagno, L.J.V. 1998. Carcharhinidae. Requiem sharks. Pp. 1312-1360. In Carpenter K. & Niem V. (eds.) FAO Identification Guide for Fishery Purposes. The Living Marine Resources of the Western Central Pacific. FAO, Rome.

3 - IGFA. 2001. Database of IGFA angling records. IGFA, Fort Lauderdale, USA.

4 – Smith, S., Au, D., Show, C. 1998. Intrinsic rebound potential of 26 species of Pacific sharks. *Mar. Freshwat. Res.*, 49: 663-678.

5 – Branstetter, S. 1987. Age, growth and reproductive biology of the silky shark, *Carcharhinus falciformis*, and the scalloped hammerhead, *Sphyrna lewini*, from the northwestern Gulf of Mexico. *Environ. Biol. Fish.,* 19(3): 161-173.

6 – Joung, S.-J., Chen, C.-T., Lee, H.-H., Liu, K.-M. 2008. Age, growth, and reproduction of silky sharks, *Carcharhinus falciformis*, in northeastern Taiwan waters. *Fish. Res.*, 90(1-3): 78-85.

7 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

8 – Cortés, E. 1999 Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

9 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. *FAO Fish. Synop.* ,125(4/2): 251-655.

10 – Romanov, E., Romanova, N. 2009. Size distribution and length-weight relationships for some large pelagic sharks in the Indian Ocean. 5th Working Party on Ecosystems and Bycatch, 12-14 October 2009, Mombasa, Kenya. IOTC document IOTC-2009-WPEB-06: 12 pp.

11 – Oshitani, S., Nakano, H., Tanaka, S. 2003. Age and growth of the silky shark *Carcharhinus falciformis* from the Pacific Ocean. *Fisher. Sci.*, 69(3): 456-464.

12 – Bonfil, R., Mena, R., de Anda, D. 1993. Biological parameters of commercially exploited silky sharks, *Carcharhinus falciformis*, from the Campeche Bank, Mexico. *NOAA Tech. Rep. NMFS*, 115: 73–86.

13 – Hall, N., Bartron, C., White, W., Dharmadi, Potter, I. 2012. Biology of the silky shark *Carcharhinus falciformis* (Carcharhinidae) in the eastern Indian Ocean, including an approach to estimating age when timing of parturition is not well defined. *J. Fish Biol.,* 80: 1320–1341.

14 – Cortés, E., Neer, J. 2006. Preliminary reassessment of the validity of the 5% fin to carcass weight ratio for sharks. *Collect. Vol. Sci. Pap. ICCAT,* 59: 1025-1036.

15 – Springer, S. 1960. Natural history of the sandbar shark, *Eulamia milberti*. *Fish. Bull.,* 61: l-38.

16 - Guitart Manday, D. 1975. Las pesquerias pelagico-oceanicas de *corto* radio de accion en la region noroccidental de Cuba. [Short-range marine pelagic fishing of northwest Cuba.] *Seria Oceanologica, Oceanographic Institute Cuba*, 31: 3-26.

17 – Bowman, R., Stillwill, C., Michaels, W., Grosslein, M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dep Commer, *NOAA Tech Memo NMFS NE*, 155 : 1-137.

18 – Stevens, J. 1984. Biological observation on sharks caught by sport fishermen off New South Wales. *Aust. J. Mar. Freshw. Res.,* 35: 573–590.

19 – Séret, B., Blaison, A., Dagorn, L., Filmater, J.D. 2012. Fin to carcass weight rations for the silky shark *Carcharhinus falciformis* in the western Indian Ocean. 8th Working Party on Ecosystems and Bycatch, 17-19 September 2012, South Africa. IOTC document IOTC-2012-WPEB08-18: 9 pp.

20 – Rabehagasoa, N., Lorrain, A., Bach, P., Potier, M., Jaquemet, S., Richard, P., Ménard, F. 2012. Isotopic niches of the blue shark *Prionace glauca* and the silky shark *Carcharhinus falciformis* in the southwestern Indian Ocean. *Endang. Spec. Res*., 17: 83-92.

21 - Garcia-Cortes, B., Ramos-Cartelle, A., Mejuto, J. 2012. Biological observations of silky shark (*Carcharhinus falciformis*) on Spanish surface longliners targeting swordfish in the

Pacific Ocean over the period 1990-2011 and applicability to the Atlantic case. *Collect. Vol. Sci. Pap. ICCAT*, 68(4): 1601-1617.

22 - Hoyos-Padilla, E.M., Ceballos-Vazquez, B.P., Galván-Magana, F. 2012. Reproductive biology of the silky shark *Carcharhinus falciformis* off the West coast of Baja California Sur, Mexico. *Aqua, Internat. J. Ichthyol.*, 18(1): 15-24.

23 - Galvan-Tirado, C., Galván-Magñna, F., Ochoa-Baez, R.I. 2014. Reproductive biology of the silky shark *Carcharhinus falciformis* in the southern Mexican Pacific. *J. Mar. Biol. Assoc. UK,* 95(3): 561-567.

24 - Aires da Silva, A., Lennert-Cody, C., Maunder, M. 2014. Stock status of the silky shark in the eastern Pacific Ocean. 4th meeting of the IATTC Scientific Advisory meeting, La Jolla, 29 April - 3 May 2013. P.P. Presentation: 84 pp.

Table III.21. Biological parameters for oceanic whitetip (OCS, *Carcharhinus longimanus*).

Carcharhinus longimanus **(Poey, 1861)** **Oceanic whitetip shark** **FAO code: OCS**	**Atlantic Ocean**	**Ref.**	**Mediter -ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L∞ for female in cm	L∞=525.4	7					L∞=244.6 L∞=309.4 L∞=316.7	8 23 24		
K for female /year	k=0.0075	7					k=0.1 k=0.085 k=0.057	8 23 24		
t_o for female in years	t_0=-3.342	7					t_0=-2.7 L_0=74.7	8 24		
L∞ for male in cm	L∞=284.9	7					L∞=244.6 L∞=309.4 L∞=315.6	8 23 24		
K for male /year	k=0.996	7					k=0.1 k=0.085 k=0.059	8 23 24		
t_o for male in years	t_0=-3.391	7					t_0=-2.7 L_0=75.1	8 24		
Longevity in years	22	1-4	22	1-4	22 17	1-4 11	22 18 (males) 17 (females)	1-4 24 24	22	1-4
Maximum size TL in cm	396 260 350 395	1 9 8-14 8-14	396	1	396	1	396	1	396	1
Common size (FL) in cm										
Maximum weight in kg	167.4	1	167.4	1	167.4	1	167.4	1	167.4	1
REPRODUCTION										
Female maturity size in cm	189-198 180-190 180-200 181-203 170.0	16 7 10 13 22	180-200	10	180-190 180-200 187 TL (50%)	9 10 25	180-200 170-180 125-135 PCL 175-189 TL 170-180 193 (50°%) 224 TL	10 11 8 8 8 23 24	180-200 125-135 PCL 175-189 TL	10 8 8
Female maturity age in years	6-7	7					4-5 8.5 15.8	8-11 23 24	4-5	8

Male maturity size in cm	180-190 175-198 160-196 170-190	7 10 13 22	175-198	10	185-198 175-198 207 TL (50%)	9 10 25	175-198 170-180 125-135 PCL 175-189 TL 172 (50%) 193 TL	10 11 8 8 23 24	175- 198 125-135 PCL 175-189 TL	10 8 8
Male maturity age in years	6-7	7					4-5 8 10.0	8- 11 23 24	4-5	8
Birth size TL in cm	60-65 65-70 65-75	9 7 16	60-65	10	60-65 64-65 TL	9 25	60-65 45-55 PCL 64	10 8 23	60-65 45-55 PCL	10 8
Sex ratio	1:21									
Mode of development	placental viviparous	7	placental viviparous	7	placental viviparous	7	placental viviparous	7	placental viviparous	7
Gestation period in months	12 9-12	10 16	9-12	16	12 9-12	10 16	12 9-12	10 16	12 9-12	10 16
Spawning & mating periods	early Summer	10			early Summer	10	June-July	8	June-July	8
Fecundity: number of embryos per litter	1-15 1-14 1-10	1- 10 13 22	1-15	1- 10	1-15 6-8 3-9	1- 10 9- 13 25	1-15 1-14 10-11	1- 5- 10 8 23	1-15 1-14	1- 10 8
Nursery ground										
CONVERSION FACTORS										
Length / Weight relationships	$W=0.7272*10^{-4}$ $TL^{2.678}$	10			$W=0.386*10^{-4}$ $FL^{2,75586}$ $W=0.508*10^{-4}$ $FL^{2.70428}$ fem. $W=0.120*10^{-4}$ $FL^{2.98524}$ males	11 - 12 12 12	$W=3.077*10^{-5}PCL^{2.860}$ males $W=5.076*10^{-5}$ $PCL^{2.761}$ fem. $W=1.405*10^{-7}$ $TL^{3.72}$ $W=1.66*10^{-5}$ $TL^{2.891}$	8 8 18 23	$W=3.077*10^{-5}PCL^{2.860}$ males $W=5.076*10^{-5}$ $PCL^{2.761}$ fem.	8 8
Wet weight / dressed weight ratio										
TL / FL	TL=1.224*FL	1	TL=1.224*FL	1	TL=1.224*FL	1	TL=1.224*FL	1	TL=1.224*FL	1
TL/PCL	TL=1.397*PCL	13	TL=1.397*PCL	13	TL=1.397*PCL	13	TL=1.397*PCL	13	TL=1.397*PCL	13
Fins / carcass ratios	FW/BW=7.34	19	FW/BW=7.34	19	FW/BW=7.34	19	FW/BW=7.34	19	FW/BW=7.34	19
Stables isotopes N^{15} & C^{14}										
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality							catch rate declining 17%/year	21		
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)										

Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.2	6	4.2	6	4.2	6	4.2	6	4.2	6

References

1 – Fishbase. 2017. *Carcharhinus longimanus.* http://www.fishbase.org/summary/Carcharhinus-longimanus.html

2 – Randall, J., Allen, G., Steene, R. 1990. Fishes of the Great Barrier Reef and Coral Sea. University of Hawaii Press, Honolulu, Hawaii. 506 pp.

3 – IGFA. 2001. Database of IGFA angling records. IGFA, Fort Lauderdale, USA.

4 – Smith, S., Au, D., Show C., 1998. Intrinsic rebound potential of 26 species of Pacific sharks. *Mar. Freshwat. Res.,* 49: 663-678.

5 – Myers, R. 1991. Micronesian reef fishes. Second Ed. Coral Graphics, Barrigada, Guam, 298 p.

6 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

7 – Lessa, R., Santana, F., Paglerani, R. 1999. Age, growth and stock structure of the oceanic whitetip shark, (*Carcharhinus longimanus*), from the southwestern equatorial Atlantic. *Mar. Freshwater Res.,* 50: 383-388.

8 – Seki, T., Taniuchi, T., Nakano, H., Shimizu, M. 1998. Age, growth and reproduction of the oceanic whitetip shark from the Pacific Ocean. *Fish. Sci.,* 64(1): 14-20.

9 – Bass, A., D'Aubrey, D., Kitnasamy, N. 1973. Sharks of the east coast of Southern Africa. I. Genus *Carcharhinus* (Carcharhinidae). *S. Afr. Assoc. Mar. Biol. Res. Invest. Rep*., 38: 1-100.

10 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. *FAO Fish. Synop.,* 125(4/2): 251-655 pp.

11 – IOTC. 2011. Etat de la ressource du requin océanique (*Carcharhinus longimanus*). 14th Scientific Committee, 12-17 December 2011, Victoria, Seychelles. IOTC document IOTC-2011-SC14-28.

12 – Romanov, E., Romanova, N. 2009. Size distribution and length-weight relationships for some large pelagic sharks in the Indian Ocean. 5th Working Party on Ecosystems and Bycatch, 12-14 October 2009, Mombasa, Kenya. IOTC document IOTC-2009-WPEB-06: 12 pp.

13 – Coelho, R., Burgess, G. 2009. Note on the reproduction of the oceanic whitetip shark, *Carcharhinus longimanus* in the south-western equatorial Atlantic Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 64(5): 1734-1740.

14 – Bigelow, H., Schroeder, W. 1948. Fishes of the Western North Atlantic, Lancelets, Cyclostomes, Sharks, *Mem. Sears Foundn. Mar. Res.,* 1: 1-576.

15 – Saika, S., Yoshimura, H. 1985. Oceanic whitetip shark (*Carcharhinus longimanus*) in the western Pacific. *Reps. Japanese Society for Elasmobranch Studies*, 20: 11-21.

16 – Bonfil, R., Clarke, S., Nakano, H. 2008. The biology and ecology of the oceanic whitetip shark, *Carcharhinus longimanus*. 129-139 pp. In Camhi M., Pikitch E., Babcock E. (eds), Sharks of the open ocean; biology, fisheries and conservation. Blackwell Publ. Ltd.

17 – Backus, R., Springer, S., Arnold, E. 1956. A contribution to the natural history of the white-tip shark, *Pterolamiops longimanus* (Poey). *Deep Sea Res*., 3: 178-188.

18 – Stevens, J. 1984. Biological observation on sharks caught by sport fishermen off New South Wales. *Aust. J. Mar. Freshw. Res*., 35: 573–590.

19 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

20 - Garcia-Cortes, B., Ramos-Cartelle, A., Gonzalez-Gonzalez, I., Mejuto, J., 2012. Biological observations of oceanic whitetip shark (*Carcharhinus longimanus*) on Spanish surface longline fishery targeting swordfish in the Indian Ocean over the period 1993-2011. 8th Working Party on Ecosystems and Bycatch, 17-19 September 2012, South Africa. IOTC document IOTC-2012-WPEB08-25: 16 pp.

21 – Clarke, S.C., Harley, S., Hoyle, S.D., Rice, J.S. 2013. Population trends in Pacific Oceanic sharks and the utility of regulations on shark finning. *Conserv. Biol*., 27(1): 197-209.

22 - Tambourgi, M.R.S., Hazin, F., Oliviera, P., Coelho, R., Burgess, G., Roque, P. 2013. Reproductive aspects of the oceanic whitetip shark, *Carcharhinus longimanus* (Elamsobranchii: Carcharhinidae) in the equatorial and southwestern Atlantic Ocean. *Braz. J. Oceanogr.*, 61(2): 161-168.

23 - Joung, S.-J., Chen, N.-F., Hsu, H.-H., Liu, K.-M. 2016. Estimates of life parameters of the oceanic whitetip shark, *Carcharhinus longimanus*, in the Western North Pacific. *Mar. Biol. Res*., 22(7): 758-768.

24 - D'Alberto, B.M., Chin, A., Smart, J.J., Baje, L., White, W.T., Simpfenforger, C.A. 2016. Age, growth and maturity of oceanic whitetip shark *(Carcharhinus longimanus*) from Papua New Guinea. *Mar. & Freshw. Res.*, 68: 1118–1129.

25 – Verghese, S.P., Unnikrishnan, N., Deepak, K.G., Ayoob, A.E. 2017. Size, sex and reproductive biology of seven pelagic sharks in the eastern Arabian Sea. *J. Mar. Biol. Assoc. UK*, 97(1): 181-196.

Table III.22. Biological parameters for great white shark (WHS, *Carcharodon carcharias*).

Carcharodon carcharias **(Linnaeus, 1758) Great White Shark FAO code: WSH**	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L∞ for female in cm	L∞=776	15	L∞=776	15	L∞=776 L∞=744 L∞=659.8 L∞=497.77	15 11 15-16 28	L∞=776 L∞=659.8 L∞=607	15 15-16 20	L∞=776	15
K for female /year	k=0.058	15	k=0.058	15	k=0.058 k=0.065 k=0.071	15 11 15-16	k=0.058 k=0.071 k=0.159	15 15-16 20	k=0.058	15
t_0 for female in years	t_0=-3.5	15	t_0=-3.5	15	t_0=-3.5 t_0=-4.4 t_0=-2.33	15 11 15-16	t_0=-3.5 t_0=-2.33 t_0=-1.8	15 15-16 20	t_0=-3.5	15
L∞ for male in cm	L∞=776	15	L∞=776	15	L∞=776 L∞=744 L∞=659.8 L∞=497.77	15 11 15-16 28	L∞=776 L∞=659.8 L∞=607	15 15-16 20	L∞=776	15
K for male /year	k=0.058	15	k=0.058	15	k=0.058 k=0.065 k=0.071	15 11 15-16	k=0.058 k=0.071 k=0.159	15 15-16 20	k=0.058	15
t_0 for male in years	t_0=-3.5	15	t_0=-3.5	15	t_0=-3.5 t_0=-4.4 t_0=-2.33	15 11 15-16	t_0=-3.5 t_0=-2.33 t_0=-1.8	15 15-16 20	t_0=-3.5	15
Longevity in years	23 (females) 27 40-50 30 44 40 (fem. 526 cm FL) 73 (male 493 cm TL)	1 1-2 15 2-19 27 25 25	23 (females) 27 40-50	1 1-2 15	23 (females) 27 40-50 38	1 1-2 15 28	23 (females) 27 40-50	1 1-2 15	23 (females) 27 40-50 30	1 1-2 15 26
Maximum size TL in cm	760 estimated #600 640 -720 792 640	1-2 1 8 9 18	760 estimated #600 640 -720 792	1-2 1 8 9	760 estimated #600 640 -720 792	1-2 1 8 9	760 estimated #600 640 -720 792 602	1-2 1 8 9 24	760 estimated #600 640 -720 792	1-2 1 8 9
Common size (FL) in cm										
Maximum weight in kg	3400	9	3400	9	3400	9	3400 2530	9 24	3400	9
REPRODUCTION										

Female maturity size in cm	400-500 450-500	1 15-17	400-500 450-500	1 15-17	400-500 450-500	1 15-17	400-500 450-500	1 15-17	400-500 450-500	1 15-17
Female maturity age in years	12-14 12-17	1 15	12-14 12-17	1 15	12-14 12-13 12-17	1 11 15	12-14 12-17 7	1 15 20	12-14 12-17 9-10	1 15 2-10
Male maturity size in cm	350-410 366-427 360-380	1 2 15	350-410 366-427 360-380	1 2 15	350-410 366-427 360-380	1 2 15	350-410 366-427 360-380 310	1 2 15 20	350-410 366-427 360-380	1 2 15
Male maturity age in years	9-10	1-2	9-10	1-2	9-10	1-2	9-10	1-2	9-10	1-2
Birth size TL in cm	109-165 120-150	1 15-17	109-165 120-150	1 15-17	109-165 120-150 100-135	1 15-17 11	109-165 120-150	1 15-17	109-165 120-150	1 15-17
Sex ratio	1:1 (embryos)	15	1:1 (embryos)	15	1:1 (embryos)	15	1:1 (embryos) 1:1	15 24	1:1 (embryos)	15
Mode of development	ovoviviparous	1	ovoviviparous	1	ovoviviparous	1	ovoviviparous	1	ovoviviparous	1
Gestation period in months	>12	15-17	>12	15-17	>12	15-17	>12 20	15-17 24	>12	15-17
Spawning & mating periods	Spring/Summer	2-5-14	Spring/Summer	2-14	Spring/Summer	2-14	Spring/ Summer	2-14	Spring/Summer	2-14
Fecundity: number of embryos per litter	2-14 up to 10 7-14 2-17	1 8 9 15	2-14 up to 10 7-14 2-17	1 8 9 15	2-14 up to 10 7-14 2-17	1 8 9 15	2-14 up to 10 7-14 2-17 4-10	1 8 9 15 24	2-14 up to 10 7-14 2-17 7	1 8 9 15 10
Nursery ground	females aggregation in coastal waters in Spring/ Summer	22			females aggregation in coastal waters in Spring/ Summer	22			Pont Conception California	14
CONVERSION FACTORS										
Length / Weight relationships	$W=4.34*10^{-6}*TL^{3.14}$ $W=3.026*10^{-6}*TL^{3.188}$ $W=4.804*10^{-6}*TL^{3.095}$ $W=7.5763*10^{-6}*FL^{3.0848}$	1-3 3 1-5 1-7	$W=4.34*10^{-6}* TL^{3.14}$ $W=3.026*10^{-6}*TL^{3.188}$	1-3 3	$W=4.34*10^{-6}*TL^{3.14}$ $W=3.026*10^{-6}*TL^{3.188}$ $W=3.8*10^{-6}*TL^{3.15}$ $W=2.14*10^{-5}*PCL^{2.944}$	1-3 3 1-4 1-6	$W=4.34*10^{-6}*TL^{3.14}$ $W=3.026*10^{-6}*TL^{3.188}$ $W=3.8*10^{-6}*TL^{3.15}$ $W=1.5710*10^{-5}*TL^{2.932}$	1-3 3 1-4 20	$W=4.34*10^{-6}* TL^{3.14}$ $W=3.026*10^{-6}*TL^{3.188}$	1-3 3
Wet weight / dressed weight ratio										
TL / FL	PCL=0.8550*TL -0.0955	11-12	PCL=0.8550*TL - 0.0955	11-12	TL=1.251 *PCL + 5.207 PCL=0.8550*TL -	11 11-12	PCL=0.8550*TL -0.0955 TL=1.159*PCL	11-12 20	PCL=0.8550* TL -0.0955	11-12

					0.0955		+15.76			
TL/PCL										
Fins / carcass ratios										
Stables isotopes N15 & C14										
POPULATION DYNAMICS										
Stock delineation/range									>2000 ind. (California)	23
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) (year^{-1})							0.039	29		
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.5	13	4.5	13	4.5	13	4.5	13	4.5	13

References

1 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). *FAO Spec. Cat. Fish. Purp*. 1(2): 269 pp. Rome, FAO.

2 – Cailliet, G., Natanson, L., Welden, B., Ebert, D. 1985. Preliminary studies on the age and growth of the white shark, *Carcharodon carcharias*, using vertebral bands. *Mem. S. Calif. Acad. Sci.,* 9: 49-60.

3 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1 - Hexanchiformes to Lamniformes. *FAO Fish. Synop*. 125(4/1): 1-249. Rome, FAO.

4 – Tricas, T., McCosker, J. 1984. Predatory behavior of the white shark (*Carcharodon carcharias*), with notes on its biology. *Proc. Calif. Acad. Sci.,* 43: 221-238.

5 – Casey, J., Pratt, H.Jr. 1985. Distribution of the white shark, *Carcharodon carcharias*, in the western North Atlantic. *Mem. Southern Calif. Acad. Sci*., 9: 2-14.

6 – Cliff, G., Dudley, S., Jury, M. 1996. Catches of white sharks in KwaZulu-Natal, South Africa and environmental influences. 351-362 pp. In Klimley, A., Ainley, D. (eds.), Great white sharks. The Biology of *Carcharodon carcharias*. Academic Press, Inc., San Diego.

7 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

8 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome, 716 pp.

9 – Fishbase. 2017. Carcharodon carcharias. http://fishbase.mnhn.fr/summary/Carcharodon-carcharias.html

10 – Smith, S., Au, D., Show, C. 1998. Intrinsic rebound potential of 26 species of Pacific sharks. *Mar. Freshw. Res*., 49: 663-678.

11 – Wintner, S., Cliff, G. 1999. Age and growth determination of the white shark, *Carcharodon carcharias*, from the east coast of South Africa. *Fish. Bull.*, 97(1): 153-169.

12 – Mollet, H., Cailliet, G. 1996. Using allometry to predict body mass from linear measurements of the white shark. Pp. 81-90. In Klimley, A., Ainley, D. (eds.) Great white sharks. The biology of *Carcharodon carcharias*. Academic Press, Inc., San Diego.

13 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

14 – Gilmore, R. 1993. Reproductive biology of lamnoid sharks. *Environ. Biol. Fish.,* 38(1/3): 95-114.

15 – Bruce, B. 2008. The biology and ecology of the white shark, *Carcharodon carcharias*. 69-81 pp. In Camhi, M., Pikitch, E., Babcock, E. (eds.) Sharks of the open ocean; biology, fisheries and conservation. Blackwell Publishing Ltd.

16 – Malcom, H., Bruce, B., Stevens, J. 2001. A review of the biology and status of white sharks in Australian waters. CSIRO Marine Research, Hobart, Tasmania, Australia. 81 pp.

17 – Francis, M. 1996. Observations on a pregnant white shark with a review of reproductive biology. 157-172 pp. In Klimley, A., Ainley, D. (eds.), Great White Sharks: the biology of *Carcharodon carcharias*. Academic Press, Inc., New York.

18 – Randall, J. 1973. Size of the great white shark (*Carcharodon*). *Science*, 181: 169-170.

19 – Fergusson, I., Compagno, L., Marks, M. 2009*. Carcharodon carcharias*. In: IUCN. 2011. IUCN Red List of Threatened Species. Version 2011.2. http://www.iucnredlist.org/.

20 – Tanaka, S., Kitamura, T., Mochizuki, T., Kofuji, K. 2011. Age, growth and genetic status of the white shark (*Carcharodon carcharias*) from Kashima-nada, Japan. *Mar. Freshw. Res*., 62: 548–556.

21 – Hussey, N.E., McCann, H.M., Cliff, G., Dudley, S.F.J., Wintnere, S.P., Fisk, A.T. 2012. Size-based analysis of diet andt rophic position of the white sharkn *Carcahrodon carcharias*, in South Africa, waters. 27-49 pp. In Domeier, M.L., Global perspectives on the biology and life history of the white shark. Boca Raton, CRC Press.

22 – Kock, A., O'Riain, J., Mauff, K., Meyer, M., Kotze, D., Griffiths, C. 2013. Residency, habitat use and sexual segregation of white sharks, *Carcharodon carcharias*, in False Bay South Africa. *PLOS one 8(1): e55048.*

23 – Burgess, G. H., Bruce, B.D., Caillet, G.M., Goldman, K.J., Grubbs, R.D., Lowe, C.G., MacNeil, M.A., Mollet, H.F., Weng, K.C., O'Sullivan, J.B. 2014. A re-evaluation of the size of the white shark (*Carcharodon carcharias)* population off California, USA. *PLOS one*, 9(6): e98078.

24 – Christiansen, H.M., Lin, V., Tanaka, S., Velikanov, A., Mollet, H.F., Wintner, S.P., Fordham, S.V., Fisk, A.T, Husey, N.E. 2014. The last frontier: catch record of white sharks (*Carcharodon carcharias)* in the Norhwest Pacific Ocean. *PLOS one,* 9(4):e94407.

25 – Hamady, L.L., Natanson, L.J., Skomal, G.B., Thottod, S.R. 2014. Vertebral bomb radiocarbon suggests extreme longevity in white sharks. *PLOS one*, 9(1): e84006.

26 – Andrews, A. 2015. Validated age estimates for large white sharks of the northeastern Pacific Ocean: altered perceptions of vertebral growth shed light on complicated bomb C^{14} results. *Envir. Biol. Fish.*, 98(3): 971-978.

27 – Natanson, L.J, Skomal, G.B. 2015. Age and growth of the white shark, *Carcharodon carcharias*, in the western North Atlantic Ocean. *Mar. & Freshw. Res.*, 66(5): 387-398.

28 – Christiansen, H.M., Campana, S.E., Fisk, A.T., Cliff, G., Wintner, S.P., Dudley, S., Kerre, L.A., Hussey, N.E. 2016. Using bomb radiocarbon to estimate age and growth of the white shark, *Carcharodon carcharias*, from the southwestern Indian Ocean. *Mar. Biol.*, 163: 144.

29 - Ward-Paige, C.A., Keith, D.M., Worm, B., Lotze, H.K. 2012. Recovery potential and conservation options for elasmobranchs. *J. Fish Biol*., 80: 1844-1869.

Table III.23. Biological parameters for basking shark (BSK, *Cetorhinus maximus*).

Cetorhinus maximus (Gunnerus, 1765) Basking Shark FAO code: BSK	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L_∞ for female in cm	L_∞=1314 L_∞=1226 L_∞=1000	3 3 7	L_∞=1314 L_∞=1226 L_∞=1000	3 3 7	L_∞=1314 L_∞=1226 L_∞=1000	3 3 7	L_∞=1314 L_∞=1226 L_∞=1000	3 3 7	L_∞=1314 L_∞=1226 L_∞=1000	3 3 7
K for female /year	k=0.0357 k=0.045 k=0.062	3 3 7	k=0.0357 k=0.045 k=0.062	3 3 7	k=0.0357 k=0.045 k=0.062	3 3 7	k=0.0357 k=0.045 k=0.062	3 3 7	k=0.0357 k=0.045 k=0.062	3 3 7
t_0 for female in years	t_0=-3.4 t_0=-2.9 t_0=-2.26	3 3 7	t_0=-3.4 t_0=-2.9 t_0=-2.26	3 3 7	t_0=-3.4 t_0=-2.9 t_0=-2.26	3 3 7	t_0=-3.4 t_0=-2.9 t_0=-2.26	3 3 7	t_0=-3.4 t_0=-2.9 t_0=-2.26	3 3 7
L_∞ for male in cm	L_∞=1226 L_∞=1000	3 7	L_∞=1226 L_∞=1000	3 7	L_∞=1226 L_∞=1000	3 7	L_∞=1226 L_∞=1000	3 7	L_∞=1226 L_∞=1000	3 7
K for male /year	k=0.045 k=0.062	3 7	k=0.045 k=0.062	3 7	k=0.045 k=0.062	3 7	k=0.045 k=0.062	3 7	k=0.045 k=0.062	3 7
t_0 for male in years	t_0=-2.9 t_0=-2.26	3 7	t_0=-2.9 t_0=-2.26	3 7	t_0=-2.9 t_0=-2.26	3 7	t_0=-2.9 t_0=-2.26	3 7	t_0=-2.9 t_0=-2.26	3 7
Longevity in years	50 > 9.1	2 10	50	2	50	2	50	2	50	2
Maximum size TL in cm	1220 to 1520	1	1220 to 1520	1	1220 to 1520	1	1220 to 1520	1	1220 to 1520	1
Common size (FL) in cm	<980	1	<980	1	<980	1	<980	1	<980	1
Maximum weight in kg	7500 4000	1 4	7500 4000	1 4	7500 4000	1 4	7500 4000	1 4	7500 4000	1 4
REPRODUCTION										
Female maturity size in cm	800-980	1	800-980	1	800-980	1	800-980	1	800-980	1
Female maturity age in years	up to 20	1	up to 20	1	up to 20	1	up to 20	1	up to 20	1
Male maturity size in cm	400-700	1	400-700	1	400-700	1	400-700	1	400-700	1
Male maturity age in years	6-8 12-16	2 1	6-8 12-16	2 1	6-8 12-16	2 1	6-8 12-16	2 1	6-8 12-16	2 1
Birth size TL in cm	150-170 150 150-200 153	1 1 4 2	150-170 150 150-200 153	1 1 4 2	150-170 150 150-200 153	1 1 4 2	150-170 150 150-200 153	1 1 4 2	150-170 150 150-200 153	1 1 4 2
Sex ratio										
Mode of development	ovoviviparous	5	ovoviviparous	5	ovoviviparous	5	ovoviviparous	5	ovoviviparous	5

Gestation period in months	3.5 2.6 1-3.5	2 1 4	3.5 2.6 1-3.5	2 1 4	3.5 2.6 1-3.5	2 1 4	3.5 2.6 1-3.5	2 1 4	3.5 2.6 1-3.5	2 1 4
Spawning & mating periods	early Summer	4	early Summer	4	early Summer	4	early Summer	4	early Summer	4
Fecundity: number of embryos per litter										
Nursery ground										
CONVERSION FACTORS										
Length / Weight relationships	W=0.0075* TL^3 W=0.00494* TL^3	1 4	W=0.0075*T L^3 W= 0.00494* TL^3	1 4	W=0.0075*T L^3 W= 0.00494* TL^3	1 4	W=0.0075* TL^3 W= 0.00494* TL^3	1 4	W=0.0075*T L^3 W= 0.00494* TL^3	1 4
Wet weight / dressed weight ratio										
TL / FL										
TL/PCL										
Fins / carcass ratios										
Stables isotopes N15 & C14										
POPULATION DYNAMICS										
Stock delineation/range	population estimated to 985 in 2010 and 201 in 2011	11					CPUE close to zero since mi-2000 on east and west coast of New Zealand fluctuating in south islands	12		
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)	0.025	13								
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	3.2	6	3.2	6	3.2	6	3.2	6	3.2	6

References

1 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). *FAO Spec. Cat. Fish. Purp*. 1(2): 269 pp. Rome, FAO.

2 – Parker, H., Stott, F. 1965. Age, size and vertebral calcification in the basking shark, *Cetorhinus maximus* (Gunnerus). *Zoologissche Mededelingen*, 40(34): 305-319.

3 – Pauly, D. 1978. A critique of some literature data on the growth, reproduction and mortality of the lamnid shark *Cetorhinus maximus* (Gunnerus). ICES CM 1978/H:17: 10 pp.

4 – Fishbase. 2017. *Cetorhinus maximus*. http://fishbase.mnhn.fr/summary/Cetorhinus-maximus.html

5 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1 - Hexanchiformes to Lamniformes. *FAO Fish. Synop*. 125(4/1): 1-249. Rome, FAO.

6 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

7 – Pauly, D. 1997. Growth and mortality of basking shark *Cethorhinus maximus*, and their implications for whale shark *Rhincodon typus*. MS, presented at the International Seminar on Shark and Ray Biodiversity, Conservation and Management, Kota Kinabalu, Sabah, Malaysia, 7-10 July 1997.

8 - Shark Trust. 2010. An Illustrated Compendium of Sharks, Skates, Rays and Chimaera. Chapter 1: The British Isles and Northeast Atlantic. Part 2: Sharks.

9 – Gore, M., Rowat, D., Hall, J., Gell, F., Ormond, R. 2008. Trans-Atlantic Migration and Deep Mid-Ocean Diving by Basking Sharks. *Biol. Lett.*, 4 (4): 395–398.

10 – Hoogenboom, J.L., Wrong, S., Ronconi, R.A., Koopman, H.N., Murison, L.D., Westgate, A.J. 2015. Environmental predictors and temporal patterns of basking shark (*Cetorhinus maximus)* occurrrence in the lower Bay of Fundy, Canada. *J. Exp. Mar. Biol. & Ecol*., 465: 24-32.

11 – Gore, M.A., Frey, P.H., Ormond, R., Allan, H., Gilkjes, G. 2016. Use of photo-identification and mark-recapture methology to assess basking shark (*Cetorhinus maximus)* population. *PLOS one,* 11(3): e0150160.

12 – Francis, M. 2017. Review of commercial fishery interactions and population information for New Zealand basking shark. Prepared for Departmenty of Conservation of NZ. NIWA report 2017083WN: 45 pp.

13 - Ward-Paige, C.A., Keith, D.M., Worm, B., Lotze, H.K. 2012. Recovery potential and conservation options for elasmobranchs. *J. Fish Biol*., 80: 1844-1869.

Table III.24. Biological parameters for shortfin mako (SMA, *Isurus oxyrinchus*).

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako FAO code: SMA	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
					AGE & GROWTH					
L∞ for female in cm	L∞=366 FL L∞=345 FL L∞=247.75	10 10 - 11 38			L∞=285.4	41 - 44	L∞=732.41 FL L∞=403.62 FL L∞=349 FL L∞=308.3 FL L∞=239.4 PCL	15 10 - 16 17 24 50	L∞=321 T L∞=411 TL	2- 12 13
K for female /year	k=0.087 k=0.203 k=0.11	10 10 - 11 38			k=0.113	41 - 44	k=0.0154 k=0.040 k=0.155 k=0.09 k=0.25	15 10 - 16 17 24 50	k=0.072 k=0.05	2- 12 13
t_0 for female in years							t_0=-10.79 t_0=-5.27 t_0=-1.97	15 10 - 16 17	t_0=-3.75 t_0=-4.7	2- 12 13
L∞ for male in cm	L∞=253 FL L∞=302 FL L∞=247.75	10 10 - 11 38			L∞=285.4	41 - 44	L∞=302.16 FL L∞=321.8 FL L∞=267 FL L∞=231 FL L∞=274.4 PCL	15 10 - 16 17 24 50	L∞=321 T L∞=411 TL	2- 12 13
K for male /year	k=0.125 k=0.266 k=0.11	10 10 - 11 38			k=0.113	41 - 44	k=0.0524 k=0.049 k=0.312 k=0.16 k=0.19	15 10 - 16 17 24 50	k=0.072 k=0.05	2- 12 13
t_0 for male in years	t_0=-1	11					t_0=-9.04 t_0=-6.07 t_0=-0.95	15 10 - 16 17	t_0=-3.75 t_0=-4.7	2- 12 13
Longevity in years	45 estimated 32 (females) 29 (males) 31.5 15 (217 cm)	1- 2 10 10 38 39	45 estimated	1- 2	45 estimated	1- 2	45 estimated 28 (females) 29 (males)	1- 2 15 15	45 estimated 38 22	1- 2 12 46
Maximum size TL in cm	396 396.2 408 estimated	2 25 1	396 408 estimated	2 1	396 408 estimated	2 1	396 408 estimated	2 1	396 408 estimated 350.7	2 1 26
Common size (FL) in cm	207	8	207	8	207	8	207	8	207	8
Maximum weight in kg	505.8	9	505.8	9	505.8	9	505.8	9	505.8 600 (fem. 373 Cm)	9 46

REPRODUCTION										
Female maturity size in cm	275-293 298 273 275 FL 270-300	1 7 10 22	275-293 270-300	1 2 2	275-293 270-300 273 250 FL 266 TL (50%)	1 22 7 41 - 44 43	275-293 280 273 275-285 278 270-300	1 3 7 18 20 22	275-293 273 270-300	1 7- 13 22
Female maturity age in years	18 7 9.8	10 10 - 11 38			15	41	19.1-21 18-19 16	15 10 - 17 24	7-8 15	12 13
Male maturity size in cm	203-215 185 FL 180 FL 200-220	1 10 21 22	203-215 200-220	1 2 2	203-215 200-220 190 FL 189 TL (50%)	1 2 41 - 44 43	203-215 200-220 195 180-185 FL 210	1 22 3 18 20	203-215 200-220 180 180-195 190.3 TL (50%)	1 22 13 - 14 20 48
Male maturity age in years	8 3 9.8	10 10 - 11 38			7	41	6.9-9 13-14 6	15 10 - 17 24	7-8 7	12 13
Birth size TL in cm	60-70 70-90 70 60-110 60-70	1 2 7 23 32	60-70 70-90 70 60-110	1 2 7 2 3	60-70 70-90 70 60-110 60-70 74 #70	1 2 7 23 32 20 3	60-70 70-90 70 60-110 60-70	1 2 7 23 32	60-70 70-90 70 60-110 60.5	1 2 7 23 12
Sex ratio	1:1	21	1:1	2 1	1:1	21	1:1	21	1:1	21
Mode of development	ovoviviparous	21	ovoviviparous	2 1	ovoviviparous	21	ovoviviparous	21	ovoviviparous	21
Gestation period in months	15-18	1- 7	15-18	1- 7	15-18	1- 7- 41	15-18 23-25	1- 7 20	15-18	1- 7
Spawning & mating periods	late Winter to mid-Summer	1	late Winter to mid-Summer	1	late Winter to mid-Summer	1	late Winter to mid-Summer January to June	1 20	late Winter to mid-Summer	1
Fecundity: number of embryos per litter	4-30 (most. 10-18) 4-25 9-14	1 7 5- 7	4-30 (most. 10-18) 4-25 25-30	1 7 7- 2 7	4-30 (most. 10-18) 4-25 9-14 <25	1 7 5- 7- 44 41	4-30 (most. 10-18) 4-25 9-15 4-16	1 7 20 3	4-30 (most. 10-18) 4-25 2-16	1 7 12
Nursery ground					juveniles use outer continental shelf, slope, canyons and oceanic waters	42			coastal waters	48
CONVERSION FACTORS										

Length / Weight relationships	$W=1.193*10^{-6}*TL^{3.46}$ $W= 1.47*10^{-5}*PCL^{2.95}$ $W=5.2432*10^{-6}*FL^{3.1407}$ $W=7.299 * TL(m)^{3.224}$	1-4 1-5 6 7			$W= 1.47*10^{-5}*PCL^{2.95}$ $W=0.349*10^{-4}*FL^{2.7544}$	1-5 41	$W=4.832*10^{-6}*TL^{3.10}$ $W= 5.755 *10^{-6}*TL^{3.06}$	1-3 3-31		
Wet weight / dressed weight ratio										
TL / FL	FL= 0.9286*TL - 1.7101 FL=0.972TL - 9.36 TL= 1.02FL + 11.75 TL=0.0 + 1.127*FL	6 20 20 40					FL=0.918TL - 2.078 FL=0.952 + 0.890TL	15 20		
TL/PCL	FL=5.292 + 1.069*PCL	40					PCL= 0.784+0.816TL PCL=0.84TL - 2.13	20 24		
Fins / carcass ratios	FW/BW=3.14	33	FW/BW=3.14	33	FW/BW=3.14	33	FW/BW=3.14	33	FW/BW=3.14	33
Stables isotopes N^{15} & C^{14}	iso. Ratio 5.2	36								
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality	0.150	51					0.155 fishing mortality focus in immature stages catch rate declining 7%/year	51 45 49	fishing mortality focus in immature stages catch rate declining 7%/year	45 49
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)										
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.3 5.0	19 36	4.3	19	4.3	19	4.3	19	4.3	19

References

1 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). *FAO Spec. Cat. Fish. Purp.*, 1(2): 1-269. Rome, FAO.

2 – Caillet, G., Martin, L., Kusher, D., Wolf, P., Welden, B. 1983. Preliminary studies on the age and growth of the blue, *Prionace glauca*, common thresher, *Alopias vulpinus*, and shortfin mako, *Isurus oxyrinchus*, sharks from California waters. In Prince ED & LM Pulos (eds). Proceedings of the International workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. *NOAA Tech. Rep. NMFS,* 8: 179-188.

3 – Stevens, J. 1983. Observation on reproduction in the shortfin mako *Isurus oxyrinchus*. *Copeia,* 1983(1): 126-130.

4 - Guitart Manday, D. 1975. Las pesquerias pelagico-oceanicas de corto radio de accíon en la regíon noroccidental de Cuba. *Ser. Oceanol. Acad. Cienc. Cuba*, 31: 1-26.

5 – Cliff, G., Dudley, S., Davis, B. 1990. Sharks caught in the protective gillnets of Natal, South Africa. 3. The shortfin mako shark *Isurus oxyrinchus* (Rafinesque). *Sth Afric. J. Mar. Sci.*, 9: 115-126.

6 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

7 - Mollet, H., Cliff, G., Pratt, H. Jr., Stevens, J. 2000. Reproductive biology of the female shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, with comments on the embryonic development of lamnoids. *Fish. Bull.,* 98: 299-318.

8 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome. 716 pp.

9 – Fishbase. 2017. *Isurus oxyrinchus*. http://fishbase.mnhn.fr/summary/Isurus-oxyrinchus.html

10 – Natanson, L., Kohler, N., Ardizzone, D., Cailliet, G., Wintner, S., Mollet, H. 2006. Validated age and growth estimates for the shortfin mako, *Isurus oxyrinchus*, in the North Atlantic Ocean. *Environ. Biol. Fish.,* 77: 367-383.

11 – Pratt, H.Jr., Casey, J. 1983. Age and growth of the shortfin mako, *Isurus oxyrinchus*, using four methods. *Can. J. Fisher. Aquat. Sci.,* 40(11): 1944–1957.

12 – Cailliet, G., Bedford, D. 1983. The biology of three pelagic sharks from California waters and their emerging fisheries: a review. *Cal. COFI Rep.* vol. XXIV.

13 - Ribot-Carballal, M., GalvánMagaña, G., Quiñónez-Velázquez, F. 2005. Age and growth of the shortfin mako shark *Isurus oxyrinchus* from the western coast of Baja California Sur, Mexico. *Fisher. Res.,* 76: 14-21.

14 – Conde, M. 2005. Aspectos de la biología reproductiva del tiburón mako *Isurus oxyrinchus* (Rafinesque 1810) en la costa occidental de Baja California Sur, México. B.Sc. dissertation, Universidad Autónoma de Baja California Sur, México. 72 pp.

15 – Bishop, S., Francis, M., Duffy, C., Montgomery, J. 2006. Age, growth, maturity, longevity and natural mortality of the shortfin mako (*Isurus oxyrinchus*) in New Zealand waters. *Mar. Freshw. Res*., 57:143–154.

16 – Hsu, H. 2003. Age, growth, and reproduction of shortfin mako, *Isurus oxyrinchus* in the northwestern Pacific. MS thesis, National Taiwan Ocean Univ., Keelung, Taiwan. 107 pp. [In Chinese].

17 – Chan, R. 2001. Biological studies on sharks caught off the coast of New South Wales. PhD Thesis, University of New South Wales, Sydney, Australia. 323 pp.

18 – Francis, M., Duvy, C. 2005. Length at maturity in three pelagic sharks (*Lamna nasus, Isurus oxyrinchus and Prionace glauca*) from New Zealand. *Fish. Bull.*, 103: 489-500.

19 – Cortés, E. 1999 Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.*, 56: 707-717.

20 – Joung, S.J., Hsu, H.H. 2005. Reproduction and embryonic development of the shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, in the northwestern Pacific. *Zool. Stud.*, 44(4): 487-496.

21 – Maia, A., Queiroz, N., Cabral, H., Santos, A., Correia, J. 2007. Reproductive biology and population dynamics of the shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, off the southwest Portuguese coast, eastern North Atlantic. *J. Appl. Ichthyol*., 23: 246-251.

22 – Campana, S., Marks, L., Joyce, W. 2005. The biology and fishery of shortfin mako sharks (*Isurus oxyrhinchus*) in Atlantic Canadian waters. *Fisher. Res*., 73: 341-352.

23 – Gilmore, R. 1993. Reproductive biology of lamnoid sharks. *Environ. Biol. Fish.*, 38(1-3): 95-114.

24 – Semba, Y., Nakano, H., Aoki, I. 2009. Age and growth analysis of the shortfin mako, *Isurus oxyrinchus*, in the western and central North Pacific Ocean. *Environ. Biol. Fish*., 84: 377–391.

25 – Bigelow, H., Schroeder, W. 1948. Sharks. In Fishes of the western North Atlantic. Mem. Sears Found. Mar. Res., Yale Univ., No. I (Part I): 59-546.

26 – Applegate, S. 1977. A new record-size bonito shark, *Isurus oxyrinchus* Rafinesque, from southern California. *Calif. Fish Game,* 63:126-129.

27 – Sanzo, L. 1912. Embrione di Carcharodon Rondeletii M. Hie. (?) con particolare disposizione del sacco vitellino. *Regio Comitate Talassografico Italiano, Memoria*, 11: 1-12.

28 – Suk, S., Smith, S., Raon, D. 2009. Bioaccumulation of mercury in pelagic sharks from the northeast Pacific Ocean. *Calif. COFI Rep*., 5: 172-177.

29 – Walker, T. 1988. Mercury concentrations in edible tissues of elasmobranchs, teleosts, crustaceans and mollusks from south-eastern Australian waters*. Austr. J. Mar. Freshw. Res.*, 39: 39-49.

30 – Bowman, R., Stillwill, C., Michaels, W., Grosslein, M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dept. Commer., *NOAA Tech. Mem. NMFS NE*, 155: 1-137.

31 – Stevens, J. 1984. Biological observation on sharks caught by sport fishermen off New South Wales. *Aust. J. Mar. Freshw. Res*., 35: 573–590.

32 – Bass, A., D'Aubrey, J., Kistnasamy, N. 1975: Sharks of the east coast of Southern Africa. IV. The Families Odontaspidae, Scapanorhynchidae, Isuridae, Cetorhinidae, Alopiidae, Orectolobidae and Rhiniodontidae. *Invest. Rep. Oceanog. Res. Inst.*, 39: 1-102.

33 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

34 – Rogers, P.J., Huveneers, C., Page, B., Hamer, D.J., Goldsworthy, S.D., Mitchell, J.G., Seuront, L. 2012. A quantitative comparison of the diets of sympatric pelagic sharks in gulf and shelf ecosystemsn off southern Australia. *ICES J. Mar. Sco. 69 (8*): 1382-1393.

35 – Biton Porsmoguer, S., Banaru, D., Béarez, P., Dekeyser, I., Fornelino, M.M. 2014. Unexpected headless and tailless fish in the stomach contente of shortfin mako *Isurus oxyrinchus. PLOS on*e, 9(2): e88488.

36 - Biton Porsmoguer, S., 2015. Biologie, écologie et conservation du requin peau bleue (Ptionace glauca) et du requin makp *(Isurus oxyrinchus*) en Atlantique nord-est. Thèse doctorat Océanographie, Université de Marseille. 20 Novembre 2015.

37 – Gorni, G., Loibel, S., Goitein, R., Amorim, A.F. 2012. Stomach contents analysis of shortfin mako (*Isurus oxyrinchus*) caught off southeren Brazil: a Baysesina analysis. *Collect. Vol. Sci. Pap. ICCAT,* 68(5): 1933-1937.

38 – Kone, A., N'Da, K., Kouassi, S.K., Agnissan, J.P. 2014. Dynamique de la population exploitée de deux requins: *Sphyrna zygaena* (Linnaeus, 1758) et *Isurus oxyrinchus* (Rafinesque, 1809) des côtes ivoiriennes. *Internat.l J. Biol.l & Chem. Sci*., 8(4).

39 – Doño, F., Montealegre-Quijanao, M., Domingo, A., Kinas, P.G. 2104. Bayesian age and growth analysis of the shortfin mako shark *Isurus oxyrinchus* in the Western South Atlantic Ocean using a flexible model. *Environ. Biol. Fish.*, 98(2): 517-533.

40 – Mas, F., Forselledo, R., Domingo, A. 2014. Length-Length relationships for six pelagic shark species commonly caught in the southwestern Atlantic Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 70(5): 2441-2445.

41 – IOTC. 2014. Proposition: Résumé exécutif: Requin-taupe bleu. 17th Scientific Committee, 8-12 December 2014, Victoria, Seychelles. IOTC document IOTC-2014-SC17-ES20(F): 7 pp.

42 – Rogers, P.J., Huveneers, C., Page, B., Goldsworthy, S.D., Coyne, M., Lowther, A.D., Mitchell, J.G., Seuront, M. 2015. Living on the continental shelf edge: habitat use of juvenile shortfin makos *Isurus oxyrinchus* in the Great Australian Bight, southern Australia. *Fish Oceanogr.* 24(3): 205-218.

43 – Verghese, S.P., Unnikrishnan, N., Deepak, K.G., Ayoob, A.E. 2017. Size, sex and reproductive biology of seven pelagic sharks in the eastern Arabian Sea. *J. Mar. Biol. Assoc. UK*, 97(1): 181-196.

44 – Groeneveld, J.C., Cliff, G., Dudley, S.F., Foulis, A.J., Santos, J., Wintner, S.P. 2014. Population structure and biology of shorfin mako, *Isurus oxyrinchus*, in the south-west Indian Ocean. *Mar. & Freshw. Res.*, 65(12): 1045-1058.

45 - Tsai, W.-P., Sun, C.-L., Punt, A.E., Lui, K.-M. 2014. Demographic analysis of the shortfin mako shark, *Isurus oxyrinchus*, in the Northwest Pacific using a two-sex stage-based matrix model. *ICES J. Mar. Sci.* 71(7): 1604-1618.

46 – Lyons, K., Preti, A., Madigan, D. J., Wells, R. J. D., Blasius, M. E., Snodgrass, O. E., Kacev, D., Harris, J. D., Dewar, H., Kohin, S., MacKenzie, K., Lowe, C. G. 2015. Insights into the life history and ecology of a large shortfin mako shark *Isurus oxyrinchus* captured in southern California. *J. Fish Biol.*, 87(1): 200-221.

47 – Wells, R.J., Smith, D., Kohin, S.E., Freund, S., Spear, E., Ramon, N., Darlen, A. 2013. Age validation of juvenile shortfin mako *(Isurus oxyrinchus)* tagged and marked with oxytetracycline off southern California. *Fish. Bull.* 111(2): 147-160.

48 – Bustamante, C., Bennett, M.B. 2013. Insights into the reproductive biology and fisheries of two commercially exploited species, shortfin mako *(Isurus oxyrinchus*) and blue shark (*Prionace galuca*) in the south-east Pacific Ocean. *Fish. Res.*, 143: 174-183.

49 – Clarke, S.C., Harley, S., Hoyle, S.D., Rice, J.S. 2013. Population trends in Pacific Oceanic sharks and the utility of regulations on shark finning. *Cons. Biol*., 27(1): 197-209.

50 – Kai, M., Shiozaki, K., Ohshimo S., Yokawa, K. 2015. Growth and spatiotemporal distribution of juvenile shortfin mako *(Isurus oxyrinchus*) in the western and central North Pacific. *Mar. & Freshw. Res*, 66(12): 1176-1190.

51 – Au, D.W., Smith, S.E., Show, C. 2015. New abbreviated calculation for measuring intrinsic rebound potential inexploited fish population - example for sharks. *Can. J. Fish. Aquat. Sci*., 72: 767-773.

Table III.25. Biological parameters for longfin mako (LMA, *Isurus paucus*).

Isurus paucus Quitart Manday, 1966 Longfin mako FAO code: LMA	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L∞ for female in cm										
K for female /year										
t_o for female in years										
L∞ for male in cm										
K for male /year										
t_o for male in years										
Longevity in years										
Maximum size TL in cm	417 426.7	1 7	417 426.7	1 7	417 426.7	1 7	417 426.7	1 7	417 426.7	1 7
Common size (FL) in cm										
Maximum weight in kg										
REPRODUCTION										
Female maturity size in cm	245	1	245	1	245	1	245	1	245	1
Female maturity age in years	14	8	14	8	14	8	14	8	14	8
Male maturity size in cm	245 229	1 7	245 229	1 7	245 229 263 TL (50%)	1 7 10	245 229	1 7	245 229	1 7
Male maturity age in years										
Birth size TL in cm	97-120 122 97	1-7 5 6	97-120 122 97	1-7 5 6	97-120 122 97	1-7 5 6	97-120 122 97	1-7 5 6	97-120 122 97	1-7 5 6
Sex ratio										
Mode of development	ovoviviparous	1	ovoviviparous	1	ovoviviparous	1	ovoviviparous	1	ovoviviparous	1
Gestation period in months										
Spawning & mating periods										
Fecundity: number of embryos per litter	2 2-8 2-4 2	2 3-7 8 6	2 2-8 2-4	2 3-7 8	2 2-8 2-4	2 3-7 8	2 2-8 2-4	2 3-7 8	2 2-8 2-4	2 3-7 8
Nursery ground										
CONVERSION FACTORS										
Length / Weight relationships					$W=2.54*10^{-4} *FL^{2.32}$	9				

Wet weight / dressed weight ratio										
TL / FL	FL=0.888*TL based on photo measurements	3	FL=0.888*TL based on photo measurements	3	FL=0.888*TL based on photo measurements	3	FL=0.888*TL based on photo measurements	3	FL=0.888*TL based on photo measurements	3
TL/PCL										
Fins / carcass ratios										
Stables isotopes N^{15} & C^{14}										
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)										
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.5	3	4.5	3	4.5	3	4.5	3	4.5	3

References

1 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). *FAO Spec. Cat. Fish. Purp*. 1(2): 269 p. Rome, FAO.

2 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome, 716 pp.

3 – Fishbase. 2017. *Isurus paucus*. http://fishbase.mnhn.fr/summary/Isurus-paucus.html

4 – Bowman, R., Stillwell, C., Michaels, W., Grosslein, M. 2000. Food of northwest Atlantic fishes and two common species of squid. *NOAA Tech. Memo. NMFS-NE*, 155: 1-138.

5 – Gilmore, R. 1993. Reproductive biology of lamnoid sharks. *Environ. Biol. Fish.,* 38(1/3): 95-114.

6 – Gilmore, R. 1983. Observations on the embryos of the longfin mako, *Isurus paucus,* and the bigeye thresher, *Alopias superciliosus. Copeia*, 1983: 375-382.

7 – Reardon, M., Gerber, L., Cavanagh, R. 2006. *Isurus paucus*. In IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1. www.iucnredlist.org.

8 – Simpfendorfer, C., Cortés, E., Heupel, M., Brooks, E., Babcock, E., Baum, J. 2008. An Integrated Approach to Determining the Risk of Over-exploitation for Data-poor Pelagic Atlantic Sharks: An Expert Working Group Report. Lenfest Ocean Program, Washington, D.C.

9 - García-Cortés, B., Mejuto, J. 2002. Size-weight relationships of the swordfish (*Xiphias gladius*) and several pelagic shark species caught in the Spanish surface longline fishery in the Atlantic, Indian and Pacific oceans. *Collect. Vol. Sci. Pap. ICCAT*, 54: 1132-1149.

10 – Verghese, S.P., Unnikrishnan, N., Deepak, K.G., Ayoob, A.E. 2017. Size, sex and reproductive biology of seven pelagic sharks in the esatern Arabian Sea. *J. Mar. Biol. Assoc. UK*, 97(1): 181-196.

Table III.26. Biological parameters for porbeagle (POR, *Lamna nasus*).

Lamna nasus (Bonnaterre, 1788) Porbeagle FAO code: POR	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L∞ for female in cm	L∞=253 FL L∞=309.8 FL	3 10 - 21								
K for female /year	k=0.097 k=0.061	3 10 - 2&								
t_0 for female in years	t_0=-4.89 t_0=-5.90	3 10 - 21								
L∞ for male in cm	L∞=253 FL L∞=257.7 FL	3 10 - 21								
K for male /year	k=0.097 k=0.08	3 10 - 21								
t_0 for male in years	t_0=-4.89 t_0=-5.78	3 10 - 21								
Longevity in years	30-45 25 (males) 24 (females) 45-46 (calculated) 26	1 11 11 11 14 - 17 - 18	26	1 4	26	1 4	26	1 4	26	1 4
Maximum size TL in cm	300 (possibly 370) 355 335	1 14 17	300 (possibly 370) 355	1 1 4	300 (possibly 370) 355	1 1 4	300 (possibly 370) 355 208 FL	1 1 4 1 7	300 (possibly 370) 355	1 1 4
Common size (FL) in cm										
Maximum weight in kg	230	5- 10	230	5- 1 0	230	5- 1 0	230	5- 1 0	230	5- 1 0
REPRODUCTION										
Female maturity size in cm	237 TL 212 FL 210-230 FL 217.5 FL (50%)	1 3 7 21					185-202 170-180 FL 185 TL 165-180 FL	1 6 1 4 4	185-202 195 TL	1 1 4
Female maturity age in years	14 13.1	1 3- 21								

Male maturity size in cm	196 TL 150-200 TL 175 FL 162-185 FL 173.7 FL (50%)	1 1 3 7 21	150-200 TL	1	150-200 TL	1	150-200 TL 140-150 FL 165 TL	1 6 1 4	150-200 TL 165 TL	1 1 4
Male maturity age in years	7 8.1	1- 3 7- 21								
Birth size TL in cm	60-75 65-75 61-76	1 3 15	60-75 65-75 61-76	1 3 1 5	60-75 65-75 61-76	1 3 1 5	60-75 65-75 61-76 60-80 58-67 FL	1 3 1 5 1 4	60-75 65-75 61-76 60-80	1 3 1 5 1
Sex ratio	3:1 embryos	17	3:1 embryos	1 7	3:1 embryos	1 7	3:1 embryos	1 7	3:1 embryos	1 7
Mode of development	ovoviviparous	1	ovoviviparou s	1	ovoviviparou s	1	ovoviviparous	1	ovoviviparou s	1
Gestation period in months	8-9	1					8-9	1- 4	8-9	1
Spawning & mating periods	late Summer Spring	1			Winter	1 4	Winter June-Juy	1 4 4	Winter	1 4
Fecundity: number of embryos per litter	1-5 4 4	1- 17 3 7	1-5	1- 1 7	1-5	1- 1 7	1-5	1- 1 7	1-5	1- 1 7
Nursery ground	off the coast of Europe & the British south of 54°12'S and over the continental edge	10 22	may be in continental waters	1	may be in continental waters	1	may be in continental waters	1	may be in continental waters	1
CONVERSION FACTORS										
Length / Weight relationships	$W=1.4823*10^{-6} *FL^{2.9641}$ $W=0.5*10^{-4} *FL^{2.713}$ $W=0.001922*TL^{2.008}$ (males) $W=0.000315*TL^{2.327}$ (females) $W=5e^{-05}*TL^{2.6307}$ $W=6e^{-05}*FL^{2.6535}$	2 3 12 - 13 12 - 13 19 19					$W=0.0000286 * FL^{2.924}$ Log10 W= -5.050 + 3.128 Log10 FL	1 0 4		
Wet weight / dressed weight ratio										
TL / FL	FL=1.7939 + 0.8971*TL FL=0.99+ 0.885*TL TL=1.12*FL TL=1.1755*FL+0.6 03 TL=0.742 + 1.147*FL	2 3 3 19 22					TL= 4.165 +1.098*FL F = -0.567 +0.881*TL	4		
TL/PCL	PCL=0.8918*FL-0.7261 FL=2.619 + 1.102*PCL(males) FL=2.082 + 1.102*PCL (female)	19 23 23					PCL= -1.366 +0.907*FL FL= - 1.990 + 1.098*PCL PC = 4.165 +1.098*FL FL= -0.567	4		

							+0.881*TL			
Fins / carcass ratios										
Stables isotopes N^{15} & C^{14}										
POPULATION DYNAMICS										
Stock delineation/range	migrations 5000 to 13 000 km / year with site fidelity to Bay of Biscay	20			CPUE do not show declining trend	24	CPUE do not show declining trend	24	CPUE do not show declining trend	24
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)	0.223	25								
Intrinsic rebound potential ($r_{z(MSY)}$)	0.0309 - 0.0331	25								
Trophic level	4.2	9	4.2	9	4.2	9	4.2	9	4.2	9

References

1 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). *FAO Spec. Cat. Fish. Purp*., 1(2): 1-269. Rome, FAO.

2 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

3 – Campana, S., Marks, L., Joyce, W., Hurley, P., Showell, M., Kulka, D. 1999. An analytical assessment of the porbeagle shark (*Lamna nasus*) population in the northwest Atlantic. CSAS. Res. Doc. 99/158.

4 – Francis, M., Stevens, J. 2000. Reproduction, embryonic development and growth of the porbeagle shark, *Lamna nasus*, in the South-west Pacific Ocean. *Fisher. Bull.,* 98: 41–63.

5 – IGFA. 2001. Database of IGFA angling records until 2001. IGFA, Fort Lauderdale, USA.

6 – Francis, M., Duvy, C. 2005. Length at maturity in three pelagic sharks (*Lamna nasus*, *Isurus oxyrinchus* and *Prionace glauca*) from New Zealand. *Fish. Bull.,* 103: 489-500.

7 – Jensen, C., Natanson, L., Pratt, H., Kohler, N., Campana, S. 2002. The reproductive biology of the porbeagle shark, *Lamna nasus,* in the western North Atlantic Ocean. *Fish. Bull.,* 100: 727-738.

8 – Campana, S., Joyce, W. 2004. Temperature and depth associations of porbeagle shark (*Lamna nasus*) in the northwest Atlantic. *Fish. Oceanogr.,* 13(1): 52-64.

9 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

10 – Fishbase. 2017. *Lamna nasus*. http://fishbase.mnhn.fr/summary/Lamna-nasus.html

11 – Natanson, L., Mello, J., Campana, S. 2002. Validated age and growth of the porbeagle shark (*Lamna nasus*) in the western North Atlantic Ocean. *Fish. Bull.,* 100(2): 266-278.

12 – Coull, K., Jermyn, A., Newton, A., Henderson, G., Hall, W. 1989. Length/weight relationships for 88 species of fish encountered in the North Atlantic. *Scottish Fish. Res. Rep*., 43: 1-80.

13 – Shanks, A. 1988. Whole weight/length and gutted weight/length relationships for porbeagles. DAFS Marine Laboratory Internal Report.

14 – Stevens, J., Fowler, S., Soldo, A., McCord, M., Baum, J., Acuña, E., Domingo, A., Francis, M., 2006. *Lamna nasus*. In IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1.

15 – Gilmore, R. 1993. Reproductive biology of lamnoid sharks. *Environ. Biol. Fish.,* 38: 95-114.

16 – Bowman, R., Stillwill, C., Michaels, W., Grosslein, M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dept. Commer., *NOAA Tech. Mem. NMFS NE,* 155: 1-137.

17 – Francis, M., Natanson, L., Campana, S. 2008. The biology and ecology of the porbeagle shark, *Lamna nasus*. 105-113 pp. In Cahmi, M.D., Pikitch, E.K., Babcock, E.A. (Eds.) Sharks of the open ocean, Biology, Fishery and Conservation. Blackwell Publishing, Oxford UK.

18 – Campana, S., Joyce, W., Marks, L., Natanson, L., Kohler, N., Jensen, C., Mello, J., Pratt, H. Jr., Myklevoll, S. 2002. Population dynamics of the porbeagle in the Northwest Atlantic Ocean. *North. Am. J. Fish. Managt.*, 22:106–121.

19 – Bendall, V.J., Ellis, J.R., Hetherington, S.J., McCully, S.R., Righton, D., Silva, J.F. 2013. Preliminary observations on the biology and movements of porbeagle *Lamna nasus* around the British Isles. *Collect. Vol. Sci. Pap. ICCAT*, 69(4): 1702-1722.

20 – Biais, G., Coupeau, Y., Séret, B., Calmettes, B., Lopez, R., Hetherington, S., Righton, D. 2017. Return migration patterns of porbeagle shark (*Lamna nasus*) in the Northeast Atlantic: implications for stock range and structure. *ICES J. Mar. Sci*., 74 (5): 1268: 1276.

21 – Campana, S.E., Gibson, A.J.F., Fowler, M., Dorey, A., Joyce, W., 2012. Population dynamics of Northwest Atlantic porbeagle (*Lamna nasus)*, with an assessment of status and projections for recovery. Research document of the Canadain Science Advisory Secretariat n° 2012/096: 88 pp.

22 – Cortès, F., Waessie, J.A. 2016. Hotspots for porbeagle shark (*Lamna nasus*) byctach in the southwestern Atlantic (51°S-57°S). *J. Canad. Sci. Halieut. & Aquat*., 74(7): 1100-1110.

23 – Mas, F., Forselledo, R.,Domingo, A. 2014. Length-Length relationships for six pelagic shark species commonly caught in the southwestern Atlantic Ocean*. Collect. Vol. Sci. Pap. ICCAT*, 70(5): 2441-2445.

24 – Semba, Y., Yokawa, K., Matsunaga, H., Shono, H. 2013. Distribution and trend in abundance of the porbeagle *(Lamna nasus)* in the southern hemisphere. *Mar. & Freshw. Res.*, 64(6): 518-529.

25 – Au, D.W., Smith, S.E., Show, C. 2015. New abbreviated calculation for measuring intrinsic rebound potential inexploited fish population - example for sharks. *Can. J. Fish. Aquat. Sci*., 72: 767-773.

Table III.27. Biological parameters for blue shark (BSH, *Prionace glauca*).

Prionace glauca (Linnaeus, 1758) Blue shark FAO code: BSH	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
					AGE & GROWTH					
L∞ for female in cm	L∞=310 FL L∞=394 L∞=423 L∞=311.6 TL	13 21 - 23 21 - 34 50			L∞=311.6 TL	50	L∞=235.5 L∞=304 L∞=243.3	7 21 16 - 29	L∞=237.5 TL L∞=241.9 L∞=243.3	12 12 - 14 16 - 29
K for female /year	k=0.16 k=0.13 k=0.11 k=0.12	13 21 - 23 21 - 34 50			k=0.12	50	k=0.2297 k=0.16 k=0.144	7 21 16 - 29	k=0.15 k=0.25 k=0.144	12 12 - 14 16 - 29
t_0 for female in years	t_0=-1.56 t_0=-0.80 t_0=-1.04 t_0=-1.66	13 21 - 23 21 - 34 50			t0=-1.66	50	t_0= -1.01 t_0=-0.849	21 16 - 29	t_0=-2.15 t_0=-0.79 t_0=-0.849	12 12 - 14 16 - 29
L∞ for male in cm	L∞=282 FL L∞=394 L∞=423 L∞=311.6 TL	13 21 - 33 21 - 34 50			L∞=311.6 TL	50	L∞= 297.18 L∞=369 L∞=289.7	7 21 16 - 29	L∞=299.85 TL L∞=295.3 TL L∞=289.7	12 12 - 14 16 - 29
K for male /year	k=0.18 k=0.13 k=0.11 k=0.12	13 21 - 33 21 - 34 50			k=0.12	50	k=0.1650 k=0.1 k=0.129	7 21 16 - 29	k=0.10 k=0.18 k=0.129	12 12 - 14 16 - 29
t_0 for male in years	t_0=-1.35 t_0=-0.80 t_0=-1.04 t_0=-1.66	13 21 - 33 21 - 34 50			t0=-1.66	50	t_0=-1.38 t_0=-0.756	21 16 - 29	t_0=-2.44 t_0=-1.11 t_0=-0.756	12 12 - 14 16 - 29
Longevity in years	>20 16-20	1- 3 13	>20	1- 3	>20	1- 3	>20 22.76 (males) 19.73 (females)	1- 3 7 7	>20	1- 3
Maximum size TL in cm	383 396.2	2 30	383 396.2	2 30	383 396.2	2 30	383 396.2	2 30	383 396.2	2 30

Common size (FL) in cm	335 93-387 TL 240 FL 156-250	3 20 22 25	335 180-240 FL	3 22	335 170-330 (males) 130-330 (females) 180-240FL	3 22-23 22-23 22	335 180-240 FL	3 22	335 180-240 FL	3 22
Maximum weight in kg										
REPRODUCTION										
Female maturity size in cm	221 >185 228 TL 180 FL (50%) 194.4 TL 171.1 FL	1 19 25-28 35 50 56	221	1	221 194.4 TL	1 50	221 170-190 FL 170-195 FL 186-212 199.2 TL (50%)	1 6 7 16-17 58	221 186-212 199.2 TL (50%)	1 16 58
Female maturity age in years	5-6 6 5-7 5 6 5-6	1 19 28-29 25-28 50 56	5-7	28-29	5-7 6	28-29 50	5-7 7-9 5-6	28-29 7 16-17	5-6 5-7	16-17 28-29
Male maturity size in cm	182-281? 193-210 FL (50%) 183 FL 225 FL L_{95}=205 FL 201.4 TL 185-241 FL 180.2 FL	1-3 17-18 19 25-28 36 50 52 56	182-281?	1-3	182-281? 201.4 TL 207 TL (50%)	1-3 50 57	182-281? 190-195 FL 203 190.3 TL (50%)	1-3 6-7 16-17 58	182-281? 203 190.3 TL (50%)	1-3 16-17 58
Male maturity age in years	4-5 4-6 7	1 28-29 50	4-6	28-29	4-6	28-29	4-6 8 4-5	28-29 7 16-17	4-6 4-5	28-29 16-17
Birth size TL in cm	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50 43.5	1-19 29 46-47 14-30
Sex ratio	1:1 (embryos)	17-35			1:1 (embryos)	1	1:1 (embryos) 4:5	17 46	1:1 (embryos)	17
Mode of development	placental viviparous	1-19	placental viviparous	1-19	placental viviparous	1-19	placental viviparous	1-19	placental viviparous	1-19
Gestation period in months	9-12	1-19-29	9-12	1-29	9-12	1-29	9-12	1-29	9-12	1-29

Spawning & mating periods	Spring to early Summer December/ July pupping group off Azores	1- 7 36 54	Spring to early Summer	1	Spring to early Summer	1	Spring to early Summer	1- 7	Spring to early Summer	1- 7
Fecundity: number of embryos per litter	4-135 4-63 up to 82 30 in average 43-55 33 (median litter)	1 2 3 19 50 56	4-135 4-63 up to 82 30 in average	1 2 3 19	4-135 4-63 up to 82 30 in average 43-55	1 2 3 19 50	4-135 4-63 up to 82 30 in average 1-62 4-57	1 2 3 19 16 - 17 46	4-135 4-63 up to 82 30 in average 1-62	1 2 3 19 16 - 17
Nursery ground	nursery in central North Atlantic where juveniles stay up to 2 years									
CONVERSION FACTORS										
Length / Weight relationships	LogW=-5.396 + 3.134logTL WT=0.0110*$TL^{2.828}$ WT=3.1841*10^{-6}*$FL^{3.1313}$ WT= 0.392 *10^{-6}*$TL^{3.41}$ (males) WT= 0.131*10^{-5}*$TL^{3.20}$ (females)	1 9 10 34 - 37 34 - 37	LogW=-5.396 + 3.134logTL		LogW=-5.396 + 3.134logTL WT=0.159*10^{-4}*$LF^{2.84554}$	1 26	LogW=-5.396 + 3.134logTL WT= 3.8838*10^{-6} *$TL^{3.174}$ (males) WT= 2.328*10^{-6}*$PCL^{3.294}$ (females) W= 3.113*10^{-6}*$TL^{3.04}$	1 37 - 38 37 - 38 46	LogW=-5.396 + 3.134logTL WT= 3.8838*10-6 *TL3.174 (males) WT= 2.328*10-6*PCL3.294 (females) WT= 2.57*10^{-5}*$TL^{3.05}$	1 37 - 38 37 - 38 37 - 40
Wet weight / dressed weight ratio										
TL / FL	FL=0.8313TL+ 1.3908 FL=1.73872 + 0.82995TL TL=1.175*FL +4.103 FL=11.27 + 0.78TL (males) FL=23.52 + 0.73TL FL=-1.2+0.842TL TL=3.8+1.17FL FL=-1.061 + 0.8203TL TL=1.716 + 1.2158FL FL=1.837 + 1.091*PCL males FL=1.837 + 1.086*PCL females TL=2.045 + 1.200*FL males TL=1.694 +1.200*FL females	10 19 22 37 - 39 37 - 39 27 27 35 35 55 55 55 55					FL= -1.615+0.838TL_{nat}	6	FL= -1.615+0.838TL_{nat}	6
TL/PCL	PCL= 3.92 + 0.74TL (males) PCL= 28.95 + 0.63TL (females)	27 - 39			ratio 2.40-2.47	20	PCL=0.762TL - 2.505	37 - 38		
Fins / carcass ratios	FW=65.84BW/0.0888	27	FW/BW=5.65	48	FW/BW=5.65	48	FW/BW=5.65	48	FW/BW=5.65	48
Stables isotopes N^{15} &										

C^{14}										
POPULATION DYNAMICS										
Stock delineation/range							catch rate declining 5%/ year horizontal & vertical sex-size segregation	59 60	catch rate declining 5%/ year horizontal & vertical sex-size segregation	59 60
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)	0.278	61								
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.1 4.8	32 51	4.1	32	4.1	32	4.1	32	4.1	32

References

1 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. *FAO Fish. Synop.,* 125(4/2): 251-655. Rome, FAO.

2 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome, 716 pp.

3 – Fishbase. 2017. *Prionace glauca*. http://www.fishbase.org/summary/speciessummary.php?id=898

4 – IGFA. 2001. Database of IGFA angling records until 2001. IGFA, Fort Lauderdale, USA.

5 – ICES. 1997. Demersal Fish Committee, 1997 Report of the Study Group on Elasmobranchs.ICES CM /G:2: 123 pp.

6 – Francis, M., Duvy, C. 2005. Length at maturity in three pelagic sharks (*Lamna nasus*, *Isurus oxyrinchus* and *Prionace glauca*) from New Zealand. *Fish. Bull.,* 103: 489-500.

7 – Manning, M. 2005. Age and growth of blue shark (*Prionace glauca*) from New Zealand Exclusive Economic Zone. New Zealand Fisheries Fisheries Assessment Report 2005/26: 52 pp.

8 - Florida Museum of Natural History. Biological profiles: blue shark. Ichthyology at the Florida Museum of Natural History: Education-Biological Profiles. FLMNH, University of Florida. http://www.flmnh.ufl.edu/fish/Gallery/Descript/BlueShark/BlueShark.html

9 – Frota, L., Costa, P., Braga, A. 2004. Length-weight relationships of marine fishes from the central Brazilian coast. *NAGA WorldFish Center Q.*, 27: 20-26.

10 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

11 – McCord, M., Campana, S. 2003. A quantitative assessment of the diet of the blue shark (*Prionace glauca)* off Nova Scotia, Canada. *J. Nthwest. Atl. Fisher. Sci.*, 32: 57–63.

12 - Blanco-Parra, M., Galvan-Magana, F., Marquez-Farias, F. 2008. Age and growth of the blue shark, *Prionace glauca* Linnaeus, 1758, in the Northwest coast off Mexico. *Revist. Biol. Mar. Oceanog.*, 43(3): 513-520.

13 – Skomal, G., Natanson, L. 2003. Age and growth of the blue shark, *Prionace glauca*, in the North Atlantic Ocean. *Fisher. Bull.,* 101(3): 627-639.

14 – Caillet, G., Martin, L., Kusher, D., Wolf, P., Welden, B. 1983. Preliminary studies on the age and growth of the blue, *Prionace glauca*, common thresher, *Alopias vulpinus*, and shortfin mako, *Isurus oxyrinchus*, sharks from California waters. In Prince E. & Pulos L. (eds). Proceedings of the International workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. *NOAA Tech. Rep. NMFS,* 8: 179-188.

15 – Nakano, H., Nagasawa, K. 1996. Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. *Fisher. Sci.,* 62(6): 860-865.

16 – Nakano, H. 1994. Age, reproduction and migration of blue shark in the North Pacific Ocean. *Bull. Natl. Res. Inst. Far Sea Fisher*., 31: 141-256.

17 - Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2006. Assessment and Status Report on the Blue Shark, *Prionace glauca*, Atlantic Population, Pacific Population, in Canada. COSEWIC, Ottawa, ON.

18 – Campana, S., Marks, L., Joyce, W., Kohler, N. 2004. Influence of recreational and commercial fishing on the blue shark (*Prionace glauca*) population in Atlantic Canadian Waters. Canadian Science Advisory Secretariat Research Document 2004/069: 67 pp.

19 – Pratt, H. 1979. Reproduction in the blue shark, *Prionace glauca*. *Fish. Res. Bull,.* 77: 445-470.

20 – Arocha, F., Tavares, R., Silva, J., Marcano, L. 2005. Blue shark, *Prionace glauca*, length composition from the Venezuelan longline fleet in the northwestern Atlantic: Period 1994-2003. *Collect. Vol. Sci. Pap*. *ICCAT*, 58: 942-950.

21 – Tanaka, S., Cailliet, G., Yudin, K. 1990. Differences in growth of the blue shark, *Prionace glauca*: technique or population? 177-187 pp. In Pratt, H.Jr., Gruber, S., Taniuchi, T. (eds), Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Systematics, and Status of the Fisheries. *NOAA Tech. Rep.,* 90.

22 – IOTC. 2007. Compilation of information on blue shark (*Prionace glauca*), silky shark (*Carcharhinus falciformis*), oceanic whitetip shark (*Carcharhinus longimanus*), scalloped hammerhead (*Sphyrna lewin*i) and shortfin mako (*Isurus oxyrinchus*) in the Indian Ocean. 3rd Working Party on Ecosystems and Bycatch, 11-13 July 2007, Victoria, Seychelles. IOTC document IOTC-2007-WPEB-INF01: 18 pp.

23 – Gubanov, Y., Grigoryev, V. 1975. Observations on the distribution and biology of the blue shark *Prionace glauca* (Carcharhinidae) of the Indian Ocean. *J. Ichthyol.,* 15: 37−43.

24 - Santos, M. Garcia, A. 2005. Factors for conversion of fin weight into round weight for the blue shark (*Prionace glauca*). *Collect. Vol. Sci. Pap. ICCAT,* 58(3): 935-941.

25 – Hazin, F., Boeckman, C., Leal, E., Lessa, R., Kihara, K., Otsuka, K. 1994. Distribution and relative abundance of the blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean. *Fish. Bull.,* 92: 474-480.

26 – IOTC. 2011. Etat de la ressource du requin peau bleue (*Prionace glauca*). 14th Scientific Committee, 12-17 December 2011, Victoria, Seychelles. IOTC document IOTC-2011-SC14-26.

27 – Campana, S., Marks, L., Joyce, W., Kohler, N. 2005. Catch, by-catch and indices of population status ofblue shark (*Prionace glauca*) in the Canadian Atlantic. *Collect. Vol. Sci. Pap. ICCAT,* 58(3): 891-934.

28 – ICCAT. Manuel de l'ICCAT : Requin peau bleue. 2.2.1.1 BSH.

29 – Nakano, H., Stevens, J. 2008. The biology and ecology of the blue shark, *Prionace glauca*. 140-151 pp. In Camhi, M., Pikitch, E., Babcock, E. (Eds.). Sharks of the open ocean, Biology, Fishery and Conservation. Blackwell Publishing, Oxford UK.

30 – Cailliet, G., Bedford, D. 1983. The biology of three pelagic sharks from California waters, and their emerging fisheries: a review. *Calif. Coop. Oceanic Fish. Invest. Rep.*, 24: 57–69.

31 – Stevens, J., Brown, B. 1974. Occurrence of heavy metals in the blue shark (*Prionace glauca)* and selected pelagic in the N.E. Atlantic Ocean. *Mar. Biol.*, 26: 287–293.

32 – Cortés, E. 1999 Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

33 – Aasen, O. 1966. Blahaien, *Prionace glauca* (Linnaeus), 1758. *Fisken Havet*, 1:1-15.

34 – Stevens, J. 1975. Vertebral rings as a means of age determination in the blue shark *(Prionace glauca* L.). *J. Mar. Biol. Assoc. U.K*., 55: 657-665.

35 – Castro, J., Mejuto, J. 1995. Reproductive parameters of blue shark, *Prionace glauca*, and other sharks in the Gulf of Guinea. *Mar. Freshw. Res.,* 46: 967-973.

36 – Hazin, F., Boeckmann, C., Leal, E., Otsuka, K., Kihara, K. 1994. Reproduction of the blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean. *Fish. Sci.,* 60: 487-491.

37 – Nakano, H., Seki, M. 2002. Synopsis of biological data on the blue shark, *Prionace glauca* Linnaeus. *Bull. Fish. Res*., 6: 18-55.

38 – Nakano, H. Makihara, M., Himazaki, K. 1985. Distribution and biological characteristics of the blue shark in the central North Pacific. *Bull. Fac. Fisher., Hokkaido Univ.,* 36(3): 99-113.

39 – Hazin, F., Lessa, R., Ishio, M., Otsuka, K., Kihara, K. 1991. Morphometric description of the blue shark, *Prionace glauca*, from the Southwestern equatorial Atlantic. *Tokyo Suisandai Kempo*, 78: 137-144.

40 – Harvey, J. 1989. Food habits, seasonal abundance, size, and sex of the blue shark, *Prionace gluaca*, in Montery Bay, California. *Calif. Fish & Game,* 75(1): 33-44.

41 – Walker, T. 1988, Mercury concentrations in edible tissues of elasmobranchs, teleosts, crustaceans and mollusks from south-eastern Australian waters. *Austr. J. Mar. Freshw. Res.,* 39: 39-49.

42 – Branco, V., Canario, J., Vale, C., Raimundo, J., Reis, C. 2004. Total and organic mercury concentrations in muscle tissue of the blue shark (*Prionace glauca* L.1758) from the Northeast Atlantic. *Mar. Pol. Bull.,* 49: 871–874.

43 – Davenport, S. 1995. Mercury in blue sharks and deepwater dogfish from around Tasmania. *Austr. Fish.,* 54 (3): 20–22.

44 – Storelli, M., Giacominelli-Stuffer, R., Marcotrigiano, G. 2001. Total mercury and methylmercury in tuna fish and sharks from the South Adriatic sea. *Ital. J. Food Sci.*, 13 (1): 101–106.

45 – Bowman, R., Stillwill, C., Michaels, W., Grosslein, M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dept. Commer., *NOAA Tech. Mem. NMFS NE*, 155: 1-137.

46 – Stevens, J. 1984. Biological observation on sharks caught by sport fishermen off New South Wales. *Aust. J. Mar. Freshw. Res.,* 35: 573–590.

47 – Bass, A., D'Aubrey, J., Kistnasamy, N. 1973. Sharks of the east coast of southern Africa. I. The genus *Carcharhinus* (Carcharhinidae). *Invest. Rep. Oceanogr. Res. Inst.* 33: 1-168.

48 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

49 – Rabehagasoa, N., Lorrain, A., Bach, P., Potier, M., Jaquemet, S., Richard, P., Ménard, F. 2012. Isotopic niches of the blue shark *Prionace glauca* and the silky shark *Carcharhinus falciformis* in the southwestern Indian Ocean. *Endang. Spec. Res*., 17: 83-92.

50 – Jolly, K.A., da Silva, C., Attwood, C.G. 2013. Age, growth and reproductive biology of the blue shark *Prionace glauc*a in South African waters. *Afr. J. Mar. Sci., 35*(1): 99-109.

51 – Biton, S. 2015. Biologie, écologie et conservation du requin peau bleue (*Prionace glauca*) et du requin mako (*Isurus oxyrinchus*) en Atlantique nord-est. Thèse doctorat Océanographie, Université de Marseille. 20 Novembre 2015.

52 – Calich, H.J., Campana, S.E. 2015. Mating scars reveal size in immature female blue shark *Prionace glauca. J. Fish Biol.*, 86 (6): 1845-1851.

53 – Vandeperre, F., da Silva, A.A., Fontes, J., Dantos, M., Santos, S.S., Afonso, P. 2014. Movements of Blue Sharks (*Prionace glauca*) across their life history*. PLOS one*, 9(8): e103538.

54 – Vandeperre, F., da Silva, A.A., Santos, M., Ferreira, R., Bolten, A.B., Santos, R.S., Afonso, P. 2014. Demography and ecology of blue shark (*Prionace glauca*) in the central North Atlantic. *Fish. Res.*, 153: 89-102.

55 – Mas, F., Forselledo, R., Domingo, A. 2014. Length-Length relationships for six pelagic shark species commonly caught in the southwestern Atlantic Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 70(5): 2441-2445.

56 - Montealegre-Quijano, S., Cardosos, A.T.C., Silva, R.Z., Kinas, P.G., Vooren, C.M. 2014. Sexual development, size at maturity, size at maternity and fecudity of the blue shark *Prionace glauca* (Linnaeus, 1758) in the Southwest Atlantic. *Fish. Res.*, 160: 18-32.

57 – Verghese, S.P., Unnikrishnan, N., Deepak, K.G., Ayoob, A.E. 2017. Size, sex and reproductive biology of seven pelagic sharks in the esatern Arabian Sea. *J. Mar. Biol. Assoc. UK,* 97(1): 181-196.

58 – Bustamante, C., Bennett, M.B. 2013. Insights into the reproductive biology and fisheries of two commercially exploited species, shortfin mako (*Isurus oxyrinchus)* and blue shark *(Prionace galuca)* in the south-east Pacific Ocean. *Fish. Res.,* 143: 174-183.

59 – Clarke, S.C., Harley, S., Hoyle, S.D., Rice J.S., 2013. Population trends in Pacific Oceanic sharks and the utility of regulations on shark finning. *Conserv. Biol.,* 27(1): 197-209.

60 – Vögler, R., Beier, E., Ortega-Garcia, S., Santana-Hernandez, H., Valdez-Flores, J.J. 2012. Ecological patterns, distrtibution and populations stucture of *Prionace glauca* in the tropical-subtropical transition zone of the northeastern Pacific. *Mar. Environ. Res*., 73: 37-52.

61 – Au, D.W., Smith, S.E., Show, C. 2015. New abbreviated calculation for measuring intrinsic rebound potential inexploited fish population - example for sharks. *Can. J. Fish. Aquat. Sci*., 72: 767-773.

Table III.28. Biological parameters for scalloped hammerhead (SPL, *Sphyrna lewini*).

Sphyrna lewini (Griffith & Smith, 1834) Scalloped hammerhead FAO code: SPL	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L_∞ for female in cm	L_∞=329 TL L_∞=233.1 FL L_∞=300 TL	5 12 16					L_∞=319.72 TL	6	L_∞=353.3 TL L_∞=376 TL	13 17
K for female /year	k=0.073 k=0.09 k=0.05	5 12 16					k=0.249	6	k=0.156	13 17
t_0 for female in years	t_0=-2.2 t_0=-2.2 L_0= 51 cm TL	5 12 16					t_0=0.413	6	t_0=-0.63 t_0=-1.16	13 17
L_∞ for male in cm	L_∞=329 TL L_∞=214.8 FL L_∞=266 TL	5 12 16					L_∞=320.59 TL	6	L_∞=336.4 TL L_∞=364 TL	13 17
K for male /year	k=0.073 k=0.13 k=0.05	5 12 16					k=0.222	6	k=0.131 k=0.123	13 17
t_0 for male in years	t_0=-2.2 t_0=-1.62 L_0= 51 cm TL	5 12 16					t_0=-0.746	6	t_0=-1.09 t_0=-1.18	13 17
Longevity in years	35 30.5 55	4 12 16	35	4	35	4	35	4	35	4
Maximum size TL in cm	370-420	1	370-420	1	370-420	1	370-420 309	1 18	370-420 309	1 18
Common size (FL) in cm										
Maximum weight in kg	152.4 166	3 9	152.4	3	152.4	3	152.4	3	152.4	3
REPRODUCTION										
Female maturity size in cm	212 250 210-250 240	1 5 11 15	212 210-250	1 11	212 200 210-250 228.5 LT_{50}	1 10 11 13	212 210 200 210-250 228.5	1 6 10 11 13	212 210-250	1 11
Female maturity age in years	15	5					4.1	6		
Male maturity size in cm	140-165 180 140-198 180	1 5 11 15	140-165 140-198	1 11	140-165 150 140-198 175.5 LT_{50}	19 10 11 13	140-165 198 150 140-198 175.6TL_{50}	1 6 10 11 13	140-165 140-198	1 11
Male maturity age in years	10	5					3.8	5		

Birth size TL in cm	42-55 45-50 49 31-57	1 2 5 11	42-55 45-50 31-57	1 2 11	42-55 45-50 31-57 40	1 2-10 11 13	42-55 45-50 31.3-48.9 31-57 40	1 2-10 6 11 13	42-55 45-50 31-57	1 2 11
Sex ratio					1:1 (embryos)	10	1:1 (embryos)	10-18-20-21	1:1	18
Mode of development	viviparous	1	viviparous	1	viviparous	1	viviparous	1	viviparous	1
Gestation period in months	9-10	3	9-10	3	9-10	3-10	9-10	3-10	9-10	3
Spawning & mating periods	Spring-Summer	11	Spring-Summer	11	September-December	10	September-December	10	Spring-Summer	11
Fecundity: number of embryos per litter	15-31 12-41 2-21 15-31	1 11 15 10-18-19	15-31 12-41 2-21 15-31	1 11 15 10-18-19	15-31 12-41 14-41 15-31	1 11 13 10-18-19	15-31 12-41 2-21 15-31	1 11 15 10-18-19	15-31 12-41 15-31	1 11 10-18-19
Nursery ground	Bulls Bay South Carolina	22					Kaneohe Bay Oahu Hawaii	18	North Gulf California Kaneohe Bay Oahu Hawaii	11 18
CONVERSION FACTORS										
Length / Weight relationships	$W=1.26*10^{-5}*TL^{2.81}$ $WT=7.7745*10^{-6}*FL^{3.0669}$	5 9			$W=3.99*10^{-6}*TL^{3.03}$	10	$W=3.99*10^{-6}*TL^{3.03}$ $W+1.35*10^{-6}*TL^{3.252}$ (males) $W=2.82*10^{-6}*TL^{3.129}$ (females)	10 6 6	$WT=1.05*10^{-5}*TL^{2.87}$ (males) $WT=2*10^{-5}*TL^{2.8}$ (females) $W=4.03*10^{-6}*TL^{3}$ (both sexes)	13 13 17
Wet weight / dressed weight ratio										
TL / FL	TL=1.31*FL-0.64 FL=0.7756*TL-0.3132 TL=1.296*FL+0.516	5 9 12			TL=1.28+1.3*TL	10	TL=1.28+1.3*TL	10		
TL/PCL										
Fins / carcass ratios										
Stables isotopes N15 & C14										
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)										

Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.1 4.5	7 8	4.1	7	4.1	7	4.1	7	4.1	7

References

1 – Compagno, LJ.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. *FAO Fish. Synop. ;* 125(4/2): 251-655. Rome, FAO.

2 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. Rome, FAO. 716 pp.

3 – Fishbase. 2017. *Sphyrna lewini*. http://fishbase.mnhn.fr/summary/Sphyrna-lewini.html

4 – Smith, S., Au, D., Show, C. 1998. Intrinsic rebound potential of 26 species of Pacific sharks. *Mar. Freshw. Res*., 49: 663-678.

5 – Branstetter, S. 1987. Age, growth and reproductive biology of the silky shark, *Carcharhinus falciformis*, and the scalloped hammerhead, *Sphyrna lewini*, from the northwestern Gulf of Mexico. *Environ. Biol. Fish*., 19(3): 161-173.

6 – Chen, C.-T., Leu, T.-C., Joung, S.-J., Lo, N.-C.-H. 1990. Age and growth of the scalloped hammerhead, *Sphyrna lewini*, in northeastern Taiwan waters. *Pac. Sci.,* 44(2): 156-170.

7 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

8 – Bowman, R., Stillwell, C., Michaels, W., Grosslein, M. 2000. Food of northwest Atlantic fishes and two common species of squid. *NOAA Tech. Mem. NMFS-NE,* 155: 1-138.

9 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

10 – Stevens, J., Lyle, J. 1989. Biology of three hammerhead sharks (*Eusphyra blochii*, *Sphyrna mokarran* and *S. lewini*) from northern Australia. *Aust. J. Mar. Freshw. Res.,* 40(2): 129-146.

11 – Baum, J., Clarke, S., Domingo, A., Ducrocq, M., Lamónaca, A., Gaibor, N., Graham, R., Jorgensen, S., Kotas, J., Medina, E., Martinez-Ortiz, J., Monzini Taccone di Sitizano, J., Morales, M., Navarro, S., Pérez-Jiménez, J., Ruiz, C., Smith, W., Valenti, S., Vooren, C. 2007. *Sphyrna lewini*. In IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1.

12 – Piercy, A., Carlson, J., Sulikowski, J., Burgess, G. 2007. Age and growth of the scalloped hammerhead shark, *Sphyrna lewini*, in the north-west Atlantic Ocean and Gulf of Mexico. *Mar. Freshw. Res.,* 58: 34-40.

13 - Anislado-Tolentino, V., Robinson-Mendoza, C. 2001. Age and growth of the hammerhead shark *Sphyrna lewini* (Griffith and Smith, 1834) along the central Pacific coast of México. *Ciencias Marinas,* 27(4): 501-520.

14 – White, W., Bartron, C., Potter, I. 2008. Catch composition and reproductive biology of *Sphyrna lewini* (Griffith & Smith) (Carcharhiniformes, Sphyrnidae) in Indonesian waters. *J. Fish. Biol.,* 72: 1675-1689.

15 – Hazin, F., Fischer, A., Broadhurst, M. 2001. Aspects of the reproductive biology of the scalloped hammerhead shark, Sphyrna lewini, of Northeastern Brazil. *Environ. Biol. Fish.,* 61: 151–159.

16 – Kotas, J., Mastrochirico, V., Petrere, M.Jr. 2011. Age and growth of the Scalloped Hammerhead shark, *Sphyrna lewini* (Griffith and Smith, 1834), from the southern Brazilian coast. *Braz. J. Biol.*, 71(3): 755-761.

17 – Tolentino, V., Cabello, M., Linares, F., Mendoza, C. 2008. Age and Growth of the Scalloped hammerhead shark, *Sphyrna lewini* (Griffith & Smith, 1834) from the southern coast of Sinaloa, México. *Hidrobiológica*, 18: 31-40.

18 – Clarke, T. 1971. The ecology of the scalloped hammerhead, *Sphyrna lewini*, in Hawaii. *Pac. Sci.,* 25: 133-144.

19 – Bass, A. J., D'Aubrey, J., Kistnasamy, N. 1975. Sharks of the east coast of southern Africa. III. The families Carcharhinidae (excluding Mustelus and Carcharhinus) and Sphyrnidae. Oceanographic Research Institute, Durban. *Investig. Rep.,* 38: 1–100.

20 – Capape, C., Diop, M., N'Dao, M. 1998. Record of four pregnant females of the scalloped hammerhead, *Sphyrna lewini* (Sphrynidae) in Senegalese waters. *Cybium*, 22: 89–93.

21 – Chen, C.T., Leu, T.C., Joung, S.J. 1988. Reproduction in the female scalloped hammerhead, *Sphyrna lewini,* in northeastern Taiwan waters. *Fish. Bull.,* 86(2): 389-393.

22 – Castro, J. 1993. The shark nursery of Bulls Bay, South Carolina, with a review of the shark nurseries of the southeastern coast of the United States. *Environ. Biol. Fish.*, 38: 37–48.

23 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80 : 1643-1677.

24 – IOTC. 2012. Ebauche: résumé éxécutif: requin-marteau halicorne (*Sphyrna lewini*). 15th Scientific Committee, 10-15 December 2012, Victoria, Seychelles. IOTC document IOTC-2012-SC15-28(F): 5 pp.

25 – IOTC. 2014. Proposition: résumé éxécutif: requin-marteau halicorne (*Sphyrna lewini*). 17th Scientific Committee, 8-12 December 2014, Victoria, Seychelles. IOTC document IOTC-2014-SC17-ES19(F): 6 pp.

26 – Drew, M., White, W.T., Dharmadi, Harry, A.V., Huveners, C. 2015. Age, growth and maturity of the pelagic thresher *Alopias pelagicus* and the scalloped hammerhead *Sphyrna lewini*. *J. Fish Biol.,* 86(1): 333-354.

27 – Brown, K.B. 2014. The scalloped hammerhead shark, *Sphyrna lewini* (Griffith & Smith, 1834) in inshore waters in the Fiji Islands. Master of University of the South Pacific. 145 pp.

28 – Malabarba, L.R., Horn, T.S. 2014. Aspecto biologicos de *Sphyrna lewini* no Litoral Norte do Rio Grande do Sul: subsisdios para a identificaçao dos seus berçàrios. Memoir Universide Federal de Rio Grande do Sul.

Table III.29. Biological parameters for great hammerhead (SPM, *Sphyrna mokarran*).

Sphyrna mokarran (Rüppel, 1837) Great hammerhead FAO code: SPK	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
					AGE & GROWTH					
L∞ for female in cm	L∞=307.8 FL	9					L∞=402.7	8		
K for female /year	k=0.11	9					k=0.079	8		
t_o for female in years	t_0=-2.86	9								
L∞ for male in cm	L∞=264.2 FL	9					L∞=402.7	8		
K for male /year	k=0.16	9					k=0.079	8		
t_o for male in years	t_0=-1.99	9								
Longevity in years	44	9								
Maximum size TL in cm	550-610	1	550-610	1	550-610	1	550-610	1	550-610	1
Common size (FL) in cm	<366 240-370	1 2	<366 240-370	1 2	<366 240-370	1 2	<366 240-370	1 2	<366 240-370	1 2
Maximum weight in kg	449.5	3	449.5	3	449.5	3	449.5	3	449.5	3
					REPRODUCTION					
Female maturity size in cm	250-300	1	250-300	1	250-300 210	1-6-10 6	250-300 210 227.9	1-6-10 6 8	250-300	1
Female maturity age in years	5-6	9					8.3	8		
Male maturity size in cm	234-269	1	234-269	1	234-269 225	1-6-10 6	234-269 225 227.9	1-6-10 6 8	234-269	1
Male maturity age in years	5-6	9					8.3	8		
Birth size TL in cm	50-70 60-70	1-6-10-11-13 2	50-70 60-70	1-6-10-11-13 2	50-70 60-70 65	1-6-10-11-13 2 6	50-70 60-70 65 70	1-6-10-11-13 2 6 8	50-70 60-70	1-6-10-11-13 2
Sex ratio	1:1 (embryos)	1	1:1 (embryos)	1	1:1 (embryos) 45.7% females 54.3% males	1-6 6	1:1 (embryos)	1-6	1:1 (embryos)	1
Mode of development	viviparous	1	viviparous	1	viviparous	1	viviparous	1	viviparous	1
Gestation period in months	7 11	1 3-7	7 11	1 3-7	7 11 10-11	1 3-7 6	7 11 10-11	1 3-7 6	7 11	1 3-7

Spawning & mating periods	July-September Spring-Summer	6-11 6-12	Spring-Summer	1	October-November Spring-Summer	6 1	Spring-Summer	1	Spring-Summer	1
Fecundity: number of embryos per litter	13-42 18-38 6-42	1-6-10-11-13 2 7	13-42 18-38 6-42	1-6-10-11-13 2 7	13-42 18-38 6-42	1-6-10-11-13 2 7	13-42 18-38 6-42	1-6-10-11-13 2 7	13-42 18-38 6-42	1-6-10-11-13 2 7
Nursery ground										
CONVERSION FACTORS										
Length / Weight relationships	$W=1.19*10^{-6}*TL^{3.16}$	5			$W=1.23*10^{-6}*TL^{3.24}$	6	$W=1.23*10^{-6}*TL^{3.24}$	6		
Wet weight / dressed weight ratio										
TL / FL	TL=1.2533*FL+3.472	9			TL=3.58+1.29*FL	6	TL=3.58+1.29*FL	6		
TL/PCL										
Fins / carcass ratios										
Stables isotopes N15 & C14	FW/BW=1.96	14	FW/BW=1.96	14	FW/BW=1.96	14	FW/BW=1.96	14	FW/BW=1.96	14
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) ($year^{-1}$)										
Intrinsic rebound potential (rz(MSY))										
Trophic level	4.3	4	4.3	4	4.3	4	4.3	4	4.3	4

References

1 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. *FAO Fish. Synop.,* 125(4/2): 251-655. Rome, FAO.

2 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. Rome, FAO. 716 pp.

3 – Fishbase. 2017. *Sphyrna mokarran.* http://fishbase.mnhn.fr/summary/Sphyrna-mokarran.html

4 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

5 - García-Arteaga, J., Claro, R., Valle, S. 1997. Length-weight relationships of Cuban marine fishes. *Naga ICLARM Q.,* 20(1): 38-43.

6 – Stevens, J., Lyle, J. 1989. Biology of three hammerhead sharks (*Eusphyra blochii*, *Sphyrna mokarran* and *S. lewini*) from northern Australia. *Aust. J. Mar. Freshw. Res.,* 40(2): 129-146.

7 - Denham J., Stevens J., Simpfendorfer C., Heupel M., Cliff G., Morgan A., Graham R., Ducrocq M., Dulvy N., Seisay M., Asber M., Valenti S., Litvinov F., Martins P., Lemine Ould Sidi M., Tous P. & Bucal D., 2007. *Sphyrna mokarran*. InIUCN Red List of Threatened Species.

8 – Harry, A., Macbeth, W., Gutteridge, A., Simpfendorfer, C. 2011. The life histories of endangered hammerhead sharks (Carcharhiniformes, Sphyrnidae) from the east coast of Australia. *J. Fish Biol.,* 78(7): 2026–2051.

9 – Piercy, A., Carlson, J., Passerotti, M. 2010. Age and growth of the great hammerhead shark, *Sphyrna mokarran*, in the north-western Atlantic Ocean and Gulf of Mexico. *Mar. Freshw. Res.,* 61 : 992–998.

10 – Fourmanoir, P. 1961. Requins de la côte ouest de Madagascar. *Mem. Lnst. Sci. Madagascar* (Ser. F) 4 : 1-81.

11 – Cadenat, J., Blache, J. 1981. Requins de Mediterranée et Atlantique. *Faune Tropicale ORSTOM,* 21: 1-330.

12 – Clark, E., von Schmidt, K. 1965. Sharks of the central gulf coast of Florida. *Bull. Mar. Sci.,* 15(1): 13-83.

13 – Bigelow, H., Schroeder, W. 1948. Fishes of the western north Atlantic. Lancelets, cyclostomes and sharks. *Mem. Sears Found. Mar. Res.*, 1(1): 1-576.

14 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

15 – Miller, M.H., Carlson, J. Kobayashi, L., D. 2014. Status review report: great hammerhead shark (*Sphyrna mokarran).* Final report to NOAA, June 2014. 116 pp.

Table III.30. Biological parameters for smooth hammerhead (SPZ, *Sphyrna zygaena*).

Sphyrna zygaena (Linnaeus, 1758) Smooth hammerhead FAO code: SPZ	**Atlantic Ocean**	**Ref.**	**Mediter-ranean Sea**	**Ref.**	**Indian Ocean**	**Ref.**	**West Pacific**	**Ref.**	**East Pacific**	**Ref.**
AGE & GROWTH										
L_∞ for female in cm	257.25 293.9	22 23							L_∞=301.6	15-16
K for female /year	0.13 0.09	22 23							k=0.14	15-16
t_0 for female in years	-0.73 L_0= 52.7 cm FL	22 23							t_0=-2.45	15-16
L_∞ for male in cm	245.22 284.6	22 23							L_∞=301.6	15-16
K for male /year	0.15 0.09	22 23							k=0.14	15-16
t_0 for male in years	-0.64 L_0=52.2 cm FL	22 23							t_0=-2.45	15-16
Longevity in years	20	13	20	13	20	13	20	13	20	13
Maximum size TL in cm	370-400 500	1 3-4	370-400 500	1 3-4	370-400 500	1 3-4	370-400 500	1 3-4	370-400 500	1 3-4
Common size (FL) in cm	275-335	2	275-335	2	275-335	2	275-335	2	275-335	2
Maximum weight in kg	400	3-5	400	3-5	400	3-5	400	3-5	400	3-5
REPRODUCTION										
Female maturity size in cm	304	1	304	1	304	1	304	1	304	1
Female maturity age in years	8	22								
Male maturity size in cm	256	1	256	1	256	1	256 >250-260	1 9	256	1
Male maturity age in years	7	22								
Birth size TL in cm	50-61 #60	1 17	50-61 #60	1 17	50-61 #60	1 17	50-61 #60	1 17	50-61 #60	1 17
Sex ratio	1:1	10					#1:1	9		
Mode of development	viviparous	1	viviparous	1	viviparous	1	viviparous	1	viviparous	1
Gestation period in months										
Spawning & mating periods										
Fecundity: number of embryos per litter	29-37	1	29-37	1	29-37	1	29-37 20-49	1 9	29-37	1
Nursery ground	coastal waters of southern Brazil & Uruguay	11-12							northern Gulf of California	8
CONVERSION FACTORS										
Length / Weight relationships	$W=1.42*10^{-6}*L^{3.3}$ $W=2.61*10^{-5}*FL^{2.709}$	7 14			$W=1.42*10^{-6}*L^{3.3}$	7	$W=3.0091*10^{-5}*FL^{2.64805}$ $W=5.270*10^{-7}*L^{3.42}$	14 9	$W=3.0091*10^{-5}*FL^{2.64805}$	14

Wet weight / dressed weight ratio										
TL / FL	FL=0.8*TL TL = 1.279*FL	3 24	FL=0.8*TL	3	FL=0.8*TL	3	FL=0.8*TL	3	FL=0.8*TL	3
TL/PCL	TL= 5.440+ 1.361*PCL	24								
Fins / carcass ratios	FW/BW=5.74	20	FW/BW=5.74	20	FW/BW=5.74	20	FW/BW=5.74	20	FW/BW=5.74	20
Stables isotopes N^{15} & C^{14}										
POPULATION DYNAMICS										
Stock delineation/range										
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) (year^{-1})										
Intrinsic rebound potential (rz(MSY))										
Trophic level	4.2	6	4.2	6	4.2	6	4.2	6	4.2	6

References

1 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. *FAO Fish. Synop.,* 125(4-2): 251-655. Rome, FAO.

2 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome, 716 p.

3 – Fishbase. 2017. *Sphyrna zygaena*. http://fishbase.mnhn.fr/summary/Sphyrna-zygaena.html

4 – Muus, B., Nielsen, J. 1999. Sea fish. Scandinavian Fishing Year Book, Hedehusene, Denmark. 340 pp.

5 – Frimodt, C. 1995. Multilingual illustrated guide to the world's commercial warm water fish. Fishing News Books, Osney Mead, Oxford, England. 215 pp.

6 – Cortés, E. 1999. Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

7 – Torres, F. Jr. 1991. Tabular data on marine fishes from Southern Africa, Part I. Length-weight relationships. *Fishbyte,* 9(1): 50-53.

8 – UNEP. 2012. Form for proposing amendments to Annex II and Annex III to the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean. Species concerned: *Sphyrna* spp.

9 - Stevens, J. 1984. Biological observations on sharks caught by sports fishermen off New South Wales. *Austr. J. Mar. Freshw. Res.,* 35: 573–590.

10 – Castro, J., Mejuto, J. 1995. Reproductive parameters of blue shark, *Prionace glauca*, and other sharks in the Gulf of Guinea. *Mar. Freshw. Res.,* 46: 967–73.

11 – Vooren, C., Klippel, S., Galina, A. 2005. Biologia e status conservação dos tubarão-martelo *Sphyrna lewini* e *S. Zygaena*. 97-112 pp. In Vooren, C., Klippel S. (eds), Ações para a conservação de tubarões e raias no sul do Brasil. Porto Alegre, Igaré.

12 - Doño, F. 2008. Identificación y caracterización de áreas de cría del tiburón Martillo (*Sphyrna spp.*) en las costas de Uruguay. Tesis de Licenciatura. Facultad de Ciencias. Universidad de la República de Uruguay. 33 pp.

13 - Florida Museum of Natural History. 2008. Biological Profile: smooth hammerhead *Sphyrna zygaena. Ichthyology at the Florida Museum of Natural History: Education-Biological Profiles. FLMNH, University of Florida.*

14 - García-Cortés, B., Mejuto, J. 2002**.** Size-weight relationships of the swordfish (*Xiphias gladius)* and several pelagic shark species caught in the Spanish surface long-line fishery in the Atlantic, Indian and Pacific Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 54(4): 1132-1149.

15 – Piercy, A., Carlson, J., Passerotti, M. 2010. Age and growth of the great hammerhead shark, *Sphyrna mokarran*, in the north-western Atlantic Ocean and Gulf of Mexico. *Mar. Freshw. Res.,* 61: 992–998.

16 - Garza Gisholt, E., 2004. Edad y crecimiento de *Sphyrna zygaena* (Linnaeus 1758) en las costas de Baja California Sur, Mexico. Thesis, Universidad Autonoma de Baja California Sur, Area Interdisciplinaria de Ciencias del Mar, La Paz, Mexico.

17 – Bass, A., D'Aubrey, J., Kistnasamy, N. 1975. Sharks of the east coast of southern Africa. III. The families Carcharhinidae (excluding *Mustelus* and *Carcharhinus*) and Sphyrnidae. South African Association for Marine Biological Research. Oceanographic Research Institute, Durban, *Investig. Rep.*, 39: 1-102.

18 – Walker, T. 1988. Mercury concentrations in edible tissues of elasmobranchs, teleosts, crustaceans and mollusks from south-eastern Australian waters. *Austr. J. Mar. Freshw. Res*., 39: 39-49.

19 – Bowman, R., Stillwill, C., Michaels, W., Grosslein M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dept. Commer., *NOAA Tech Mem. NMFS NE,* 155: 1-137.

20 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

21 – Rogers, P.J., Huveneers, C., Page, B., Hamer, D.J., Goldsworthy, S.D., Mitchell, J.G., Seuront, L. 2012. A quantitative comparison of the diets of sympatric pelagic sharks in gulf and shelf ecosystemsn off southern Australia. *ICES J. Mar. Sci*. 69(8): 1382-1393.

22 – Kone, A., N'Da, K., Kouassi, S.K., Agnissan, J.P. 2014. Dynamique de la population exploitée de deux requins: *Sphyrna zygaena* (Linnaeus, 1758) et *Isurus oxyrinchus* (Rafinesque, 1809) des côtes ivoiriennes. *Internat. J. Biol. & Chem. Sci.*, 8(4): 1633-1643.

23 – Rosa, D., Coelho, R., Fernandez-Carvalho, J., Santos, M.N. 2017. Age and growth of the smooth hammerhead, *Sphyrna zygaena*, in the Atlantic Ocean, comparison with other hammerhead species. *Mar. Biol. Res*, 13(3):300-313.

24 – Mas, F., Forselledo, R., Domingo, A. 2014. Length-Length relationships for six pelagic shark species commonly caught in the southwestern Atlantic Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 70(5): 2441-2445.

5. Fishery indicators

Ecological Risk Assessment

ICCAT

In 2012, scientists from the ICCAT sharks working group prepared and presented a quantitative ERA for pelagic elasmobranchs caught in longliners (Cortés et al., 2015). For this analysis 16 species of pelagic elasmobranchs were included: BSH, SMA, LMA, BTH, ALV, OCS, FAL, POR, SPL, SPZ, SPK, CCP, DUS, CCS, TIG, PLS. For some species there was a division between North and South Atlantic stocks (BSH, FAL, PLS and SPL).

Productivity was expressed as the intrinsic rate of population increase (*r*). The least productive species were the bigeye thresher, the more costal-pelagic sandbar shark and the longfin mako, while the two blue shark stocks, the North Atlantic pelagic sting ray and the smooth hammerhead were the most productive (Table III.31). Susceptibility was calculated as the product of availability, encounterability, selectivity and post-capture mortality. For the pelagic longliners the highest risk is to shortfin mako, followed by North Atlantic blue shark, porbeagle, bigeye thresher and South Atlantic blue shark (Table III.32).

Vulnerability is the combination of productivity and selectivity and was calculated using three methods (see Cortés et al., 2015). The three vulnerability indices classified bigeye thresher and longfin mako as highest risk; while only two assigned the highest risk to shortfin mako, porbeagle and night shark. The authors considered the third method, based on the arithmetic mean of the productivity and susceptibility, to better represent both indices as the correlation between vulnerability and each of the indices was similar. The most vulnerable species, according to this method, are the bigeye thresher, longfin and shortfin makos, porbeagle, and night sharks (Table III.33). It is noted that four out of the five most vulnerable species fall under the scope of the present study.

Table III.31. Productivity (*r*, intrinsic rate of population increase, yr^{-1}) and generation time for 20 stocks of pelagic sharks listed from highest to lowest values of productivity. NA is North Atlantic and SA is South Atlantic. LCL and UCL are the lower and upper 80% percentiles. Generation time is defined as the time required for the population to increase by R0 (the net reproductive rate) (Source: Cortés et al., 2015).

Stock	Productivity (*r*)	LCL	UCL	Generation time
BSH SA	0.314	0.279	0.345	8.2
BSH NA	0.299	0.264	0.327	9.8
PLS NA	0.230	0.181	0.279	6.2
SPZ	0.225	0.213	0.237	13.4
TIG	0.190	0.180	0.200	15.6
OCS	0.121	0.104	0.137	10.4
SPL SA	0.121	0.110	0.132	21.6
ALV	0.121	0.099	0.143	11.0
SPL NA	0.096	0.093	0.107	21.6
FAL NA	0.078	0.065	0.090	14.4
SPK	0.070	0.069	0.071	27.1
SMA	0.058	0.049	0.068	25.0
POR	0.052	0.044	0.059	20.3
PLS SA	0.051	0.004	0.096	6.6
DUS	0.043	0.035	0.050	29.6
FAL SA	0.042	0.029	0.054	16.5
CCS	0.041	0.028	0.053	14.9
LMA	0.029	0.020	0.038	25.2
CCP	0.010	-0.005	0.024	21.8
BTH	0.009	-0.001	0.018	17.8

Table III.32. Susceptibility values (listed from highest to lowest) and ranks for all fleets included in the analysis combined for 20 stocks of pelagic sharks. Productivity ranks are also listed for comparison. A lower rank indicates higher risk (Source: Cortés et al., 2015).

Stock	Susceptibility	Susceptibility rank	Vulnerability rank
SMA	0.220	1	9
BSH NA	0.166	2	19
POR	0.162	3	8
BTH	0.142	4	1
BSH SA	0.141	5	20
OCS	0.135	6	13
LMA	0.116	7	3
FAL NA	0.081	8	11
ALV	0.072	9	13
TIG	0.065	10	16
SPZ	0.054	11	17
CCS	0.043	12	4
FAL SA	0.042	13	5
SPK	0.021	14	10
SPL NA	0.014	15	12
CCP	0.012	16	2
DUS	0.010	17	6
PLS NA	0.002	18	18
SPL SA	0.002	19	13
PLS SA	0.0002	20	7

Table III.33. Vulnerability ranks for 20 stocks of pelagic sharks calculated with three methods: Euclidean distance (v1), multiplicative (v2) and arithmetic mean (v3). A lower rank indicates higher risk. Stocks listed in decreasing risk order according to the sum of the three indices. Red highlight indicates risks scores 1-5; yellow, 6-10; blue, 11-15; and green, 16-20 (Source: Cortés et al., 2015).

Stock	v_1	v_2	v_3
BTH	3	1	1
LMA	5	3	2
SMA	1	8	2
POR	2	7	4
CCS	11	4	5
FAL SA	12	5	6
CCP	15	2	6
OCS	4	13	8
FAL NA	8	11	8
ALV	9	14	11
BSH NA	6	19	10
DUS	17	6	12
SPK	14	10	13
BSH SA	7	20	14
TIG	10	16	15
PLS SA	18	9	16
SPL NA	16	12	16
SPZ	13	17	18
SPL SA	19	15	19
PLS NA	20	18	20

IOTC

Murua et al. (2012) presented a semi-quantitative ERA for shark species caught in various fisheries targeting tuna and tuna-like species in the Indian Ocean, specifically the longliner and the purse-seine fleets. For this analysis 17 species of pelagic elasmobranchs were included: BSH, SMA, LMA, BTH, ALV, PTH, OCS, FAL, CCP, DUS, POR, SPL, SPZ, SPM, GAC and PLS. All the Indian Ocean species under the scope of the current study are included in the ERA.

Productivity was expressed as the population finite growth rate (λ). The least productive species were two more coastal shark species, the sandbar shark and dusky shark, followed by longfin mako, bigeye thresher, porbeagle and shortfin mako (Table III.34 and III.35). Susceptibility was calculated as the product of availability, encounterability, selectivity and post-capture mortality. The species more susceptible for the longline fishing fleets are the pelagic thresher followed by blue shark, shortfin mako, bigeye thresher, and smooth hammerhead (Table III.34). The species more susceptible for the purse seine fishing fleets are the oceanic whitetip and silky shark followed by shortfin mako. The rest of species are ranked in much lower levels of susceptibility (Table III.35).

According to Murua et al. (2012), for the longline fleet the most vulnerable species are the shortfin mako, bigeye and pelagic thresher, followed by silky shark, oceanic whitetip shark, smooth hammerhead, porbeagle, longfin mako, great hammerhead and blue shark, while for the purse seine fleet the most vulnerable species are the oceanic whitetip and silky shark (III.34 and III.35). It is noticed that the most vulnerable species fall under the scope of the present study.

IATTC

Duffy & Olsen (2016) presented a preliminary semi-quantitative ERA to estimate the vulnerability of data-poor, non-target species caught in the purse-seine fishery in the Eastern Pacific Ocean (EPO). For this analysis 32 species where included, of which 12 pelagic elasmobranchs were included: SMA, BTH, PTH, ALV, OCS, FAL, SPL, SPZ, SPM, RMB, RMJ, RMO. All elasmobranch species considered for the ERA are under the scope of the current study for the IATTC.

Productivity was calculated as the product of 9 attributes: intrinsic rate of population increase, maximum age, von Bertalanffy growth coefficient, natural mortality, fecundity, breeding strategy, age at maturity and mean trophic level.

Susceptibility was calculated as the product of management strategy, areal overlap – geographical concentration index, vertical overlap with gear, seasonal migrations, schooling/aggregation and other behavioural responses to gear, post-capture survival, and desirability of catch (percentage of retention). Susceptibility was calculated for 3 different purse-seiners fishing methods (dolphin, unassociated and floating-object sets). Three preliminary methods of combining these different susceptibilities to obtain a species-specific purse-seiner susceptibility were tested (see Duffy & Olsen, 2016). Vulnerability was calculated from susceptibility and productivity scores as the Euclidean distance. Despite of the method for combining susceptibilities between fishing methods, sharks are always amongst the most vulnerable species, with the shortfin mako, pelagic thresher, silky shark and giant mobula among the most vulnerable of the elasmobranchs and common thresher, oceanic whitetip, spinetail manta and smoothtail manta with the lowest vulnerability scores between elasmobranchs (Figure III.17).

Griffiths et al. (2017) presented a preliminary semi-quantitative ERA for the longline fishery, specifically for large-scale tuna longline fishing vessels (vessels over 24 m length overall), in the EPO. For this analysis 68 species where included, of which 23 pelagic elasmobranchs: BSH, SMA, LMA, BTH, PTH, ALV, OCS, FAL, ALS, CCG, CCL, TIG, SPL, SPZ, SPM, LMD, POR, ODH, PSK, cookie ISB), DGS), SSQ, PLS. All the Pacific Ocean species under the scope of the current study are included in the ERA.

Productivity was calculated as the product of 5 attributes: maximum age, von Bertalanffy growth coefficient, fecundity, breeding strategy, age at maturity. Susceptibility was calculated as the product of areal overlap, seasonal availability, aggregation behaviour, encounterability, gear selectivity and post-capture survival.

Vulnerability was calculated from susceptibility and productivity scores as the Euclidean distance. Out of the 68 analysed species, 18 were classified as having a high vulnerability, of these 13 were of elasmobranch species (PTH, BTH, ALV, TIG, BSH, SMA, LMA, LMD, POR, ODH, SPL, SPK and SPZ) (Table III.35). The remaining elasmobranch species were classified as moderately vulnerable, however, it is mentioned that FAL and OCS could be considered highly vulnerable as the scores were of 1.98 (the cut off was at 2.00). Of the highly vulnerable, BTH, TIG, POR and BSH shared the highest vulnerability score, due to very low productivity and high susceptibility to this gear (Table III.36).

Table III.34. Productivity and susceptibility analysis for shark species captured and impacted in pelagic Longline fisheries in the Indian Ocean in the IOTC area (Source: Murua et al., 2012).

			Productivity	Susceptibility					Vulnerability	
FAO Code	**Species/Stock**	**Common name**	**Lambda**	**Availability**	**Encounterability**	**Selectivity**	**Post-captura mortality**	**Susceptibility**	**Vulnerability**	**RANK**
SMA	*Isurus oxyrinchus*	Shortfin mako	1.061 (1.040-1.081)	0.963	1.000	0.970	0.994	0.929	0.094	1
BTH	*Alopias superciliosus*	Bigeye thresher	1.033 (1.017-1.047)	0.968	1.000	0.968	0.970	0.909	0.097	2
PTH	*Alopias pelagicus*	Pelagic thresher	1.098 (1.075-1.119)	0.974	1.000	0.997	1.000	0.971	0.102	3
FAL	*Carcharhinus falciformis*	Silky shark	1.075 (1.057-1.093)	0.961	1.000	0.925	0.990	0.880	0.142	4
OCS	*Carcharhinus longimanus*	Oceanic whitetip shark	1.162 (1.132-1.192)	0.961	1.000	0.939	0.974	0.880	0.202	5
SPZ	*Sphyrna zygaena*	Smooth hammerhead	1.281(1.257-1.303)	0.909	1.000	0.997	0.997	0.904	0.298	6
POR	*Lamna nasus*	Porbeagle	1.041 (1.024-1.057)	0.796	1.000	0.885	0.905	0.638	0.364	7
LMA	*Isurus paucus*	Longfin mako	1.029 (1.007-1.049)	0.956	1.000	0.600	0.992	0.569	0.432	8
SPM	*Sphyrna mokarran*	Great hammerhead	1.098 (1.079-1.115)	0.925	1.000	0.622**	1.000	0.575	0.436	9
BSH	*Prionace glauca*	Blue shark	1.483 (1.414-1.546)	0.952	1.000	0.996	0.984	0.933	0.489	10
GAC	*Galeocerdo cuvier*	Tiger shark	1.147 (1.078-1.211)	0.923	1.000	0.521	0.903	0.434	0.585	11
DUS	*Carcharhinus obscurus*	Dusky shark	1.027 (1.009-1.044)	0.943	1.000	0.245	1.000	0.231	0.770	12
PLS	*Pteroplatytrygon violacea*	Pelagic stingray	1.242 (1.156-1.323)	0.941	1.000	0.758	0.370	0.264	0.775	13
SPL	*Sphyrna lewini*	Scalloped hammerhead	1.062 (1.039-1.083)	0.942	1.000	0.246	0.875	0.203	0.799	14
CCP	*Carcharhinus plumbeus*	Sandbar shark	0.978 (0.950-1.005)	0.935	1.000	0.172	1.000	0.161	0.840	15
ALV	*Alopias vulpinus*	Common thresher	1.148 (1.114-1.181)	0.970	1.000	0.562	0.180*	0.098	0.914	16
WSH	*Carcharodon carcharias*	Great white shark	1.117 (1.077-1.155)	0.974	1.000	n/a	n/a	n/a	n/a	n/a

* Mean selectivity of *Sphyrna lewini* and *Sphyrna zygaena*
** From Cortes et al., 2010

Table III.35 Productivity and susceptibility analysis for shark species captured and impacted in purse seiner fisheries in the Indian Ocean in the IOTC area (Source: Murua et al., 2012).

			Productivity	**Susceptibility**					**Vulnerability**	
FAO Code	**Species/Stock**	**Common name**	**Lambda**	**Availability**	**Encounterability**	**Selectivity**	**Post-captura mortality**	**Susceptibility**	**Vulnerability**	**RANK**
OCS	*Carcharhinus longimanus*	Oceanic whitetip shark	1.162 (1.132-1.192)	0.694	1.000	1.000	0.981	0.681	0.358	1
FAL	*Carcharhinus falciformis*	Silky shark	1.075 (1.057-1.093)	0.676	1.000	0.989	0.736	0.492	0.514	2
SMA	*Isurus oxyrinchus*	Shortfin mako	1.061 (1.040-1.081)	0.525	1.000	0.450	1.000	0.236	0.766	3
SPM	*Sphyrna mokarran*	Great hammerhead	1.098 (1.079-1.115)	0.667	1.000	0.273	1.000	0.182	0.824	4
PLS	*Pteroplatytrygon violacea*	Pelagic stingray	1.242 (1.156-1.323)	0.267	1.000	0.758	0.673	0.136	0.897	5
SPL	*Sphyrna lewini*	Scalloped hammerhead	1.062 (1.039-1.083)	0.587	1.000	0.219	0.500	0.064	0.938	6
SPZ	*Sphyrna zygaena*	Smooth hammerhead	1.281 (1.257-1.303)	0.480	1.000	0.327	0.500	0.078	0.964	7
LMA	*Isurus paucus*	Longfin mako	1.029 (1.007-1.049)	0.714	1.000	0.044	1.000	0.003	0.969	8
DUS	*Carcharhinus obscurus*	Dusky shark	1.027 (1.009-1.044)	0.510	1.000	0.055	1.000	0.028	0.973	9
GAC	*Galeocerdo cuvier*	Tiger shark	1.147 (1.078-1.211)	0.661	1.000	0.057	1.000	0.038	0.974	10
ALV	*Alopias vulpinus*	Common thresher	1.148 (1.114-1.181)	0.433	1.000	0.082	1.000	0.036	0.976	11
BTH	*Alopias superciliosus*	Bigeye thresher	1.033 (1.017-1.047)	0.624	1.000	0.022	1.000	0.014	0.987	12
CCP	*Carcharhinus plumbeus*	Sandbar shark	0.978 (0.950-1.005)	0.652	1.000	0.000	1.000	0.000	1.000	13
POR	*Lamna nasus*	Porbeagle	1.041 (1.024-1.057)	0.057	1.000	0.005	1.000	0.000	1.001	14
PTH	*Alopias pelagicus*	Pelagic thresher	1.098 (1.075-1.119)	0.714	1.000	0.000	1.000	0.000	1.005	15
WSH	*Carcharodon carcharias*	Great white shark	1.117 (1.077-1.155)	0.473	1.000	0.000	1.000	0.000	1.007	16
BSH	*Prionace glauca*	Blue shark	1.483 (1.414-1.546)	0.451	1.000	0.102	0.600	0.028	1.086	17

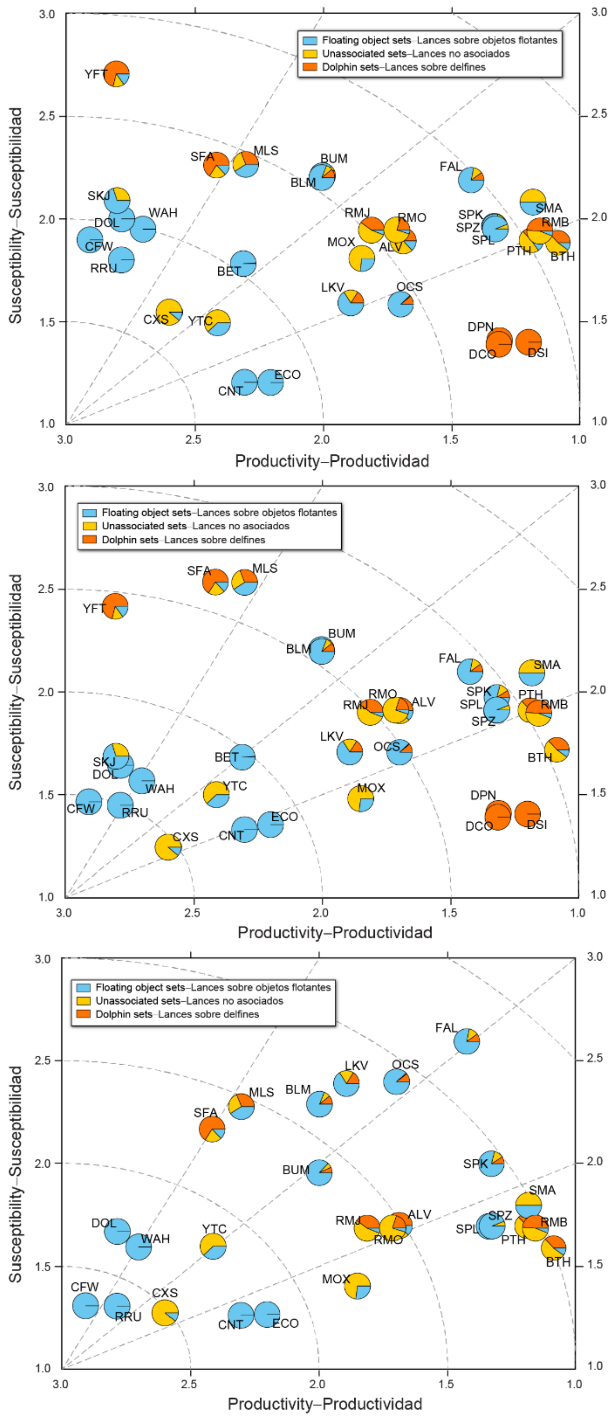


Figure III.17. Productivity and susceptibility x-y plot for bycatch species caught by the purse-seine fishery of the Eastern Pacific Ocean during 2005-2013, based on different calculations of susceptibility scores (see Duffy & Olsen, 2016). The pie charts show the proportion of bycatch (non-tuna species), by set type, for those set types with bycatch ≥ 5% for the species (Source: Duffy & Olsen, 2016).

Table III.36. Species included in the productivity-susceptibility analysis for the large-scale tuna longline fishery in the eastern Pacific Ocean, showing average productivity (p) and susceptibility (s) scores used to compute the overall vulnerability score (v) for each species, rated as low (green), medium (yellow), and high (red) (Source : Griffiths et al., 2017)

Group	Family	Scientific name	Common name	FAO code	Source	*p*	*s*	*v*
Grupo	**Familia**	**Nombre científico**	**Nombre común**	**Código FAO**	**Fuente**	***p***	***s***	***v***
Elasmobranchs	Alopiidae	*Alopias pelagicus*	Pelagic thresher shark	PTH	1	1.00	2.00	2.24
		Alopias superciliosus	Bigeye thresher shark	BTH	1	1.00	2.20	2.33
		Alopias vulpinus	Common thresher shark	ALV	2	1.40	2.20	2.00
	Carcharhinidae	*Carcharhinus albimarginatus*	Silvertip shark	ALS	3	1.60	2.00	1.72
		Carcharhinus falciformis	Silky shark	FAL	1	1.60	2.40	1.98
		Carcharhinus galapagensis	Galapagos shark	CCG	4	1.60	2.00	1.72
		Carcharhinus limbatus	Blacktip shark	CCL	1	1.80	2.20	1.70
		Carcharhinus longimanus	Oceanic whitetip shark	OCS	1	1.60	2.40	1.98
		Galeocerdo cuvier	Tiger shark	TIG	5	1.00	2.20	2.33
		Prionace glauca	Blue shark	BSH	1	1.80	3.00	2.33
	Dasyatidae	*Pteroplatytrygon violacea*	Pelagic stingray	PLS	1	1.80	2.00	1.56
	Lamnidae	*Isurus oxyrinchus*	Shortfin mako shark	SMA	1	1.40	2.60	2.26
		Isurus paucus	Longfin mako shark	LMA	1	1.20	2.40	2.28
		Lamna ditropis	Salmon shark	LMD	5	1.20	2.20	2.16
		Lamna nasus	Porbeagle shark	POR	1	1.00	2.20	2.33
	Odontaspididae	*Odontaspis noronhai*	Bigeye sand tiger shark	ODH	5	1.00	1.60	2.09
	Pseudocarchariidae	*Pseudocarcharias kamoharai*	Crocodile shark	PSK	2	1.40	1.60	1.71
	Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead shark	SPL	1	1.40	2.60	2.26
		Sphyrna mokarran	Great hammerhead	SPK	2	1.40	2.40	2.13
		Sphyrna zygaena	Smooth hammerhead	SPZ	6	1.40	2.60	2.26
	Squalidae	*Isistius brasiliensis*	Cookie cutter shark	ISB	2	2.00	1.20	1.02
		Squalus acanthias	Picked dogfish, Spiny dogfish	DGS	1	1.40	1.60	1.71
		Zameus squamulosus	Velvet dogfish	SSQ	2	1.40	1.20	1.61

Catch per unit of effort (CPUE)

ICCAT

Blue shark

A number of CPUE time series were presented for blue shark in 2015 for the ICCAT blue shark data preparatory meeting (Anon., 2015a) and ICCAT blue shark stock assessment meeting (Anon., 2015b). Contracting parties presenting standardised CPUE series were: Venezuela, EU.Portugal, US (logbook, longline observer and longline cruise), EU.Spain, Uruguay, Japan, Taiwan.China and Brazil. Additionally, Ireland presented a nominal CPUE from the recreational fishery. However, CPUE from US-logbooks and the Irish CPUE were only used for exploratory purposes in the stock assessment. The Japanese CPUE was split into two periods to represent changes in the fleet reporting system, as before 1994 catch records were not species specific. CPUE series used in the stock assessment are represented in Figure III.18. Despite some fluctuation for some fleets/years, the North Atlantic CPUEs trends show no clear trend, while in the South Atlantic series show a very slight increase in the last few years.

Shortfin mako

A number of CPUE data series were presented for shortfin mako in 2017 for the ICCAT shortfin mako data preparatory meeting (Anon., 2017a). Additionally, two CPUE series were presented at the stock assessment meeting (Anon., 2017b). Contracting parties presenting standardised CPUE series were: EU.Portugal, EU.Spain, US (logbook and longline observer), Uruguay (observer and logbook), South Africa, Japan and Taiwan.China. CPUE series used in the stock assessment for the North were EU. Portugal, EU.Spain, US (logbook), Japan and Taiwan.China, for the South used CPUEs were Brazil, EU.Spain, Japan, Taiwan.China and Uruguay (Figure III.19). US observer series will be used for sensitivity analysis if appropriate. A hierarchical cluster analysis and cross-correlation of selected CPUE indices for shortfin mako in the North and South Atlantic was conducted to assess if different CPUE series were conflicting, and it was found for both the North and South Atlantic that, in general, there was a strong agreement among selected indices. For the North Atlantic there was, in general, a stable trend, while in the south there was an increasing trend in the CPUE series.

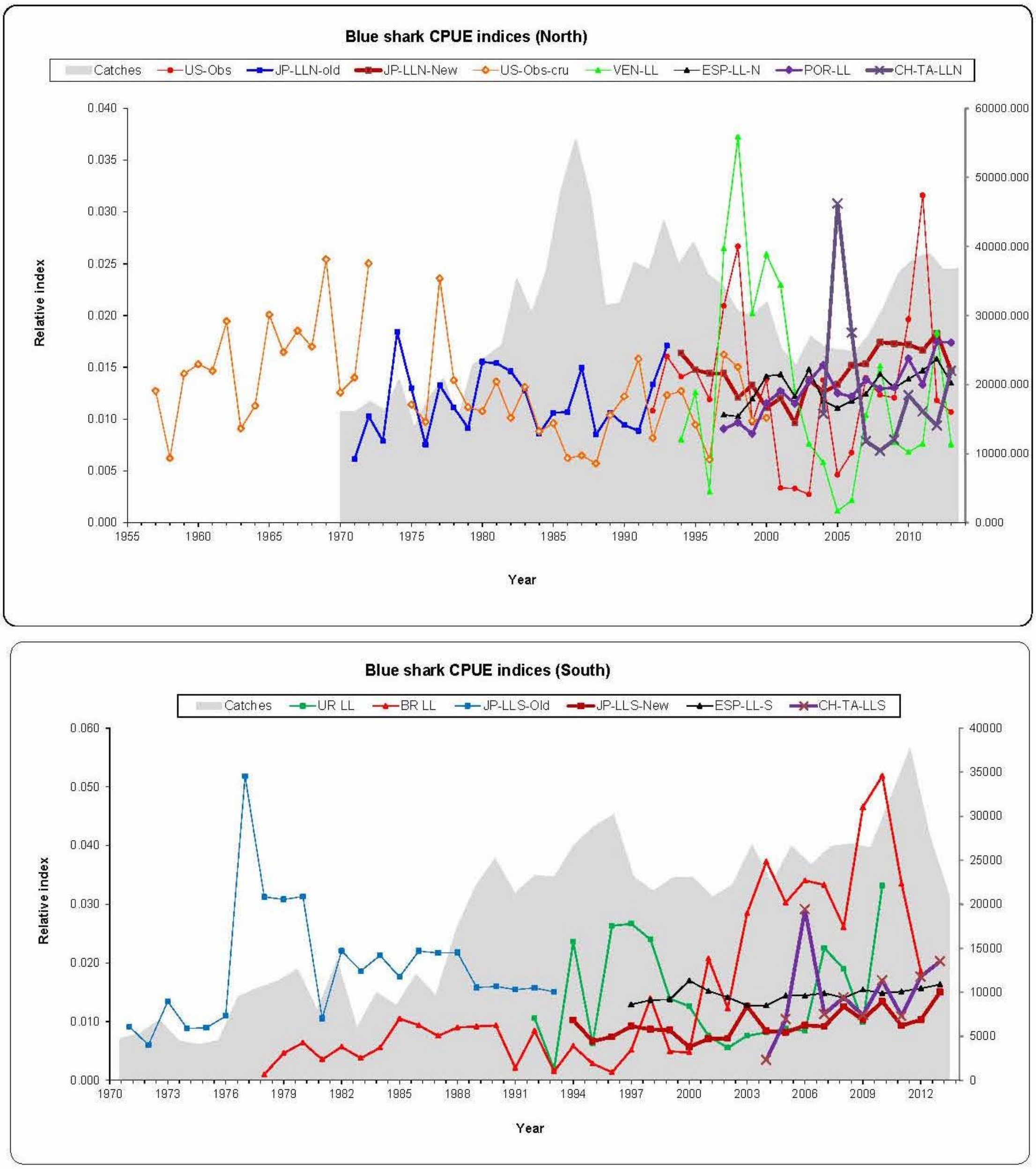
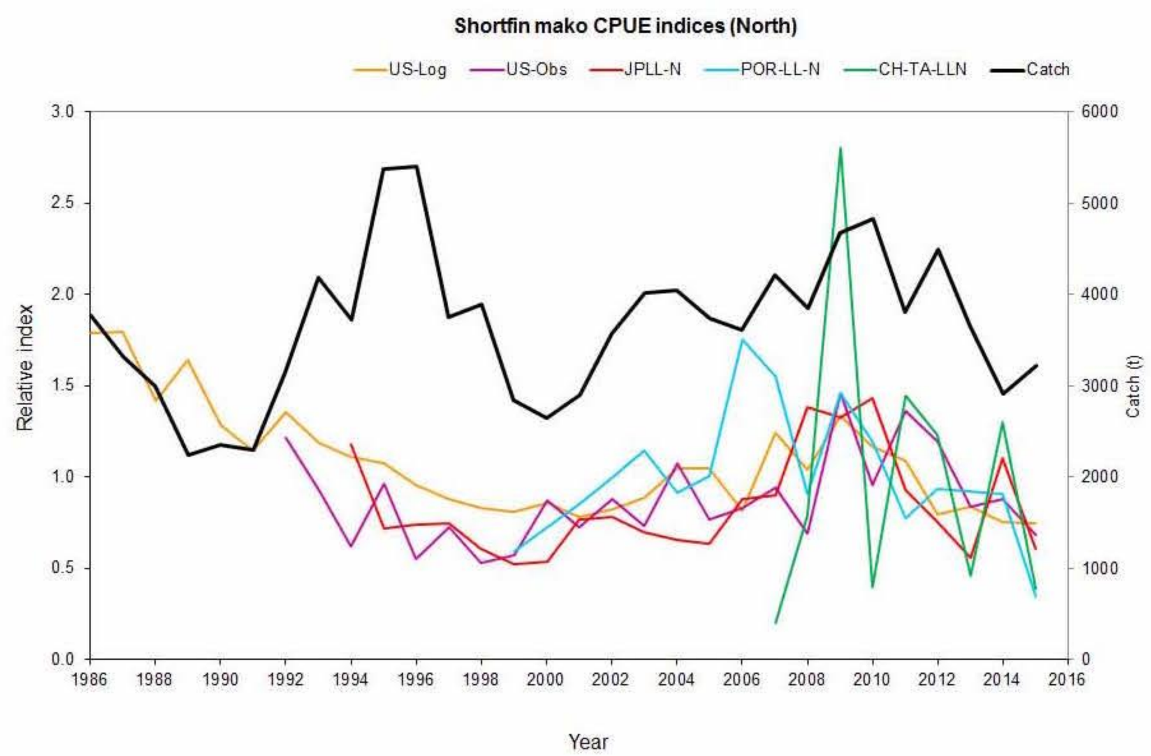


Figure III.18. Indices of abundance and catches for the North Atlantic and South Atlantic blue shark stocks, as used in the latest ICCAT stock assessment (Source: Anon., 2015b).



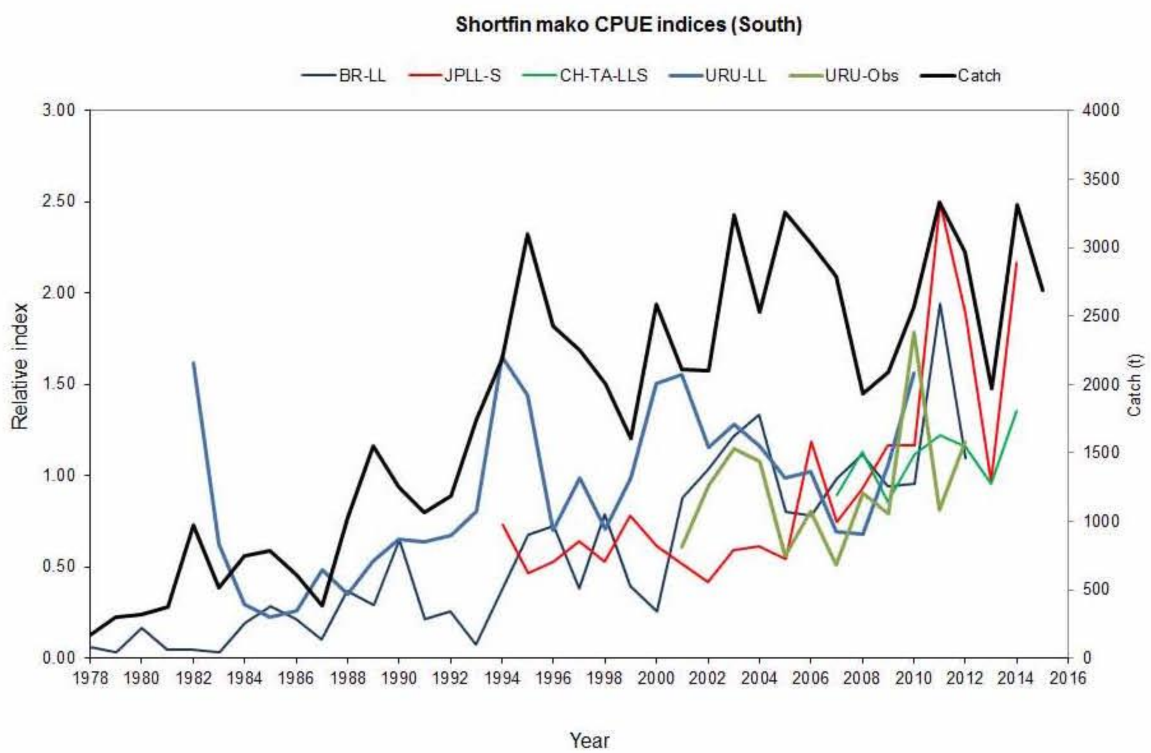


Figure III.19. Selected indices of abundance and total catches for the North Atlantic and South Atlantic shortfin mako. All indices are scaled by the mean of the overlapping years between indices (Source: Anon., 2017a).

Porbeagle

Four CPUE data series were presented for porbeagle in 2009 for the ICCAT/ICES joint porbeagle stock assessment (Anon., 2009). Countries presenting standardised CPUE series were: US, Uruguay, Japan (southern bluefin tuna fishery ground) and EU.Spain. Additionally, six Canadian series and a French series were used for the assessment. Four stocks were identified for the 2009 assessment (NW, NE, SW, SE), however only three were assessed as for SE there was not enough information. The CPUE series for NW were the Canadian, Spanish and US series, while for the NE two series were available, the Spanish and French. For the SW only the Uruguayan series was available. CPUE series used in the stock assessment are represented in Figure III.20.

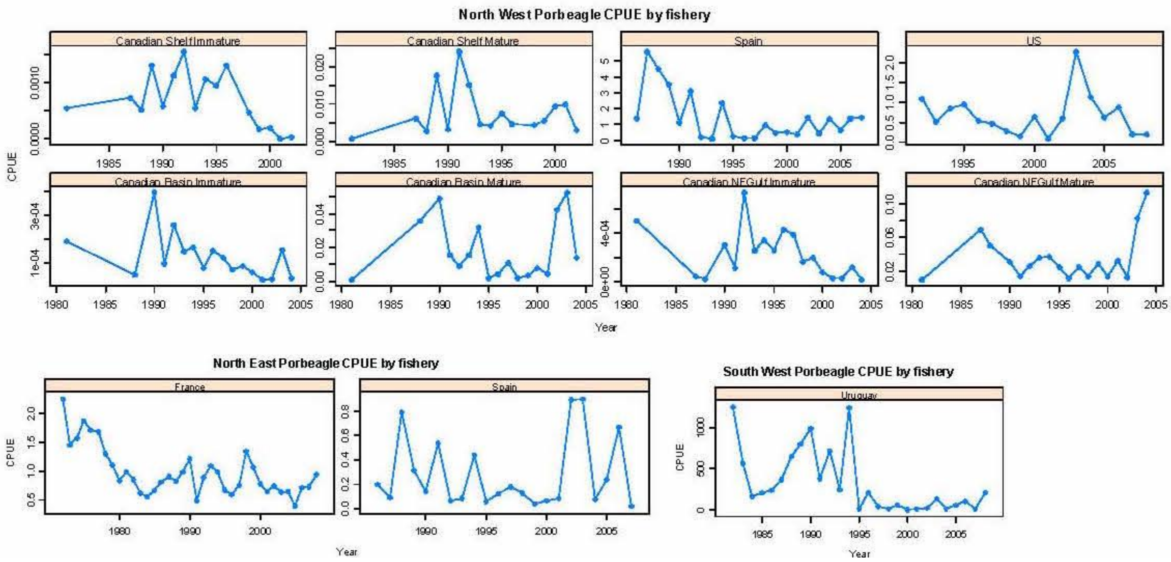


Figure III.20. CPUE series for the porbeagle NW stock (upper figures), NE stock (lower left figures) and SW stock (lower right figure) (Source: Anon., 2009).

IOTC

Blue shark

Six CPUE data series were presented for blue shark in 2017 for the IOTC Working group on Ecosystems and By-catch (IOTC, 2017). Countries presenting standardised CPUE series were: EU.Spain, EU.Portugal, EU.France, Indonesia, Japan (early and late), and Taiwan.China. From these only three (EU.France, EU.Portugal and Japan) were used in the base case assessment and the others used in sensitivity runs. CPUE series used in the stock assessment are represented in

Figure III.21. Differing trends were apparent in some of the standardised CPUE series, even in cases of fleets operating within the same areas. However, the series used in the final base case assessment were all positively correlated.

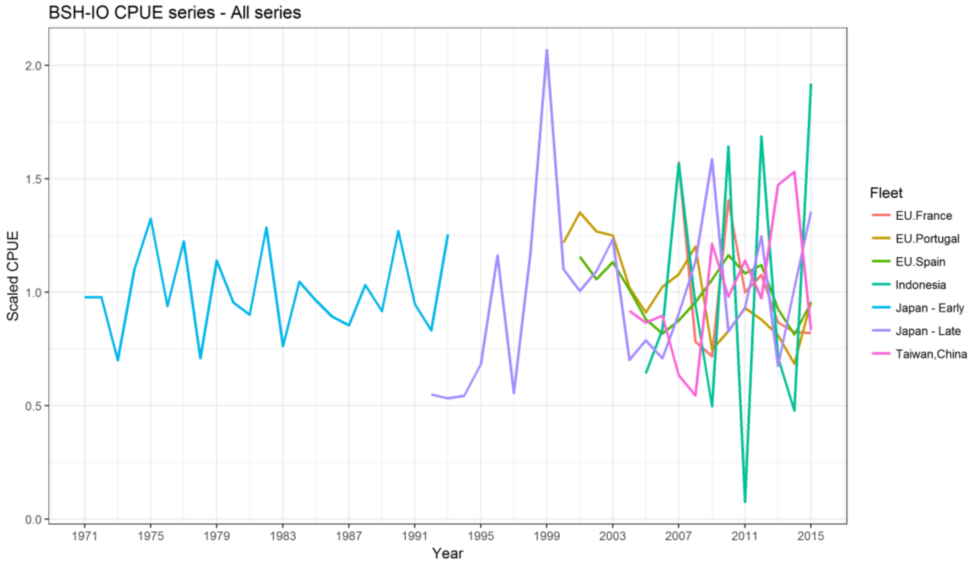


Figure III.21. Comparison of the blue shark standardised CPUE series for the longline fleets of Japan (early), Japan (late), EU.Portugal, EU.Spain, and Taiwan.China (Source: IOTC, 2017).

Shortfin mako

For shortfin mako in the Indian Ocean there are only two CPUE series available. Japan presented a standardised CPUE series (Kimoto et al. 2011) for the 2011 IOTC Working Party on Ecosystems and Bycatch meeting (IOTC, 2011). The CPUE suggest that the biomass declined from 1994 to 2003, and increased until 2010 with substantial fluctuations (Figure III.22). EU.Portugal presented a standardised CPUE series (Coelho et al., 2013) for the 2013 IOTC Working Party on Ecosystems and Bycatch meeting (IOTC, 2013). The standardised CPUE series of shortfin mako catches by the Portuguese longline fleet in the Indian Ocean showed some significant variability between 1999 and 2012, with a declining trend from 1999 to 2004 and an increasing trend in more recent years until 2012 for both models tested (Figure III.23).

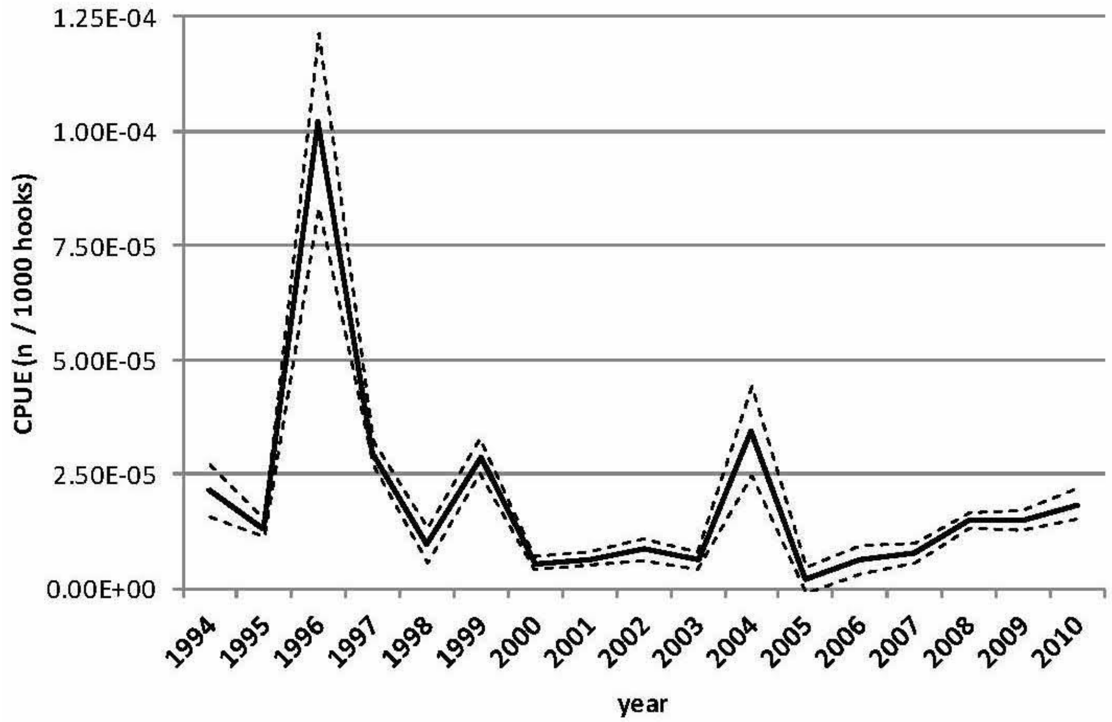


Figure III.22. Standardised CPUE (n/1000 hooks) and its confidence interval for SMA captured by the Japanese pelagic longline fleet operating in the Indian Ocean (Source: Kimoto et al. 2011).

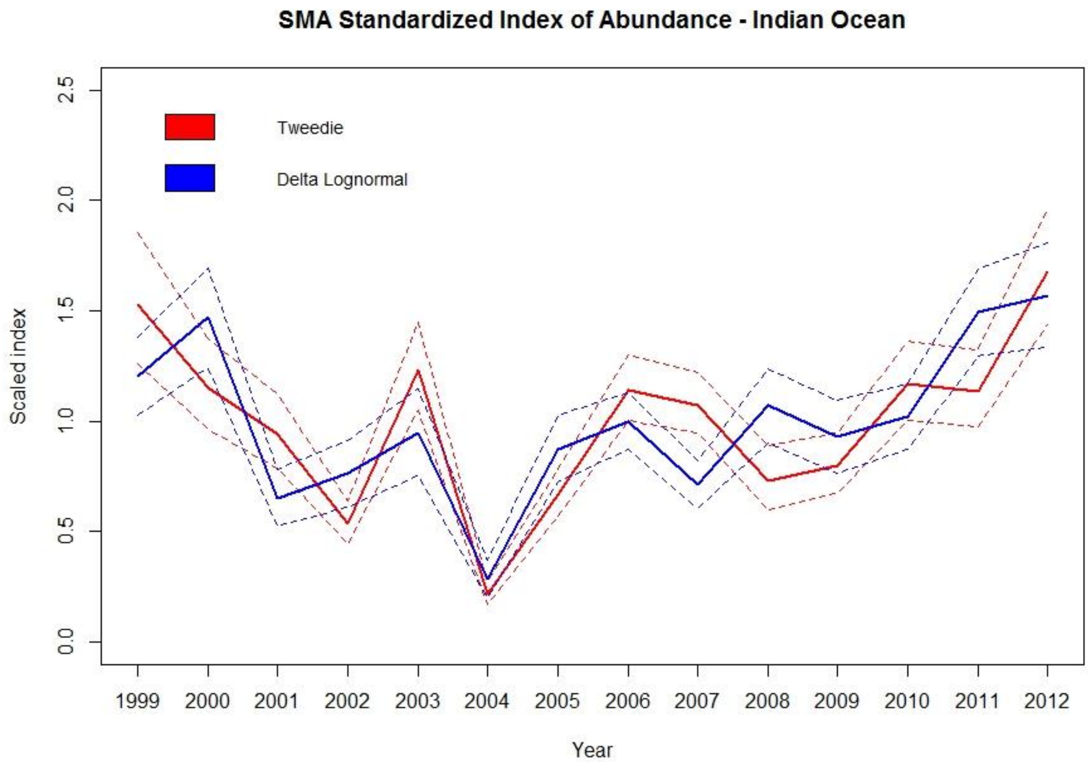


Figure III.23. Scaled annual index of abundance for SMA captured by the Portuguese pelagic longline fleet operating in the Indian Ocean. The solid lines refer to the standardised series calculated with the two different models, and the dotted lines refer to the respective 95% confidence intervals (Source: Coelho et al., 2013).

Oceanic whitetip

For oceanic whitetip there are only two CPUE series available. Japan and EU.Spain presented a standardised CPUE series for the 2012 IOTC Working Party on Ecosystems and Bycatch meeting (IOTC, 2012). Trends in the Japanese standardised CPUE series (2003–2011) suggest that the longline vulnerable biomass has decreased (Yokawa & Semba., 2012). The authors stated that the early CPUE (2000–02) were not reliable due to data problems (Figure III.24). Trends in the EU.Spain standardised CPUE series (1998–2011) suggest that the longline vulnerable biomass declined from 1999 until 2007 and has since been variable (Ramos-Cartelle et al., 2012).

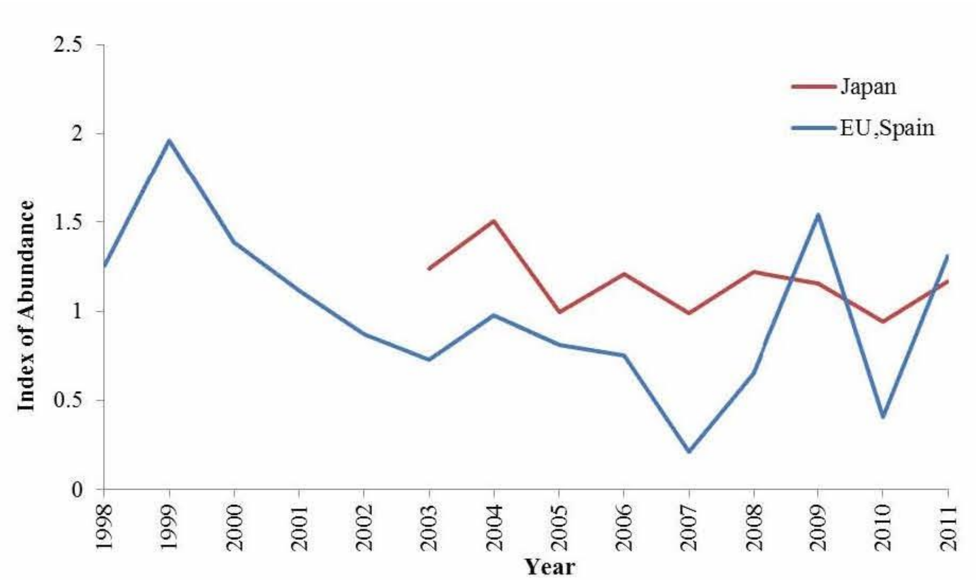


Figure III.24. Comparison of the oceanic whitetip standardised CPUE series for the longline fleets of Japan and EU.Spain (Source: IOTC, 2012).

IATTC

Silky shark

In the eastern Pacific Ocean there was an attempt to assess the status of the silky shark in 2013, however this assessment, using conventional stock assessment models, was hindered by major uncertainties in the fishery data, primarily total annual catch in the early years for all fisheries that caught silky sharks in the EPO

(Lennert-Cody et al., 2017). In 2014, a suite of possible stock status indicators that could be considered for managing the silky shark in the EPO were proposed and a standardized catch-per-set (CPS) indices from the purse-seine fishery has been carried since then. In 2017, this indicator was updated with data from 2016 (Lennert-Cody et al., 2017). Trends were analysed for Class-6 purse-seiners with floating-object (OBJ) sets. The analysis was done for all sizes and by size class (small: < 90 cm TL, medium: 90-150 cm TL, large: >150 cm TL) for the EPO north and south of the equator, and for four smaller areas within the north EPO. A preliminary comparison between the north EPO and the Western and Central Pacific Ocean (WCPO) was also conducted.

For the north EPO, the CPS index shows an initial sharp decline during 1994-1998, followed by a period of relative stability at a low level (1999-2009) and is fluctuating since then (Lennert-Cody et al., 2017); despite some differences between size classes, the trends for the three size categories of silky sharks are generally similar to the trend for all silky sharks (Figure III.25). For the south EPO, the CPS indicator for all sharks shows a sharp decline during 1994-2004, followed by a period of stability at much lower levels until 2013, and then a small increase in 2014, with little change through 2016 (Figure III.25). In general, the trend for medium sharks is similar to the trend for all sharks, while the trend for large sharks differs from the trend for all sharks in recent years in that it continued to decrease slightly in 2016 (Figure III.25). For the four north EPO sub-areas there are contradicting trends by sub-area for the most recent year, with the overall north EPO being most consistent with the offshore equatorial regions (Areas 2-3, Figure III.26). It was found that the agreement between the WCPO trend and the north EPO small and medium trends is highest in the offshore equatorial region (Figure III.27).

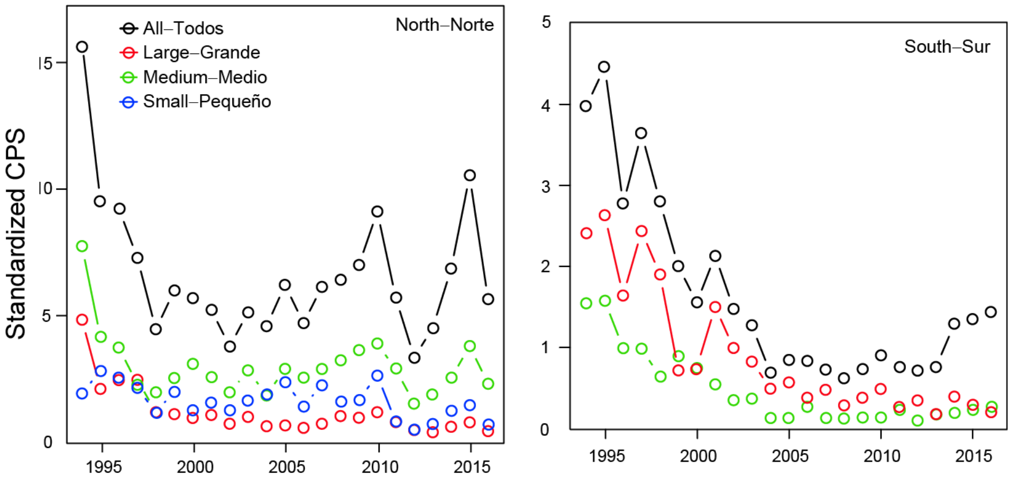


Figure III.25. Standardized catch-per-set (CPS; in numbers of sharks per set) in sets on floating objects of silky sharks of three size classes and all sizes combined in the north (left) and south (right) EPO. No index was computed for small silky sharks in the south EPO due to model instability caused by the low levels of bycatch in recent years (Source: Lennert-Cody et al., 2017).

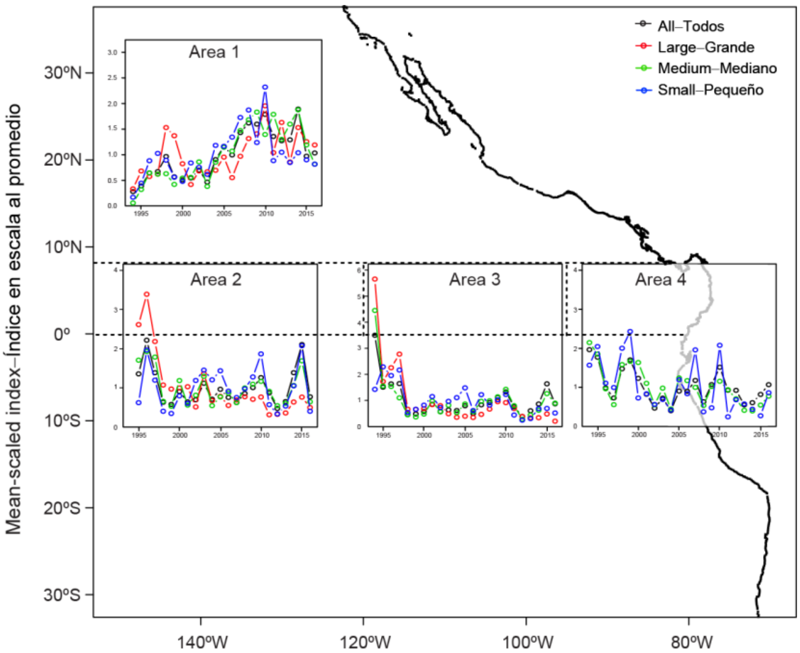


Figure III.26. Mean-scaled standardized CPS for silky sharks in the north EPO, by sub-area. The black horizontal dashed lines show the locations of the four sub-areas: Area 1 (north of 8°N); Area 2 (0°-8°N and 120°-150°W); Area 3 (0°-8°N and 95°-130°W), and Area 4 (0°-8°N, from the coast to 95°W). No trend was computed for large sharks in Area 4 because of model instability identified in previous analyses (Source: Lennert-Cody et al., 2017).

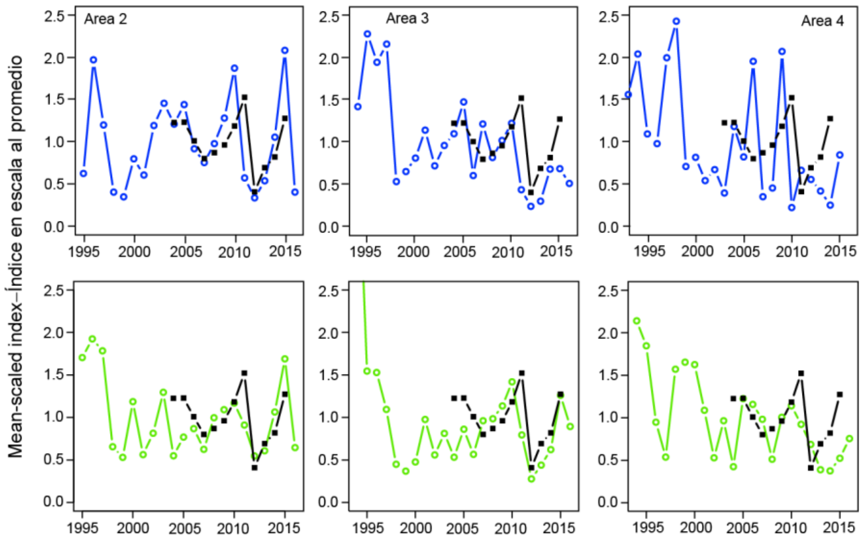


Figure III.27. Mean-scaled standardized catch-per-set for small (blue) and medium (green) silky sharks in subareas 2-4 in the north EPO (Figure 6) and the preliminary index for the WCPO (black) (145°E-180°E, 10°S-5°N) (Source: Lennert-Cody et al., 2017).

WCPFC

Silky shark

A number of CPUE data series were presented for silky shark in 2013 for the WCPFC (Rice & Harley, 2013). Standardised CPUE series presented were: Secretariat of the Pacific Community (SPC) LL No Hawaii, the Target LL, purse seine catch/set and purse seine, observer data from Hawaii and observer data collected by the Japanese research and training vessels (Rice, 2013). CPUE series used in the stock assessment are represented in Figure III.28. Despite some fluctuation for some fisheries/years, there is in most series a decreasing trend in the CPUE.

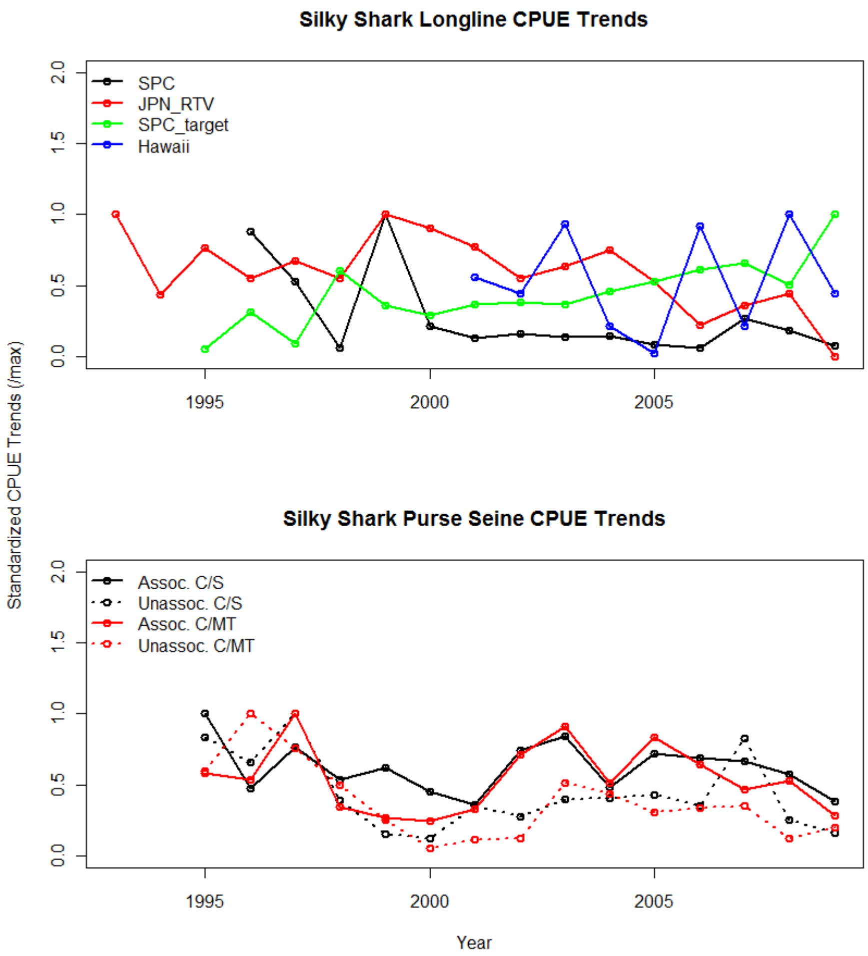


Figure III.28. Standardised silky shark CPUE time series included in the WCPFC assessment (see Rice, 2013; Source: Rice & Harley, 2013).

Furthermore, Rice et al. (2015) conducted an analysis of stock status indicators for seven WCPFC key shark species, a CPUE series from 1995 to 2014 was presented for these species. For silky shark in the WCPO the standardised series showed high inter-annual variability, it increased slightly from 2000 to 2010 but has decreased sharply in the most recent years (Figure III.29-A).

Oceanic whitetip

For the WCPO, four CPUE series (longline bycatch, target longline, purse seine – associated sets, purse seine unassociated sets) using data from 1998 to 2009, were presented in 2012 (Rice, 2012). These series were used in the WCPFC oceanic whitetip stock assessment (Rice & Harley, 2012) and are represented in Figure III.30. Despite some fluctuation for some fisheries/years, the WCPO series share the same general trend with the highest values prior to 2000 and a subsequent decline thereafter.

Furthermore, Rice et al. (2015) conducted an analysis of stock status indicators for seven WCPFC key shark species, a CPUE series from 1995 to 2014 was presented for these species. For oceanic whitetip in the WCPO the standardised series showed a steady decrease throughout the time series (Figure III.29-E).

Blue shark

Five CPUE data series were considered for the North Pacific blue shark stock assessment in 2017 of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) Shark Working Group (ISC-SHARKWG) (ISC, 2017). Standardised CPUE series were: Japan longline early (1976-1993), Japan LL late (1994-2015), Hawaii LL, Taiwan.China LL, Mexico LL, SPC LL. CPUE series used in the stock assessment are represented in Figure III.31. The Japanese series were selected for the reference case assessment model, while the other indices were selected to use in alternative runs (ISC, 2017).

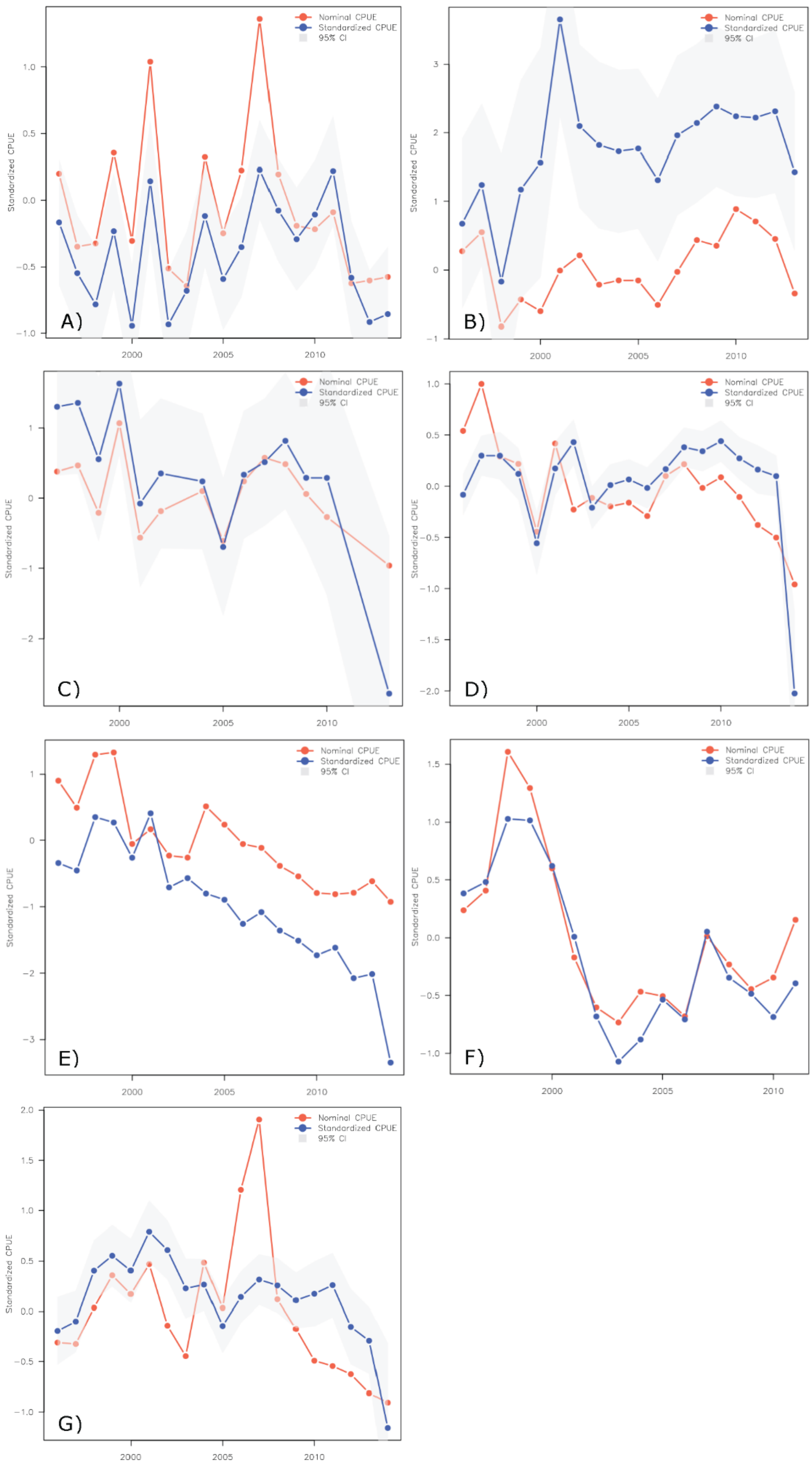


Figure III.29. Nominal and standardised CPUE for A) silky shark, B) hammerhead sharks, C) mako sharks (north), D) mako (south), E) oceanic whitetip, F) porbeagle, G) thresher sharks. Grey shaded area indicates the limits of the 5% and 95% confidence intervals.

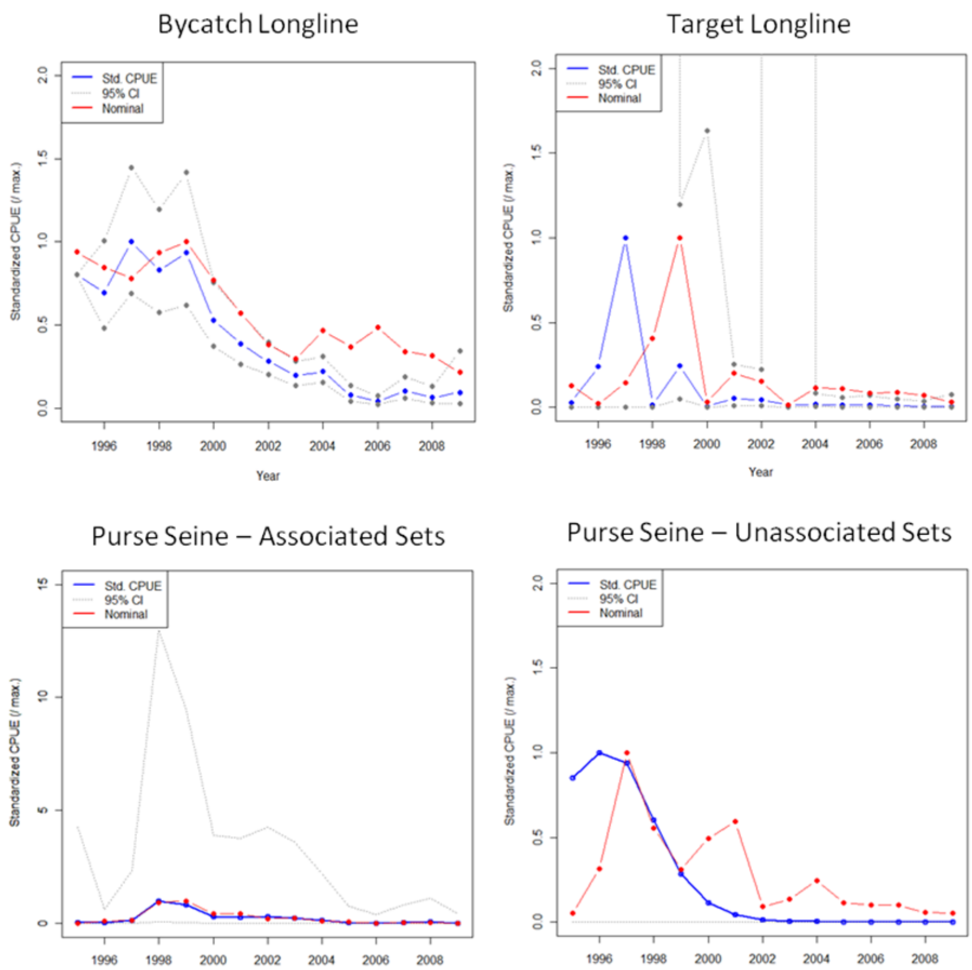


Figure III.30. Standardized and nominal oceanic whitetip CPUE time series for each of the four fisheries (Source: Rice & Harley, 2012).

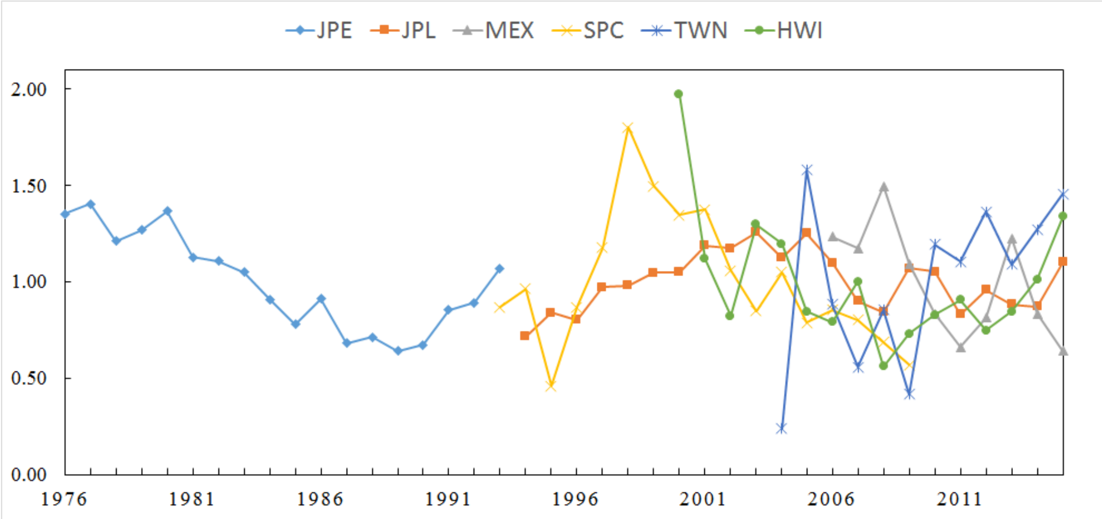


Figure III.31. Standardised CPUE indices used in the North Pacific Ocean blue shark stock assessment. JPE: Japanese offshore shallow-set longline (1976-1993), JPL: Japanese offshore shallow-set longline (1993-2015), MEX: Mexico longline (1993-2015), SPC: observed longline (1993-2015), TWN: Taiwan large-scale longline (1993-2015), and HWI: Hawaii deep-set longline (1993-2015). All indices are normalized to a mean value of 1 (Source: ISC, 2017).

Three CPUE scenarios were developed for the South West Pacific blue shark stock assessment in 2016 of the WCPFC to represent key combinations of fleet and data quality/availability (Tremblay-Boyer & Takeuchi, 2016). Standardised CPUE series were: South Pacific-wide index including all fleets based on observer data, an index for a distant water fishing nations based on observer data, an index based on high-quality operational data. These series were used individually to inform the stock assessment model (Takeuchi et al., 2016). The abundance indices produced different trends over time, with the operational series increasing after being stable in early years (Figure III.32 – top), South Pacific-wide index increasing slightly (Figure III.32 - middle), and the distant water declining (Figure III.32 – bottom) (Tremblay-Boyer &Takeuchi, 2016).

Mako sharks

Rice et al. (2015) conducted an analysis of stock status indicators for seven WCPFC key shark species, a CPUE series from 1995 to 2014 was presented for these species. For mako sharks (shortfin and longfin mako) in the north WCPO there is some poor years data and was not possible to estimate the year effects for 1996, 2003, 2011 and 2013, however the CPUE trend for 2000 to 2010 seems relatively stable (Figure III.29-C). Standardised series for the south have a relatively stable trend with a slight decrease in the last few years (Figure III.29-D).

For the North Pacific, in 2015, the ISC (2015) conducted an indicator based analysis of the status of shortfin mako. Eight fisheries or surveys were considered for CPUE standardisation. From these three were selected as the most plausible indicators of abundance based on their spatial and temporal coverage, size of sharks, data quality and model diagnostics. Selected CPUE series are presented in Figure III.33. Abundance series in two of the three series appear to be stable or increasing (Japanese shallow-set LL and Hawaii deep-set LL), while the abundance trend in the third series (Hawaii shallow-set LL) appears to be declining (ISC, 2015).

Thresher sharks

Rice et al. (2015) conducted an analysis of stock status indicators for seven WCPFC key shark species, a CPUE series from 1995 to 2014 was presented for these species. For thresher sharks (bigeye, common and pelagic threshers) in the WCPO the standardised CPUE series rises in the first years, followed by a slight decrease from 2003-2011 and from there onwards a steep decrease in CPUE is observed (Figure III.29-G). CPUE from this complex is difficult to interpret as most catches are reported as general threshers (Rice et al. 2015).

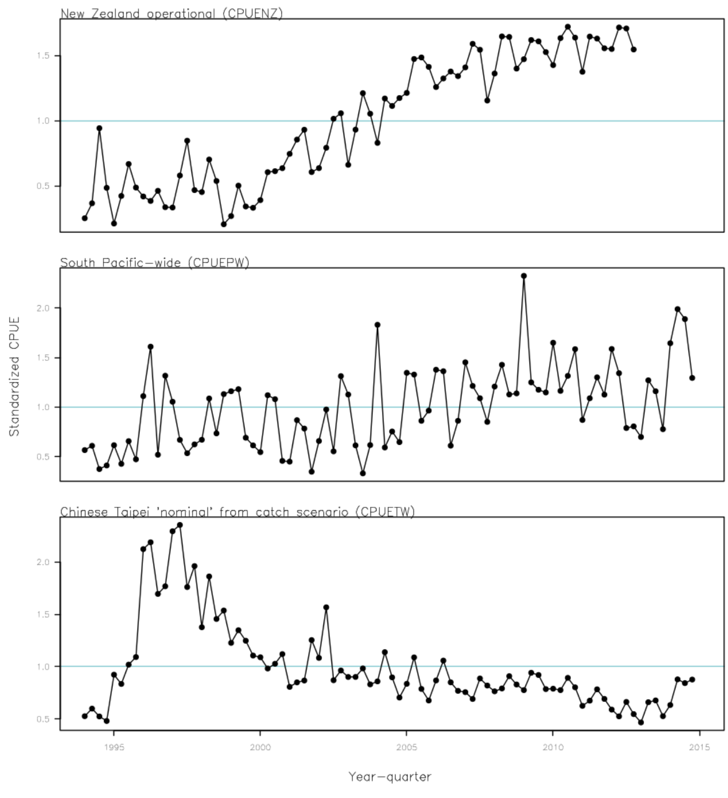


Figure III.32. Western South Pacific blue shark CPUE standardisation scenarios: operational data index (top), South Pacific-wide index (middle) and distant water fishing nations (bottom) (Source: Tremblay-Boyer & Takeuchi, 2016).

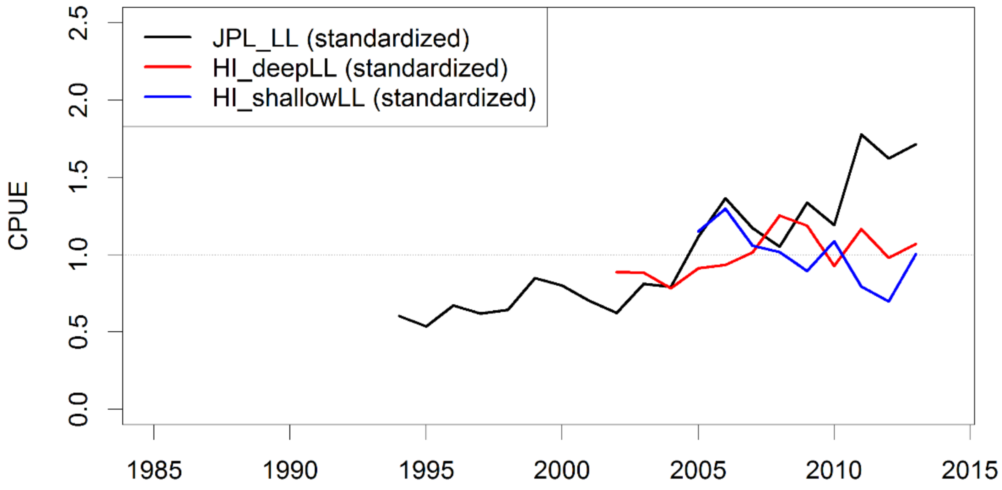


Figure III.33. North Pacific standardised indices of abundance by fishery for shortfin mako (ISC, 2015).

Hammerhead sharks

Rice et al. (2015) conducted an analysis of stock status indicators for seven WCPFC key shark species, a CPUE series from 1995 to 2014 was presented for these species. For hammerhead sharks (scalloped, smooth, great hammerhead and winghead shark *Eusphyra blochii*) in the WCPO the standardised CPUE series rises rapidly form 1997 to 2001 with a flat trend since then (Figure III.29-B). Similar to the threshers, CPUE from this complex is difficult to interpret as most catches are reported as hammerheads (Rice et al. 2015).

Porbeagle

Rice et al. (2015) conducted an analysis of stock status indicators for seven WCPFC key shark species, a CPUE series from 1995 to 2014 was presented for these species. For porbeagle in the WCPO the standardised CPUE series increased in the first 3 years, followed by an increase between 1993 and 2003, increasing steadily until the end of the series (Figure III.29-F).

In 2017, in a study requested by WCPFC, a southern hemisphere porbeagle stock status assessment was carried (Hoyle et al., 2017). The analysis was limited to the region south of 30ºS and was divided into 5 subpopulations or regions: Western Atlantic Ocean, Western Indian/ Eastern Atlantic Ocean, Eastern Indian Ocean, Western Pacific Ocean and Eastern Pacific Ocean. For each region one or two abundance indices were presented (Figure III.34, see Hoyle et al. (2017) for further references). Except for the Argentinean surimi fishery index in the Western Atlantic Ocean, that despite being very variable appears to increase, all other indices are variable and do not show any temporal trend (Hoyle et al., 2017).

Size based indicators

ICCAT

Blue shark

The time series of average size of the catch were presented for blue shark in 2015 for the ICCAT blue shark data preparatory meeting (Anon., 2015a). Coelho et al. (2015a) presented the distribution patterns of the blue shark, *Prionace glauca*, in the Atlantic Ocean, from observer data of the major fishing fleets. For this work, information was collected by fishery observers and scientific projects from several fishing nations in the Atlantic (EU.Spain, EU.Portugal, Uruguay, Taiwan, USA, Japan, Brazil, Venezuela and South Africa). The size distribution of the catch was analysed for the individual fleets and by ICCAT statistical area. The time series of the size at catch distribution was relatively stable for some fleets (e.g. Portuguese, Spanish, Japanese and US) and considerably more variable for others (Figure III.35). For the Uruguayan and Taiwanese fleets a decreasing trend was noticeable along the series, while in the Venezuelan fleet there was a period with larger sizes in the middle of the series and smaller sizes in the initial and later years. There were also differences in size at catch among regions (ICCAT statistical areas), with some regions showing relatively more stable trends than others. Some of the areas with more stable time series were regions BIL92 and BIL97, while in areas such as BIL93, BIL94A and BIL94C there was higher variability (Figure III.35).

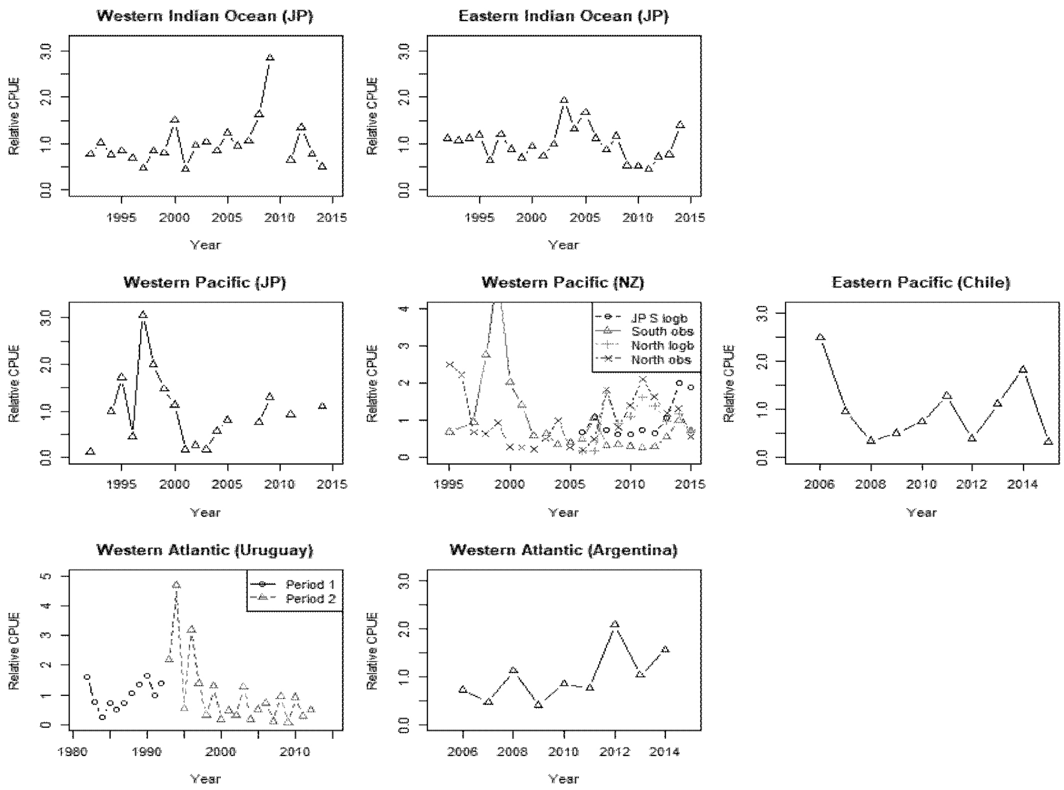


Figure III.34. CPUE indices for each region and contributing country for southern hemisphere porbeagle stock (source: Hoyle et al. 2017, see document for further references).

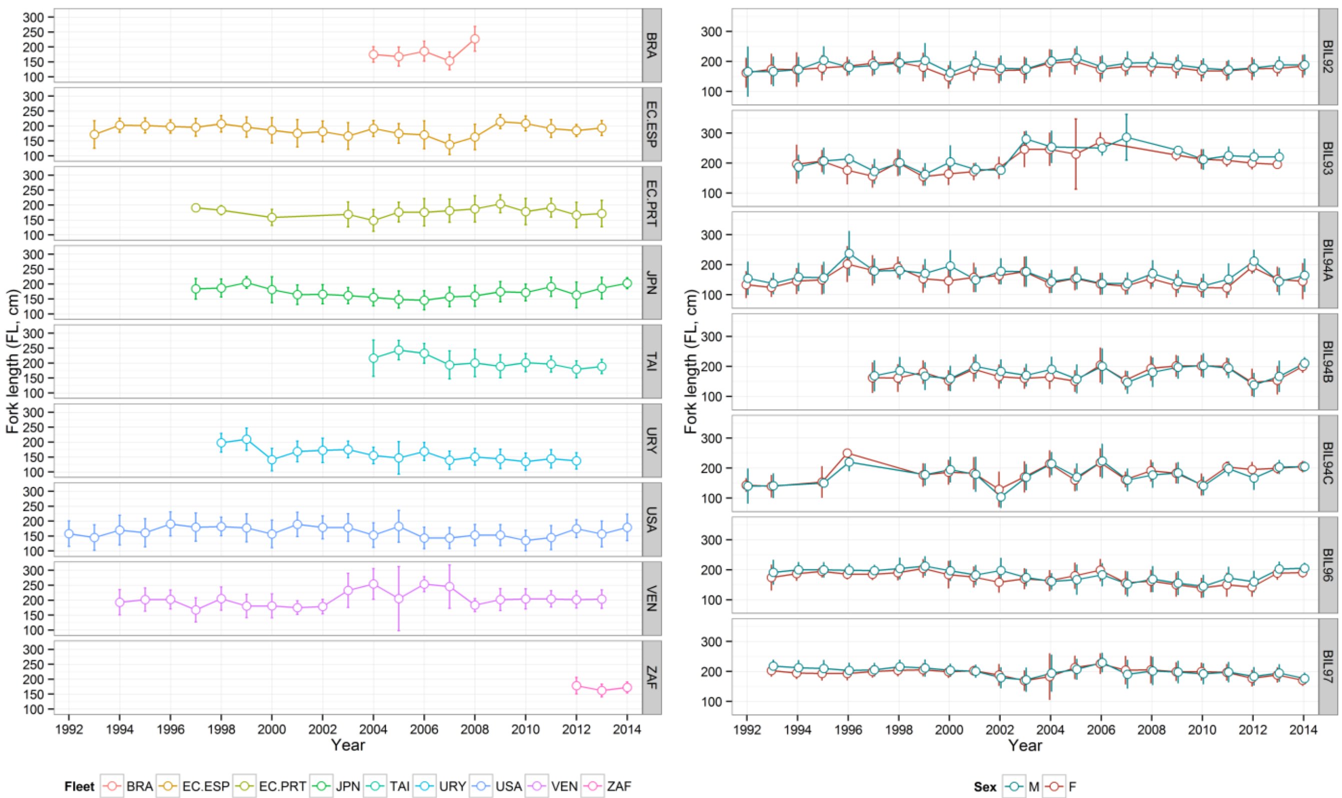


Figure III.35. Mean sizes of blue shark (*Prionace glauca*) caught by the different fishing fleets in the Atlantic (left panel) and by sex in the different ICCAT sampling regions (right panel), during the period 1992-2014. The error bars represent ± 1 standard deviation (Source: Coelho et al., 2015a).

Shortfin mako

The size distribution and time series were presented for shortfin mako in 2017 for the ICCAT shortfin mako data preparatory meeting (Anon., 2017a). Coelho et al. (2017) presented revised size data distributions and trends for shortfin mako in the Atlantic using observer data. This work was done as part of an ongoing cooperative program for fisheries and biological data collection for sharks, and currently includes information from Brazil, EU.Portugal, Japan, Uruguay, USA, Venezuela and Chinese Taipei. The size distribution of the catches was analysed for the individual fleets and by stock. The time series of the size at catch was relatively stable for the North Atlantic. By the contrary, there was a general decreasing trend in the South Atlantic (Figure III.36). There was considerable variability on the time series trends by fleet, which are shown in Figure III.37.

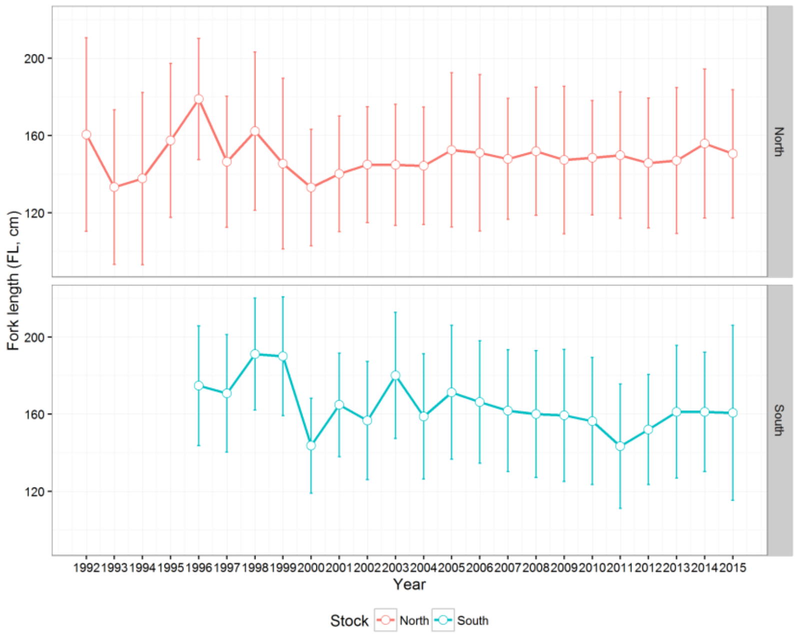


Figure III.36. Times series of the mean sizes of shortfin mako in the two stock areas (north and south Atlantic, separated by 5ºN) during the period 1992-2015. The error bars represent ± 1 standard deviation (Source: Coelho et al., 2017).

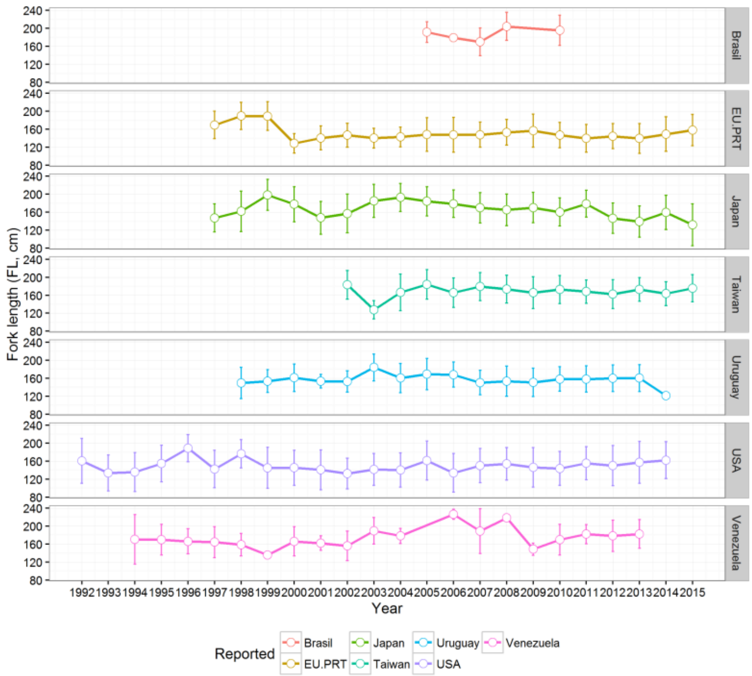


Figure III.37. Times series of the mean sizes of shortfin mako in the two stock areas (north and south Atlantic, separated by 5ºN) during the period 1992-2015. The error bars represent ± 1 standard deviation (Source: Coelho et al., 2017).

IOTC

Blue shark

Average size of catch series were presented for blue shark in 2015 for the IOTC Working group on Ecosystems and Bycatch (IOTC, 2015). Coelho et al. (2015b) presented the distribution patterns of sizes and sex-ratios of blue shark in the Indian Ocean. This included information from fishery observers, logbooks, scientific projects and scientific surveys from several fishing nations, specifically EU.Portugal, EU.France, Japan, Taiwan, South Africa and the USSR (data from historical surveys) The size at catch was analysed for four Indian Ocean regions (NW, NE, SW, SE). The NE and SE regions seemed relatively stable along the time series, with some variability but no major trends. In the NW most of the time series showed little variability, but there was a decrease in the sizes in more recent years. The region with the larger variances was the SW with relatively larger sizes in the 1970s (research cruise data), followed by a period with smaller sizes between 1992 and 2006 and then another period with larger sizes again in the more recent years (Figure III.38).

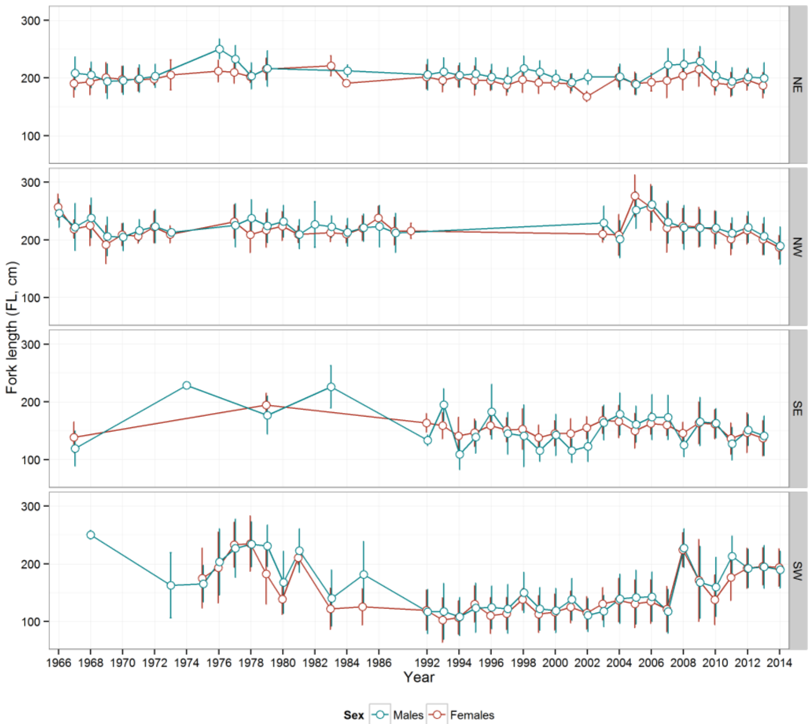


Figure III.38. Mean size of blue shark (*Prionace glauca*) by sex caught in the four different IOTC regions of the Indian Ocean, during the period 1966-2014. The error bars are ± 1 standard deviation (Source: Coelho et al., 2015b).

WCPFC

In 2015, Rice et al. (2015) conducted an analysis of stock status indicators for seven key shark species within the WCPO by region (for details on region definition see Rice et al., 2015). The standardised length at catch results are presented below (Figures III.39-III.45). Standardised lengths have declined over time for most species/sex, with the exception of the northern stock of shortfin mako for both sexes and porbeagle females, which remained the same size throughout the analysed period.

In 2017, in a study requested by WCPFC, a southern hemisphere porbeagle stock status assessment was carried (Hoyle et al., 2017). The analysis was limited to the region south of 30ºS and was divided into 5 subpopulations or regions: Western Atlantic Ocean, Western Indian/ Eastern Atlantic Ocean, Eastern Indian Ocean, Western Pacific Ocean and Eastern Pacific Ocean. For each region one or two size trends were presented (Figure III.46, see Hoyle et al. (2017), for further references). Only the Argentinian size indicators showed trends, with a small decline in sizes for both sexes (Hoyle et al., 2017).

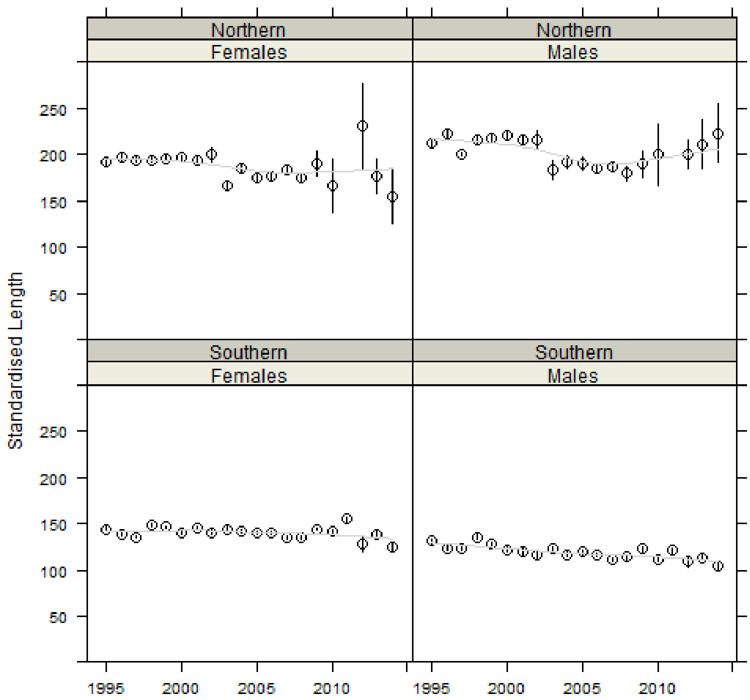


Figure III.39. Blue shark: standardised length for male and females for longline data. Light grey line shows a lowess smoother (Source: Rice et al., 2015).

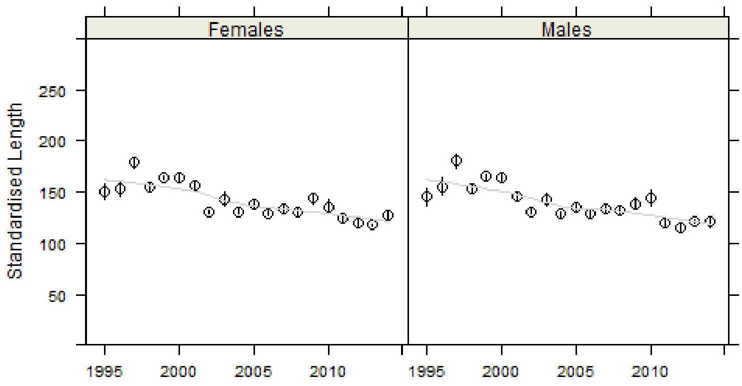


Figure III.40. Silky shark: standardised length for male and females for longline data. Light grey line shows a lowess smoother (Source: Rice et al., 2015)

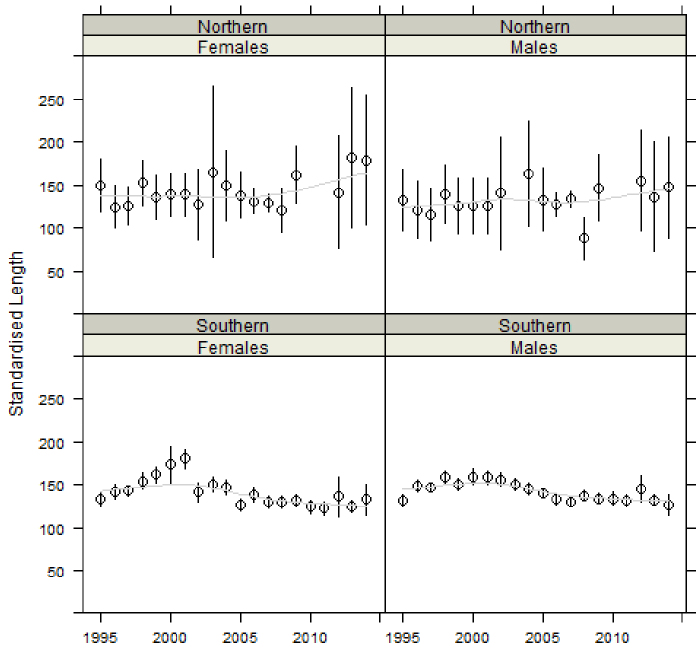


Figure III.41. Mako sharks (short and longfin mako): standardised length for male and females for longline data. Light grey line shows a lowess smoother (Source: Rice et al., 2015).

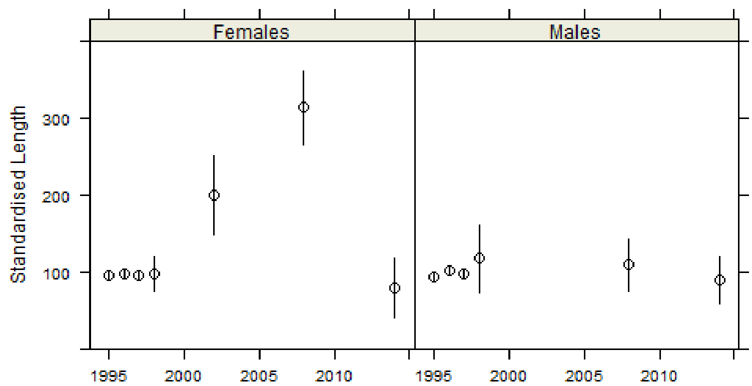


Figure III.42. Oceanic whitetip: standardised length for male and females for longline data. Light grey line shows a lowess smoother (Source: Rice et al., 2015).

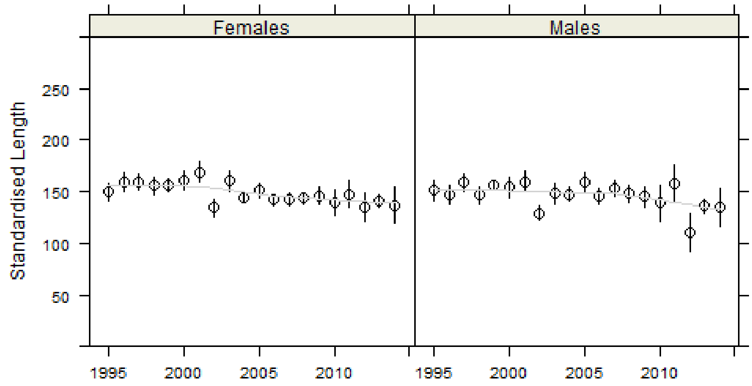


Figure III.43. Porbeagle: standardised length for male and females for longline data. Light grey line shows a lowess smoother (Source: Rice et al., 2015).

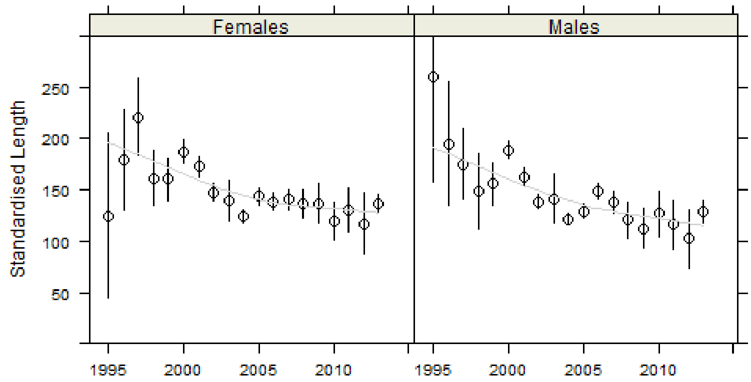


Figure III.44. Hammerhead sharks (scalloped, smooth, great hammerhead and winghead shark) standardised length for male and females for longline data. Light grey line shows a lowess smoother (Source: Rice et al., 2015).

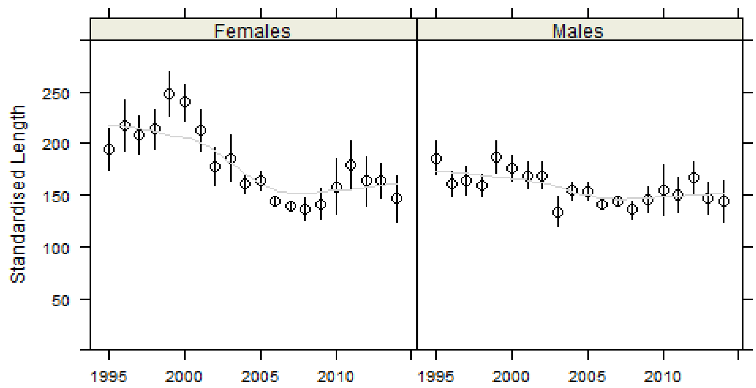


Figure III.45. Thresher sharks (bigeye, common and pelagic threshers) standardised length for male and females for longline data. Light grey line shows a lowess smoother (Source: Rice et al., 2015).

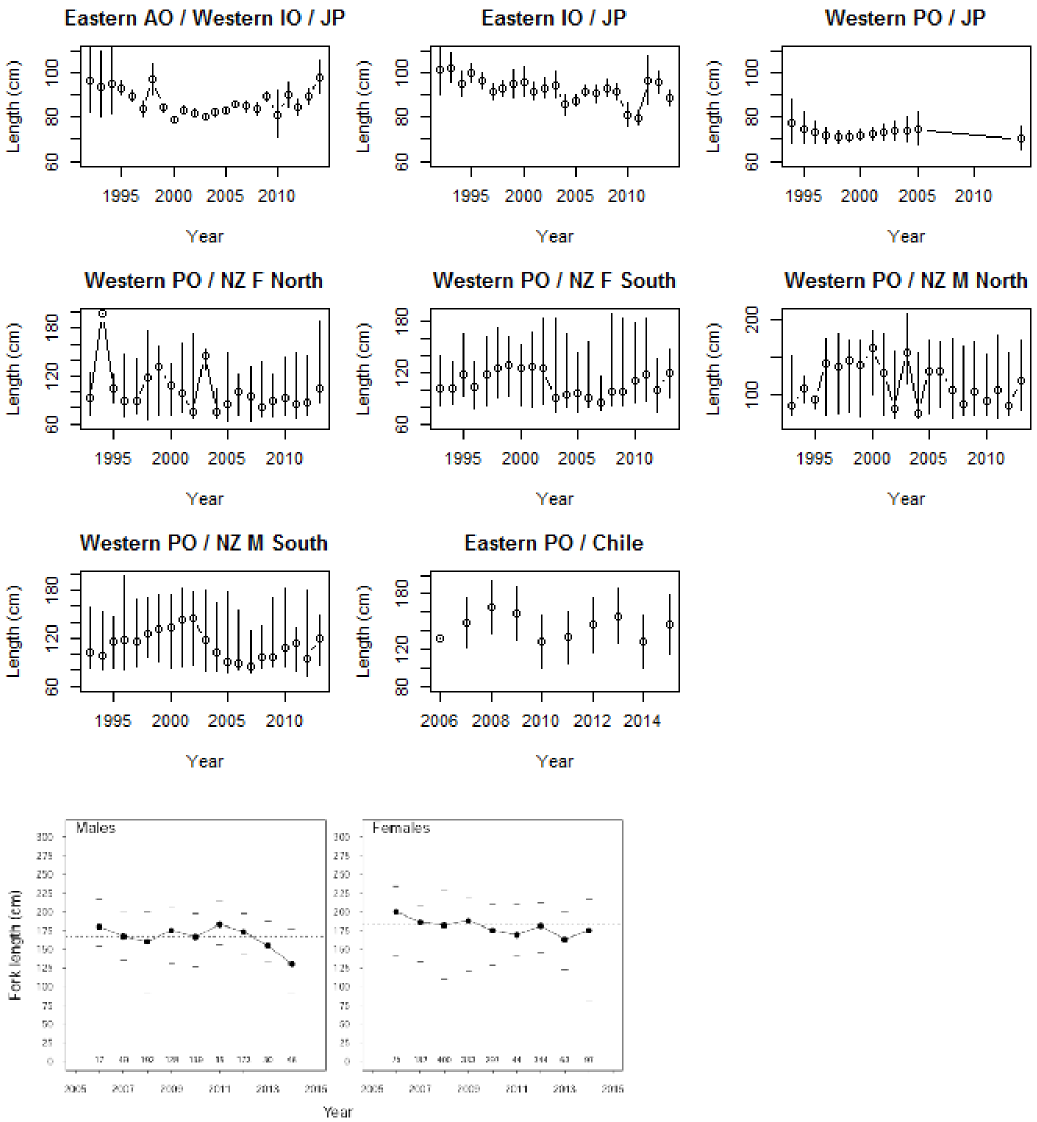


Figure III.46. Standardised predictions (Japan (JP) and Chile) and annual measurements (New Zealand (NZ) and Argentina) of lengths in the catch, by region and contributing country (source: Hoyle et al. 2017, see document for further references).

Distribution analyses

WCPFC

In 2015, Rice et al. (2015) conducted an analysis of stock status indicators for seven key shark species within the WCPO by region (for details on region definition see Rice et al., 2015). The proportion-presence (Figure III.47) and high-CPUE (Figure III.48) analyses results are presented here. The proportion-presence and High-CPUE analyses showed a more or less steady trend for all species analysed in all regions, except Regions 3 to 6 for blue shark and oceanic whitetip which, for both indicators, show decreasing trends.

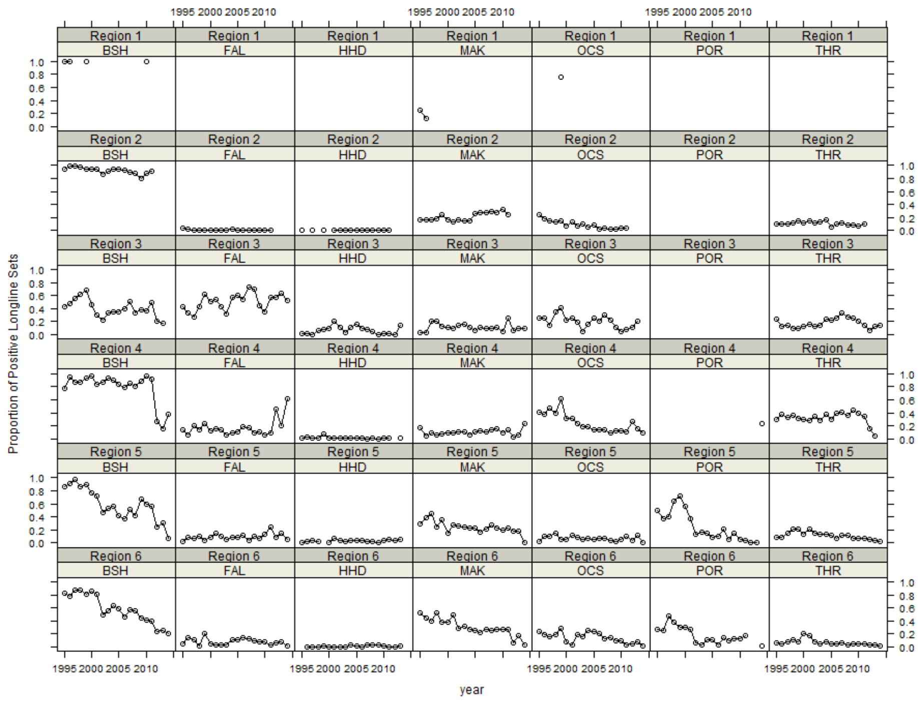


Figure III.47. The proportion of longline sets for which one or more sharks were caught by region and year (Source: Rice et al., 2015).

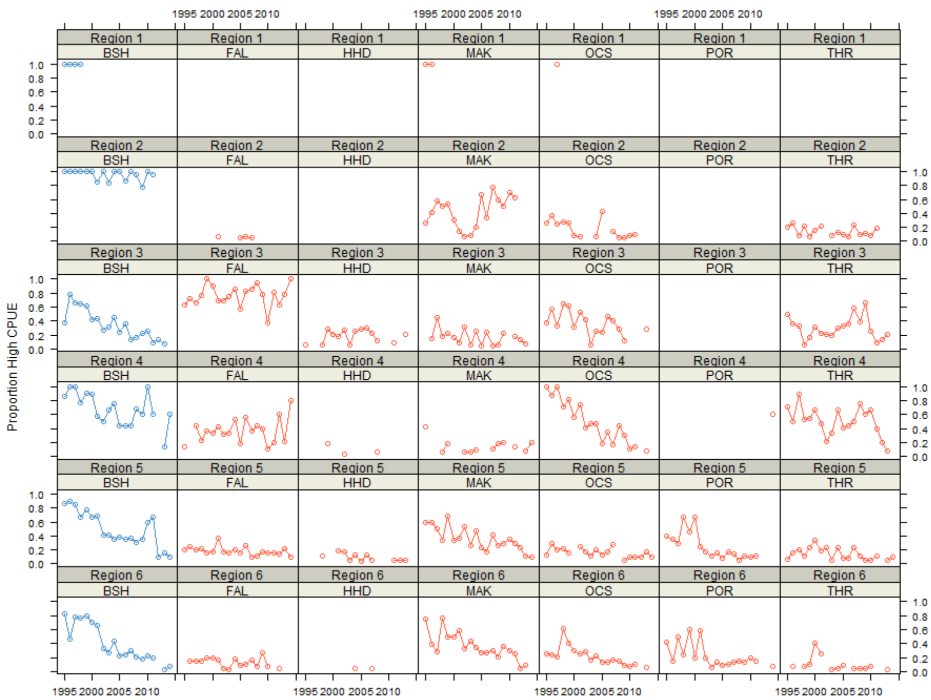


Figure III.48. Proportion of longline sets with high CPUE by species and region. High CPUE is defined as sets with more than 1 shark per 1000 hooks (for blue shark, blue lines) or more than one shark per 5000 hooks (all other species, red lines) (Source: Rice et al., 2015).

References

Anon. 2009. Report on the 2009 ICCAT porbeagle stock assessment session. 22-27 June 2009, Copenhagen, Denmark. 57 pp.

Anon. 2015a. Report of the 2015 ICCAT blue shark data preparatory meeting. 23-27 March 2015, Tenerife, Spain. 33 pp.

Anon. 2015b. Report of the 2015 ICCAT blue shark stock assessment session. 27-31 July 2015, Oceanário de Lisboa, Lisbon, Portugal. 116 pp.

Anon. 2017a. Report of the 2017 ICCAT shortfin mako data preparatory meeting. 28-31 March 2017, Madrid, Spain. 52 pp.

Anon. 2017b. Report of the 2017 ICCAT shortfin mako stock assessment meeting. 12-16 June 2017, Madrid, Spain. 64 pp.

Coelho R., Mejuto J., Domingo A., Liu K-M, Cortés E., Yokawa K., Hazin F., Arocha F., da Silva C., García-Cortés B., Ramos-Cartelle A.M., Lino P.G., Forselledo R., Mas F., Ohshimo S., Carvalho F., Santos M.N. 2015a. Distribution patterns of the blue shark Prionace glauca in the Atlantic Ocean from observer data of the major fishing fleets. ICCAT Blue Shark Stock Assessment meeting, 27-31 July 2015, Lisbon, Portugal. ICCAT document SCRS/2015/039: 24 pp.

Coelho, R., Domingo, A., Courtney, D., Cortés, E., Arocha, F., Liu, K-M., Yokawa, K., Yasuko, S., Hazin, F., Rosa, D., Lino, P.G. 2017. A revision of the shortfin mako shark catch-at-size in the Atlantic using observer data *Collect. Vol. Sci. Pap. ICCAT*, 74(4): 1562-1578.Coelho, R., Santos, M.N., Lino, P.G. 2013. Standardized CPUE series for blue and shortfin mako sharks caught by the Portuguese pelagic longline fishery in the Indian Ocean between 1999 and 2012. 9th Working Party on Ecosystems and Bycatch, 12-16 September 2013, La Reunion, France. IOTC Document IOTC–2013–WPEB09–22: 18pp.

Coelho, R., Yokawa, K., Liu, K-M., Romanov, E., da Silva, C., Bach, P., Lino, P.G., Ohshimo, S., Tsai, W-P., Santos, M.N. 2015b. Distribution patterns of sizes and sex-ratios of blue shark in the Indian Ocean. 11th Working Party on Ecosystems and Bycatch, 7-11 September 2015, Olhão, Portugal. IOTC Document IOTC–2015–WPEB11–22: 22 pp.

Cortés, E., Domingo, A., Miller, P., Forselledo, R., Mas, F., Arocha, F., Campana, S., Coelho, R., Da Silva, C., Holtzhausen, H., Keene, K., Lucena, F., Ramirez, K., Santos, M.N., Semba-Murakami, Y., Yokawa, K. 2015. Expanded ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Collect. Vol. Sci. Pap. ICCAT*, 71: 2637-2688.

Duffy, L., Olsen, R. 2016. Ecosystem considerations. 7th Meeting of the Scientific Advisoty Committe of the IATTC, 9-13 May 2016, La Jolla, California. IATTC document SAC-07-07b: 40 pp.

Griffiths, S., Duffy, L., Aires-da-Silva, A. 2017. A preliminary ecological risk assessment of the larg-scale tuna longline fishery in the Eastern Pacific Ocean using productivity-susceptibility analysis. 8th Meeting of the Scientific Advisoty Committe of the IATTC, 8-12 May 2017, La Jolla, California. IATTC document SAC-08-07d: 21 pp.

Hoyle, S.D., Edwards, C.T.T., Roux, M.-J., Clarke, S.C., Francis, M.P. 2017. Southern Hemisphere porbeagle shark stock status assessment. 13th Regular Meeting of the Scientific Committe of the WCPFC, 9-17 August 2017, Rarotonga, Cook Islands. WCPFC document WCPFC-SC13-2017/SA-WP-12: 65 pp.

IOTC. 2011. Report of the Seventh Session of the IOTC Working Party on Ecosystems and Bycatch. 24-27 October 2011, Lankanfinolhu, North Malé Atoll, Republic of Maldives. IOTC document IOTC–2011–WPEB07–R[E]: 99 pp.

IOTC. 2012. Report of the Eighth Session of the IOTC Working Party on Ecosystems and Bycatch. 17–19 September 2012, Cape Town, South Africa. IOTC document IOTC–2012–WPEB08–R[E]: 77 pp.

IOTC. 2013. Report of the Ninth Session of the IOTC Working Party on Ecosystems and Bycatch. 12–16 September 2013, La Réunion, France. IOTC document IOTC–2013–WPEB09–R[E]: 98 pp.

IOTC. 2017. Report of the Thirteenth Session of the IOTC Working Party on Ecosystems and Bycatch. 4-8 September 2017, San Sebastián, Spain. IOTC document IOTC–2017–WPEB13–R[E]: 338 pp.

ISC. 2015. Indicator-based analysis of the status of shortfin mako shark in the North Pacific Ocean. 15th Meeting of the ISC, 15–20 July 2017, Kona, Hawaii, U.S.A. ISC document ISC15/SHARKWG Annex 12: 33 pp.

ISC. 2017. Stock assessment and future projection of blue shark in the North Pacific Ocean through 2015. 17th Meeting of the ISC, 12–17 July 2017, Vancouver, Canada. ISC document ISC17/SHARKWG Annex 13: 96 pp.

Kimoto, A., Hiraoka, Y., Ando, T., Yokawa, K. 2011. Standardized CPUE of shortfin mako shark (*Isurus oxyrinchus*) caught by Japanese longliners in the Indian Ocean in the period between 1994 and 2010. 7th Working Party on Ecosystems and Bycatch, 24-27 October 2011, Lankanfinolhu, North Malé Atoll, Republic of Maldives. IOTC Document IOTC–2011–WPEB07–34: 8pp.

Lennert-Cody, C. E., Clarke, S. C., Aires-da-Silva, A., Maunder, M. N., Román, M. H. 2017. Updated stock status indicators for silky sharks in the Eastern Pacific Ocean (1994-2016), with oceanographic considerations. 8th Meeting of the Scientific Advisoty Committe of the IATTC, 8-12 May 2017, La Jolla, California. IATTC document SAC-08-08a: 20 pp.

Murua, H., Coelho, R., Santos, M.S., Arrizabalaga, H., Yokawa, K., Romanov, E., Zhu, J.F., Kim, Z.G., Bach, P., Chavance, P., Delgado de Molina, A., Ruiz, J. 2012. Preliminary Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC). 8th Working Party on Ecosystems and Bycatch, 17-19 September 2012, Cape Town, South Africa. IOTC Document IOTC–2012–WPEB08–31: 16 pp.

Ramos-Cartelle, A., García-Cortés, B., Ortíz de Urbina, J., Fernández-Costa, J., González-González, I., Mejuto, J. 2012 Standardized catch rates of the oceanic whitetip shark (*Carcharhinus longimanus*) from observations of the Spanish longline fishery targeting swordfish in the Indian Ocean during the 1998–2011 period. 8th Working Party on Ecosystems and Bycatch, 17–19 September 2012, Cape Town, South Africa. IOTC document IOTC–2012–WPEB08–27: 15 pp.

Rice, J. 2012. Catch per unit effort of oceanic whitetip sharks in the Western and Central Pacific Ocean. 8th Regular Meeting of the Scientific Committe of the WCPFC, 7-15 August 2012, Busan, Republic of Korea. WCPFC document WCPFC-SC8-2012/SA-IP-10: 35 pp.

Rice, J. 2013. Catch and catch per unit effort of silky sharks in the Western and Central Pacific Ocean. 9th Regular Meeting of the Scientific Committe of the WCPFC, 6-14 August 2013, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC9-2013/SA-IP-02: 26 pp.

Rice, J., Harley, S. 2012. Stock assessment of oceanic whitetip sharks in the western and central Pacific Ocean. 8th Regular Meeting of the Scientific Committe of the WCPFC, 7-15 August 2012, Busan, Republic of Korea. WCPFC document WCPFC-SC8-2012/SA-WP-06: 53 pp.

Rice, J., Harley, S. 2013. Updated assessment of silky sharks in the Western and Central Pacific Ocean. 9th Regular Meeting of the Scientific Committe of the WCPFC, 6-14 August 2013, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC9-2013/ SA-WP-03: 71 pp.

Rice, J., Tremblay-Boyer, L., Scott, R., Hare, S., Tidd, A. 2015. Analysis of stock status and related indicators for key shark species of the Western Central Pacific Fisheries Commission. 10th Regular Meeting of the Scientific Committe of the WCPFC, 5-13 August 2015, Pohnpei, Federated States of Micronesia. WCPFC document WCPFC-SC11-2015/EB-WP-04-Rev 1: 146 pp.

Takeuchi, Y., Tremblay-Boyer, L., Pilling, M.G., Hampton, J. 2016. Assessment of blue shark in the southwestern Pacific. 12th Regular Meeting of the Scientific Committe of the WCPFC, 3-11 August 2016, Bali, Indonesia. WCPFC document WCPFC-SC12-2016/SA-WP-08: 51 pp.

Tremblay-Boyer, L., Takeuchi, Y. 2016. Catch and CPUE inputs to the South Pacific blue shark stock assessment. 12th Regular Meeting of the Scientific Committe of the WCPFC, 3-11 August 2016, Bali, Indonesia. WCPFC document WCPFC-SC-12/SA-WP-09: 59 pp.

Yokawa, K., Semba, Y. 2012. Update of the standardized CPUE of oceanic whitetip shark (*Carcharhinus longimanus*) caught by Japanese longline fishery in the Indian Ocean. 8th Working Party on Ecosystems and Bycatch, 17–19 September 2012, Cape Town, South Africa. IOTC Document IOTC–2012–WPEB08–26: 5 pp.

APPENDIX IV – TASK 2

1. Summary of active CMMs by tRFMO

IOTC

Resolution 15/01: On the recording of catch and effort data by fishing vessels in the IOTC area of competence

Resolution 15/01 establishes a data recording system for catches and fishing operations that applies to fishing vessels from each flag CPCs. Annex II of the Resolution provides a list of sharks and rays (as well as other target and non-target species) for which catch must, as a minimum requirement, be recorded by fishing masters in vessel logbooks[48]. Recording requirements include catch in weight and/or number per set/shot/fishing event for each species and form of processing. Separate species lists are defined for purse seine, longline, pole-and-line and gillnet and include mandatory as well as optional species (these classifications are mostly harmonised between gear types with respect to the species in the scope of this study). The listing of shark and ray species explicitly was first introduced in 2011 in Resolution 11/06 (superseded); prior to this, recording of catches of sharks and rays was required only as 'other species'. Species lists have been updated several times since 2011, although changes have mostly involved re-classing species from optional to mandatory reporting (e.g. silky, oceanic whitetip and thresher sharks). A detailed summary of the changes at each amendment is presented in Table IV.1.

[48] Annex III of Res. 15/01 defines similar reporting requirements for handline and trolling, although recording of catch of sharks and rays is not required at species level.

Table IV.1. Summary of changes in shark and ray reporting obligations contained within IOTC Res. 15/01. PS = purse seine, LL=longline; BB = pole-and-line; GN = gillnet.

CMM	Date	Description	Changes since preceding CMM
Res. 15/01	2015	Annex II defines a list of sharks species for which data on shall (or may, for optional species) be recorded in bound or electronic logbooks. Supersedes Resolution 13/03	Addition of mandatory reporting of silky shark for PS (was previously optional reporting)
Res. 13/03	2013	Annex II defines a list of sharks species for which data on shall (or may, for optional species) be recorded in bound or electronic logbooks. Supersedes Resolution 12/03	Addition of mandatory reporting of thresher and oceanic whitetip for LL, PS and GN (was previously optional reporting)
Res. 12/03	2012	Annex II defines a list of sharks species for which data on shall (or may, for optional species) be recorded in bound or electronic logbooks. Supersedes Resolution 11/06 for all CPCs except India for which it remains binding	Addition of optional reporting of thresher shark for PS; downgrading from mandatory to optional reporting of oceanic whitetip for LL and GN; addition of optional reporting of manta/mobula rays for LL, PS, GN; addition of optional reporting of 'other rays' for LL, PS, GN (mandatory for BB); loss of optional reporting of great white shark for GN
Res. 11/06	2011	Annex II defines a list of sharks species for which data on shall (or may, for optional species) be recorded in bound or electronic logbooks. Supersedes Resolution 10/03	Introduction of explicit logbook reporting instructions (mandatory and optional species) for specific shark and rays in Annex II (data to be recorded once per set/shot/operation); previously reporting of shark/rays was not required at species level

<u>Resolution 11/04: On a regional observer scheme</u>

Resolution 11/04 establishes an observer scheme in order to collect verified catch data and other scientific data related to the fisheries in the IOTC area of competence. The Resolution sets out that observers shall, amongst other things:

- Observe and estimate catches as far as possible with a view to identifying catch composition and monitoring discards, by-catches and size frequency;
- Collect information to enable the cross-checking of entries made to the logbooks (species composition and quantities, live and processed weight and location, where available); and
- Carry out such scientific work (for example, collecting samples), as requested by the IOTC Scientific Committee.

Observers must record all species that interact with the fishing gear, whether they are target species or bycatch, retained or discarded. A number of identification guides and tools are provided to observers to aid identification of shark and rays species[49]. Observers also collect biological samples from oceanic whitetip (Res. 13/06) and thresher sharks (Res. 12/09) as part of research projects approved by the IOTC Scientific Committee.

The observer scheme entered into force through Resolution 09/04 in July 2010. There have been no significant changes with respect to shark and ray recording obligations since this initial CMM.

Resolution 12/09: On the conservation of thresher sharks (Family Alopiidae) caught in association with fisheries in the IOTC area of competence

Resolution 12/09 establishes a number of conservation measures applicable to thresher sharks but also sets out the following recommendation and requirements with respect to reporting:

- CPCs shall encourage their fishers to record and report incidental catches as well as live releases. These data will be then kept at the IOTC Secretariat;
- Scientific observers shall be allowed to collect biological samples (vertebrae, tissues, reproductive tracts, stomachs, skin samples, spiral valves, jaws, whole and skeletonised specimens for taxonomic works and museum collections) from thresher sharks that are dead at haulback, provided that the samples are part of the research project approved by the IOTC Scientific Committee (or IOTC Working Party on Ecosystems and Bycatch (WPEB)); and
- The Contracting Parties, Cooperating Non-Contracting Parties, especially those directing fishing activities for sharks, shall submit data for sharks, as required by IOTC data reporting procedures.

Resolution 13/06: On a scientific and management framework on the conservation of shark species caught in association with IOTC managed fisheries

Resolution 13/06 primarily outlines a general framework for the conservation and management of shark species caught in the IOTC area, although it also includes the following recommendation and requirements with respect to reporting:

- CPCs shall encourage their fishers to record incidental catches as well as live releases of oceanic whitetip sharks;

[49] IOTC Regional Observer Manual and species identification cards, available at: http://www.iotc.org/science/regional-observer-scheme-science

- CPCs shall, where possible, implement research on oceanic whitetip sharks taken in the IOTC area of competence, in order to identify potential nursery areas;
- Scientific observers shall be allowed to collect biological samples (vertebrae, tissues, reproductive tracts, stomachs, skin samples, spiral valves, jaws, whole and skeletonised specimens for taxonomic works and museum collections) from oceanic whitetip sharks taken in the IOTC area of competence that are dead at haulback, provided that the samples are a part of a research project approved by the IOTC Scientific Committee (SC)/the IOTC Working Party on Ecosystems and Bycatch; and
- The CPCs, especially those targeting sharks, shall submit data for sharks, as required by IOTC data reporting procedures.

WCPFC

Conservation and Management Measure on daily catch and effort reporting 2013-05

This CMM specifies that at a minimum, the following information should be recorded each day with fishing operations. Details specified in "Annex 1 of the Scientific Data to be provided to the Commission" include:

- Annex 1.3: Information on operation by longliners, including number of fish caught per set
- Annex 1.4: Information on operations by pole-and-line vessels and related gear types, including weight of fish caught per day
- Annex 1.5: Information on operations by purse seiners and related gear types, including weight of fish caught per set
- Annex 1.6: Information on operations by trollers and related gear types, including number of fish caught per day

All of the above should be recorded for the following shark species: blue shark, silky shark, oceanic whitetip shark, mako sharks, thresher sharks, porbeagle shark (south of 20°S, until biological data shows this or another geographic limit to be appropriate), hammerhead sharks (winghead, scalloped, great, and smooth), whale shark, and other species as determined by the Commission.

In addition to this catch, information must also be recorded for other species not listed in those sections, but required to be reported by CCMs under other Commission decisions such as, *inter alia*, key shark species according to FAO species codes.

Conservation and Management Measure for Sharks 2010-07

This CMM sets out requirements for reporting annual catches of key shark species. Table IV.2 below summarises changes in this CMM relating to reporting obligations for key shark species since 2009.

Table IV.2. Summary of changes to CMM 2010-07 on sharks in the WCPFC area since 2009.

CMM	Date	Description	Changes since preceding CMM
CMM 2010-07	2010	Similar to CMM 2009-04	Updated from 2009-04 CMM: The following shark species were added as key species: porbeagle shark (south of 20°S, until biological data shows this or another geographic limit to be appropriate) and hammerhead sharks (winghead, scalloped, great, and smooth)
CMM 2009-04	2009	Each CCM shall report annual catch (annual retained and discarded catches) and fishing effort statistics by gear type, including available historical data, for key shark species: blue shark, silky shark, oceanic whitetip shark, mako sharks and thresher sharks	Updated from previous CMMs prior to 2009

Conservation and Management Measure for silky sharks 2013-08

Commission Members, Cooperating Non-Members and Participating Territories will estimate through the data collected through observer programmes and other means the number of silky sharks caught in the Convention Area, including the status upon release and report this information to the WCPFC in the annual reports. Observers will also be allowed to collect biological samples from silky sharks that are dead on haulback in the Western Central Pacific Ocean provided that it is for a research project approved by the Scientific Committee.

Conservation and Management Measure for Oceanic Whitetip Shark 2011-04

This CMM is the same that applies to silky sharks (CCM 2013-08) but refers to oceanic whitetips whereby CCMs will estimate through data collected from the observer programmes and other means the number of release of oceanic whitetip, including the status upon release, and report this to the WCPFC in their Annual Reports. Observers can also collect biological samples what are dead on haulback in the WCPO, if it is for a research project approved by the Scientific Committee.

Conservation and Management Measure for the Regional Observer Programme 2007-01

Following CMM 2006-07 which set the procedures to develop the WCPFC Regional Observer Programme (ROP), CMM 2007-01 established the ROP. It states that the objectives of the ROP is to collect verified catch data, scientific data and additional information related to the fishery from the Convention Area and to monitor the implementation of the CMM adopted by the Commission.

IATTC

Resolution on the Management of Shark Species: Resolution C-16-05

This Resolution states that IATTC scientific staff shall develop a work plan and a timeline to deliver to the Commission in advance of the Scientific Advisory Committee meeting in 2017, for completion of a full stock assessments for silky shark and hammerhead sharks (i.e., *Sphyrna lewini, S. zygaena* and *S. mokarran*). This will identify any data requirements needed to complete the stock assessments and the action plan to meet the timeline.

CPCs will also require fishers to collect and submit catch data for silky and hammerhead sharks and will submit this data to the IATTC in accordance with their data reporting requirements. CPC's will also record through observer programmes or other means, for purse-seine vessels of all capacity classes, the number and status (dead/alive) of silky sharks and hammerhead sharks caught and released and report it to the IATTC. This Resolution shall enter into force on 1st January 2018.

Amendment to Resolution C-05-03 on the Conservation of Sharks caught in association with fisheries in the Eastern Pacific Ocean: Resolution C-16-04

This Resolution amends certain paragraphs in Resolution C-05-03, detailed in Table IV.3.

Table IV.3. Summary of changes to CMM C-16-04 on the conservation of sharks in the IATTC area since 2009.

CMM	Date	Description	Changes since preceding CMM
Res. C-16-04	2016	Amendment to Resolution C-05-03 on the conservation of sharks caught in association with fisheries in the Eastern Pacific Ocean	Addition of the following research objectives: • Improve knowledge of key biological/ecological parameters, life-history and behavioural traits, and migration patterns of key shark species; • Improve handling practices for live sharks to maximise post-release survival.
Res. C-05-03	2005	Resolution on the conservation of sharks caught in association with fisheries in the Eastern Pacific Ocean, including conservation and research objectives	Updated from previous CMMs prior to 2005.

Conservation Measures for Shark Species, with special emphasis on the Silky Shark (*Carcharhinus falciformis*), for the years 2017, 2018, and 2019: Resolution C-16-06

CPCs shall require the collection and submission of catch data for silky sharks, in accordance with IATTC data reporting requirements. They will also record, through observer programmes and other means, for purse-seine vessels all of the capacity classes, the number and status (dead/alive) of silky sharks caught and released, and report it to the IATTC. This came into force on 1st January 2017.

Resolution on the conservation of oceanic whitetip sharks caught in association with fisheries in the Antigua convention area: Resolution C-11-10

This resolution states that Members and Cooperating Non-Members (CPCs) will record, through the observer programmes, the number of discards and releases of oceanic whitetip sharks with indication of status (dead or alive) and report it to IATTC.

Resolution on Scientific Observers for Longline Vessels: Resolution C-11-08

This resolution states that the main task of the scientific observers will be to record any available information, the catches of targeted fish species, species composition and any available biological information as well as any interactions with non-target species such as sea turtles, seabirds and sharks.

ICCAT

Rec. 09-07: Recommendation by ICCAT on the conservation of thresher sharks caught in association with fisheries in the ICCAT convention area

Requires the collection and submission of Task I and Task II data for Alopias spp., other than *A. superciliosus,* in accordance with ICCAT data reporting requirements; and also that the number of discards and releases of *A. superciliosus* must be recorded with indication of status (dead or alive) and reported to ICCAT in accordance with ICCAT data reporting requirements.

Rec. 10-08: Recommendation by ICCAT on hammerhead sharks (family Sphyrnidae) caught in association with fisheries managed by ICCAT

Requires that the number of discards and releases of hammerhead sharks are recorded with indication of status (dead or alive) and reported to ICCAT in accordance with ICCAT data reporting requirements.

Rec. 10-07: Recommendation by ICCAT on the conservation of oceanic whitetip shark (*Carcharhinus longimanus*) caught in association with fisheries in the ICCAT convention area

Requires that CPCs shall record through their observer programs the number of discards and releases of oceanic whitetip sharks with indication of status (dead or alive) and report it to ICCAT.

Rec. 11-08: Recommendation by ICCAT on the conservation of silky sharks caught in association with ICCAT fisheries

Requires that CPCs shall record through their observer programs the number of discards and releases of silky sharks with indication of status (dead or alive) and report it to ICCAT.

Rec. 13-10: Recommendation on biological sampling of prohibited shark species by scientific observers

Allows that the collection of biological samples during commercial fishing operations by scientific observers or individuals is duly permitted by the CPC under certain conditions.

Rec. 14-06: Recommendation by ICCAT on shortfin mako (*Isurus oxyrinchus*) caught in association with ICCAT fisheries

Requires that CPCs shall improve their catch reporting systems to ensure the reporting of shortfin mako catch and effort data to ICCAT in full accordance with the ICCAT requirements for provision of Task I and Task II catch, effort and size data.

Rec. 15-06: Recommendation by ICCAT on porbeagle caught in association with ICCAT fisheries

Requires that CPCs shall ensure the collection of Task I and Task II data for porbeagle sharks and their submission in accordance with ICCAT data reporting requirements; and also that discards and releases of porbeagle sharks shall be recorded with indication of status (dead or alive) and reported to ICCAT in accordance with ICCAT data reporting requirements.

Rec. 16-12: Recommendation by ICCAT on management measures for the conservation of Atlantic blue shark caught in association with ICCAT fisheries

Requires the recording, reporting and use of the catch information for blue sharks; and also encourages CPCs to undertake scientific research that would provide information on key biological/ecological parameters, life-history, migrations, post-release survivorship and behavioural traits of blue sharks.

APPENDIX V – TASK 3

Table V.1. Stock assessment models, data requirements, Reference points, Management advice and Pros/Cons (Source: IOTC, 2014)

Method	**Data Requirements**		**Reference Points**	**Management Advice**	**Pros**	**Cons**
	Biology	Fishery				
PSA	Qualitative	Qualitative	No	Qualitative	Easy to use if LH parameters available	Difficult to relate to current abundances and fishing mortality.
Demographic Models/ Elasticity Analysis	Age & growth, Fecundity, Natural Mortality	Several fishery characteristics	No	Mostly qualitative (change of gear) and F	Easy to use if LH Parameters available. Can provide guidance on gear usage/ selectivity	Must assume that LH parameters are correct, but uncertainties can be introduced. Difficult to relate to current abundances and fishing mortality.
Catch free LH Based	M, growth curve parameters, and Age at full Maturity or Max Age	Selectivity	Yes (F_{MSY})	F_{MSY}	Easy to get LH parameters if available. Zhou et. al. (2011) provides equations that are relevant to species. Could run a meta-analysis and run as well using a Bayesian Hierarchical Model Approach. Provides a Target F.	Guidelines provided for Fishing Mortality, but no specifics on current status. No idea what current Biomass and F are. However some guidelines could be provided based on theoretical carrying capacity, current depletion levels, and whether current take are meeting or exceeding targets.
Catch free CPUE Based	M, growth curve parameters, and Age at full Maturity or Max Age & recruitment	Selectivity and CPUE Series	Yes (F_{MSY} & B_{MSY})	F_{MSY} & B_{MSY}	Easy to parameterize with LH data. Estimate recruitment, F and selectivity to tune to the CPUE series. Provides target F, Yield levels and where we are with regards to these rates. Provides target B as well and where we are with regards	LH based assumptions could be misleading. CPUE series may not be representative of abundance series if from a limited fleet and area. Catch at size should be estimated from the viewpoint of the operational patterns

					to that.	
Catch Based SRA	r & K	Catch series	Yes (F_{MSY} & B_{MSY})	F_{MSY} & B_{MSY}	Set of data that currently exist (but may not be too good). Tried and tested approach in ICES, Walters, etc. Easy to run, provides Yield targets and FMSY & BMSY	Uncertainty in catch series can give misleading results. Based on assumptions of depletion range in current years that may give misleading results. May not be very accurate in terms of FMSY and BMSY
Surplus Production (Bayesian or Otherwise)	r & K	Catch series & CPUE series	Yes (F_{MSY} & B_{MSY})	F_{MSY} & B_{MSY}	Traditional approaches. Used extensively in literature. Provides yield targets and FMSY and BMSY	Length of time-series and uncertainty in catch series and CPUE series can bias results. Models may have problems converging to a solution if there is no contrasting information.
Integrated assessments	Recruitment, M by age, growth parameters, maturation schedule, fecundity, recruitment	Catch series, Length based samples, CPUE data (and or have tagging data), fishery selectivity	Yes (F_{MSY} & B_{MSY})	F_{MSY} & B_{MSY}	Most robust approach. Incorporates all information in a dynamic model. Provides most representative yield targets and FMSY and BMSY	Highly data dependent. Models can have problems converging. Learning curve steep.

Table V.2. Conclusions on shark stock assessment methods and stock indicators according to the currently available information for the Atlantic Ocean (ICCAT) by species or species groups.

Color legend (data)	**Data are available**	**Not enough data**	**No data**
Color legend (SA)	**Can be conducted**	**Can be conducted by available information with additional estimation works and/or substitutions from other waters**	**Cannot be conducted**

Blue shark (BSH)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							Main fisheries catching BSH both in the N and S Atlantic provide CPUE series		
Size frequency								Main fisheries catching BSH both in the N and S Atlantic provide length data series	
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	**Distribution and movement**								Some data might be available from traditional tagging and satellite tagging (option)
	Stock structure				North and South stocks				

<table>
<tr><th colspan="10">Shortfin mako (SMA)</th></tr>
<tr><th rowspan="2">Data type</th><th rowspan="2">Data</th><th colspan="3">Stock indicator</th><th colspan="2">Data poor SA</th><th colspan="3">Traditional SA</th></tr>
<tr><th>CPUE based</th><th>Size based</th><th>ERA+PSA (demography)</th><th>Catch-free CPUE based</th><th>SRA</th><th>Production model (PM)</th><th>Age based SA</th><th>Integrated models</th></tr>
<tr><td colspan="2">Nominal catch</td><td></td><td></td><td></td><td></td><td colspan="4">Partial catch data are available. To use for SA, total catch needs to be estimated.</td></tr>
<tr><td colspan="2">Standardized CPUE</td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Some fisheries catching SMA both in the N and S Atlantic provide CPUE series</td></tr>
<tr><td colspan="2">Size frequency</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Some fisheries catching SMA both in the N and S Atlantic provide length data series</td></tr>
<tr><td rowspan="4">Biological</td><td>Length-Weight</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Reproduction (Maturity and Fecundity)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Age and Growth</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sex ratio</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">option</td></tr>
<tr><td rowspan="2">Spatial info</td><td>Distribution and movement</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Some data might be available from traditional tagging and satellite tagging (option)</td></tr>
<tr><td>Stock structure</td><td></td><td></td><td></td><td colspan="5">There is some evidence suggesting 3 stocks (North, South East and South West)</td></tr>
</table>

Porbeagle (POR)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated, especially in the South Atlantic.			
Standardized CPUE							Only a few fisheries both in the N and S Atlantic provided CPUE series		
Size frequency								Only a few fisheries both in the N and S Atlantic provided size data	
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	**Distribution and movement**								Some data might be available from traditional tagging and satellite tagging (option)
	Stock structure				Four stocks have been considered for porbeagle (NW, NE, SE, SW) in the past assessment, however there is evidente that the south stock might be a circumglobal stock shared between the Atlantic, Pacific and Indan Oceans.				

Silky shark (FAL)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	option
Spatial info	Distribution and movement								option
	Stock structure				North and South stocks defined by BIL areas				

Longfin mako (LMA)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	option
Spatial info	Distribution and movement								option
	Stock structure				North and South stocks defined by BIL areas				

Oceanic whitetip (OCS)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	option
Spatial info	**Distribution and movement**								option
	Stock structure				North and South stocks defined by BIL areas; however there is evidence supporting a West/East stock delimitation				

Hammerheads (SPN)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	option
Spatial info	Distribution and movement								option
	Stock structure				North and South stocks defined by BIL areas				

Thresher sharks (THR)										
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	option
Spatial info	Distribution and movement								option
	Stock structure				North and South stocks defined by BIL areas				

Table V.3. Conclusions on shark stock assessment methods and stock indicators according to the currently available information for the Indian Ocean (IOTC) by species or species groups.

Color legend (data)	**Data are available**	**Not enough data**						**No data**	
Color legend (SA)	**Can be conducted**	**Can be conducted by available information with additional estimation works and/or substitutions from other waters**						**Cannot be conducted**	
Blue shark (BSH)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							Four fisheries provided CPUE series for the 2015 stock assessment		
Size frequency									
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	**Distribution and movement**								option
	Stock structure				Unknown but single stock structure may be assumed				

Shortfin mako (SMA)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							Only limited CPUE (Japan and EU) are available. Careful evaluation are needed if they can be used for SA		
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown but single stock structure may be assumed				

Porbeagle (POR)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown, but there is evidence for a circumglobal south stock shared between the Atlantic, Pacific and Indian Oceans.				

Oceanic whitetip (OCS)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							Only limited CPUE (Japan and EU) are available. Careful evaluation are needed if they can be used for SA		
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown but single stock structure may be assumed				

Silky shark (FAL)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown but single stock structure may be assumed				

Hammerheads (SPN)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Majority of catch are not reported thus it is suggested not to use.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown but single stock structure may be assumed				

Thresher sharks (THR)										
Data type	Data	Stock indicator			Data poor SA		Traditional SA			
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models	
Nominal catch						Partial catch data (majority are as thresher sharks) are available. To use for SA, total catch by species needs to be estimated.				
Standardized CPUE										
Size frequency										
Biological	Length-Weight									
	Reproduction (Maturity and Fecundity)									
	Age and Growth									
	Sex ratio							option		
Spatial info	Distribution and movement								option	
	Stock structure				Unknown but single stock structure may be assumed					

Table V.4. Conclusions on shark stock assessment methods and stock indicators according to the currently available information for the Western Pacific Ocean (WCPFC) by species or species groups.

Color legend (data)	**Data are available**	**Not enough data**						**No data**	
Color legend (SA)	**Can be conducted**	**Can be conducted by available information with additional estimation works and/or substitutions from other waters**						**Cannot be conducted**	
Blue shark (BSH)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	**Distribution and movement**								Some data might be available from traditional tagging and satellite tagging (option)
	Stock structure				Although there is a separation between the East and West Pacific there is support for a single stock in the North and a single stock in the South hemispheres				

Shortfin mako (SMA)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated. Identification problems with shortfin and longfin mako being reported as "mako"			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								Some data might be available from traditional tagging and satellite tagging (option)
	Stock structure				Although there is a separation between the East and West Pacific there is support for a single stock in the North and a single stock in the South hemispheres				

Porbeagle (POR)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				There is evidence for a circumglobal south stock shared between the Atlantic, Pacific and Indan Oceans.				

Silky shark (FAL)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown but single stock structure is assumed				

Longfin mako (LMA)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated. Identification problems with shortfin and longfin mako being reported as "mako".			
Standardized CPUE									
Size frequency									
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	**Distribution and movement**								option
	Stock structure				Unknown but single stock structure is assumed				

Oceanic whitetip (OCS)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown but single stock structure is assumed				

Hammerheads (SPN)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data (majority are as generic hammerhead sharks) are available. To use for SA, total catch by species needs to be estimated.			
Standardized CPUE							CPUE series were presented for the hammerhead complex		
Size frequency								Length series were presented for the hammerhead complex	
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown but single stock structure is assumed				

Thresher sharks (THR)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data (majority are as generic thresher sharks) are available. To use for SA, total catch by species needs to be estimated.			
Standardized CPUE							CPUE series were presented for the thresher complex		
Size frequency								Length series were presented for the thresher complex	
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown, however thresher sharks are distributed in more cold, temperate waters and generally believed to be separated in North and South stocks				

Table V.5. Conclusions on shark stock assessment methods and stock indicators according to the currently available information for the Eastern Pacific Ocean (IATTC) by species or species groups.

Color legend (data)	**Data are available**	**Not enough data**	**No data**
Color legend (SA)	**Can be conducted**	**Can be conducted by available information with additional estimation works and/or substitutions from other waters**	**Cannot be conducted**

Blue shark (BSH)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	**Distribution and movement**								Some data might be available from traditional tagging and satellite tagging (option)
	Stock structure				Although there is a separation between the East and West Pacific there is support for a single stock in the North and a single stock in the South hemispheres				

Shortfin mako (SMA)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								Some data might be available from traditional tagging and satellite tagging (option)
	Stock structure				Although there is a separation between the East and West Pacific there is support for a single stock in the North and a single stock in the South hemispheres				

Porbeagle (POR)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							Report available on Chilean swordfish fishery		
Size frequency								Report available on Chilean swordfish fishery	
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				There is evidence for a circumglobal south stock shared between the Atlantic, Pacific and Indian Oceans.				

Silky shark (FAL)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE									
Size frequency									
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				North and South stocks				

Longfin mako (LMA)									
Data type	**Data**	**Stock indicator**			**Data poor SA**		**Traditional SA**		
		CPUE based	**Size based**	**ERA+PSA (demography)**	**Catch-free CPUE based**	**SRA**	**Production model (PM)**	**Age based SA**	**Integrated models**
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							No information or no report		
Size frequency								No information or no report	
Biological	**Length-Weight**								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	**Distribution and movement**								option
	Stock structure				Unknown				

Oceanic whitetip (OCS)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							No information or no report		
Size frequency								No information or no report	
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown				

Hammerheads (SPN)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							No information or no report		
Size frequency								No information or no report	
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown				

Thresher sharks (THR)									
Data type	Data	Stock indicator			Data poor SA		Traditional SA		
		CPUE based	Size based	ERA+PSA (demography)	Catch-free CPUE based	SRA	Production model (PM)	Age based SA	Integrated models
Nominal catch						Partial catch data are available. To use for SA, total catch needs to be estimated.			
Standardized CPUE							No information or no report		
Size frequency								No information or no report	
Biological	Length-Weight								
	Reproduction (Maturity and Fecundity)								
	Age and Growth								
	Sex ratio							option	
Spatial info	Distribution and movement								option
	Stock structure				Unknown				

APPENDIX VI – TASK 4

1. IUCN

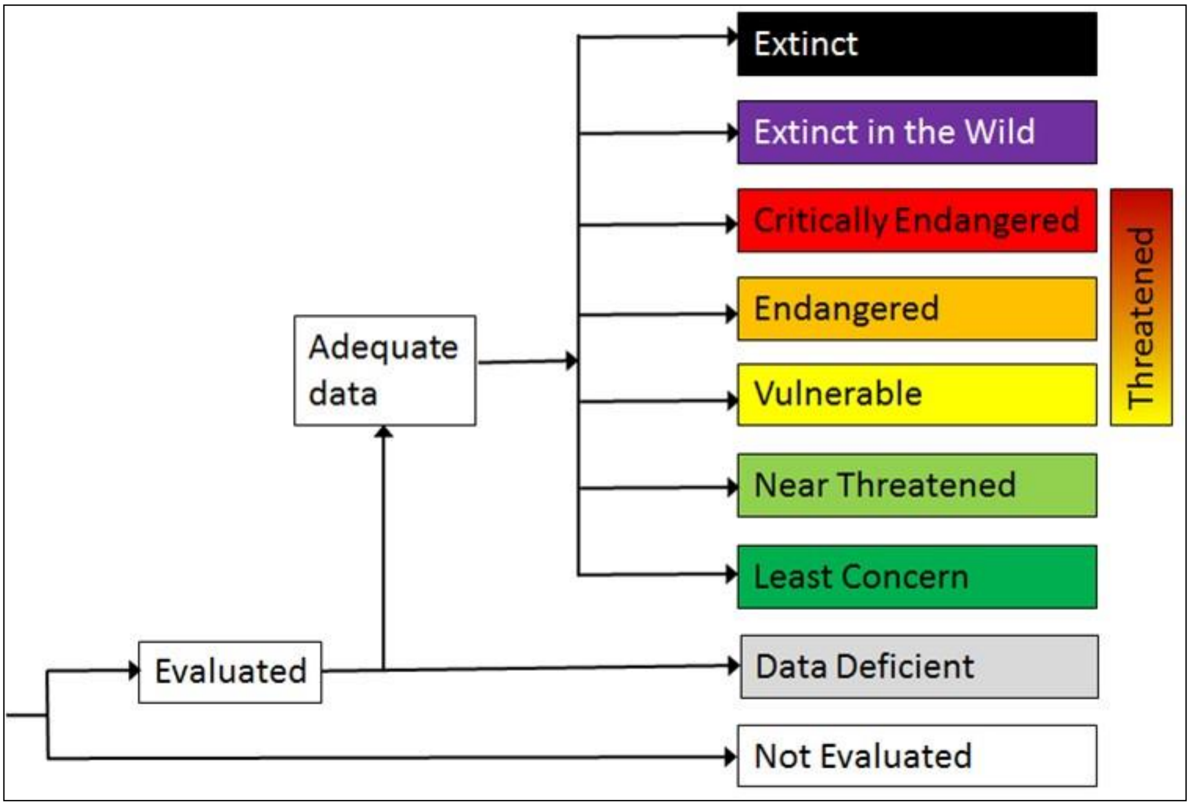


Figure VI.1. IUCN Red List categories (from IUCN, 2012)

Table VI.2. Summary of IUCN criteria, shown for illustrative purposes. Refer to the IUCN guidelines (IUCN, 2012) for more details.

		CR	EN	VU
A. Population size reduction [1] over either 10 years or 3 generations (whichever is the longest)				
A1. Reduced population in the past where the causes are reversible and understood and have ceased		≥ 90%	≥ 70%	≥ 50%
A2. Reduced population in the past where the causes may not be reversible or may not be understood or may not have ceased		≥ 80%	≥ 50%	≥ 30%
A3. Population reduction projected to be met in the future (up to a maximum of 100 years)				
A4. Population reduction where the time includes both the past and future and where the causes may not be reversible or may not be understood or may not have ceased				
B. Geographic range - extent of occurrence (B1) and/or area of occupancy (B2)				
B1. Extent of Occurrence (EOO)		< 100 km^2	< 5,000 km^2	< 20,000 km^2
B2. Area of Occupancy (AOO)		< 10 km^2	< 500 km^2	< 2,000 km^2
And at least 2 of the following three conditions:				
(a) Severely fragmented or number of locations		= 1	≤5	≤10
(b) Continuing decline in EOO; AOO; area/extent/quality of habitat; number of locations or subpopulations; number of mature individuals				
(c) Extreme fluctuations in any of: EOO; AOO; number of locations or subpopulations; number of mature individuals				
C. Small population size and decline				
Number of mature individuals		<250	<2,500	<10,000
And at least one of C1 or C2				
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 y into the future):		25% in 3 y or 1 gen [2]	20% in 5 y or 2 gen [2]	10% in 10 y or 3 gen [2]
C2. An observed, estimated, projected or inferred continuing decline AND at least one of the following three conditions:				
(a)	(i) Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
	(ii) % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b)	Extreme fluctuations in the no. of mature individuals			
D. Very small or restricted population				
D Number of mature individuals		<50	<250	D1. <1000
D2. Restricted area of occupancy or number of locations with a plausible future threat				D2. ≤5 locations or <20 km^2
E. Quantitative analysis				

Probability of extinction in the wild	≥ 50% in 10 y or 3 gen [2]	≥ 20% in 20 y or 5 gen [2]	≥ 10% in 100 y
[1] A population reduction may be either observed, estimated, inferred, or suspected, and can be based on direct observations, indices of abundance that are appropriate for the taxon, a decline in AOO or EOO or habitat quality, levels of exploitation and can also include other factors (e.g. effects of introduced taxa, hybridization, pathogens, pollutants etc.) [2] Whichever is longer, to a maximum of 100 y			

2. MSC – Risk Based Framework (RBF)

Methodology and data needs[50]

- To carry out CA, it is required that some qualitative or quantitative data exist from which trends in one or more of the four key consequence subcomponents (see Table VI.3) can be derived. Where there are no indicator data, the fishery cannot be assessed against the MSC standard. This information is used to identify the most vulnerable subcomponent for a species, as only the subcomponent on which fishing activity is supposed to have major impact must be scored based on the classification presented in Table VI.3.
- In the case of the PSA, all productivity and susceptibility attributes (see Tables VI.4 and VI.5, respectively) must be scored on a 3-point risk scale: high (3), medium (2) or low (1) for each fishery affecting the given stock, using the information in Tables VI.4 and VI.5. In the cases where there is limited information available for an attribute, the more precautionary score shall be awarded. The final score is the weighted average of PSA scores for each fishery targeting the stock, based on the weights in Table VI.6. Overall productivity and susceptibility risk scores (PSA score) and the equivalent MSC scores for each scoring element is obtained from an Excel template.
- Finally, the overall score is calculated according to the rules in Table VI.7.

[50] Material in this section and associated Tables is based on MSC, 2014.

Table VI.3. CA scoring of subcomponents.

	Consequence Category			
Subcomponent	**100**	**80**	**60**	**Fail**
Population size	Insignificant change to population size/growth rate (r). Change is unlikely to be detectable against natural variability for this population.	Possible detectable change in size/growth rate (r) but minimal impact on population size and none on dynamics.	Full exploitation rate but long-term recruitment dynamics not adversely damaged.	Consequence is higher-risk than 60 level.
Reproductive capacity	Insignificant change in reproductive capacity. Unlikely to be detectable against natural variability for this population	Possible detectable change in reproductive capacity but minimal impact on population dynamics.	Detectable change in reproductive capacity. Impact on population dynamics at maximum sustainable level, long-term recruitment dynamics not adversely affected.	
Age/size/sex structure	Insignificant change in age/size/sex structure. Unlikely to be detectable against natural variability for this population.	Possible detectable change in age/size/sex structure but minimal impact on population dynamics.	Detectable change in age/size/sex structure. Impact on population dynamics at maximum sustainable level, long-term recruitment dynamics not adversely affected.	
Geographic range	Insignificant change in geographic range. Unlikely to be detectable against natural variability for this population.	Possible detectable change in geographic range but minimal impact on population distribution and none on dynamics.	Detectable change in geographic range up to 10% of original distribution due to fishing activities.	

Table VI.4. PSA Productivity attributes and scores.

Susceptibility attribute	Low susceptibility (Low risk, score=1)	Medium susceptibility (medium risk, score=2)	High susceptibility (high risk, score=3
Areal overlap (availability) Overlap of the fishing effort with a species concentration of the stock	<10% overlap	10-30% overlap	>30% overlap
Encounterability The position of the stock/species within the water column relative to the fishing gear, and the position of the stock/species within the habitat relative to the position of the gear	Low overlap with fishing gear (low encounterability)	Medium overlap with fishing gear	High overlap with fishing gear (high encounterability) Default score for target species (P1)
Selectivity of gear type Potential of the gear to retain species	a Individuals < size at maturity are rarely caught	a Individuals < size at maturity are regularly caught	a Individuals < size at maturity are frequently caught
	b Individuals < size at maturity can escape or avoid gear	b Individuals < half the size at maturity can escape or avoid gear	b Individuals < half the size at maturity are retained by gear
Post-capture mortality (PCM) The chance that, if captured, a species would be released and that it would be in a condition permitting subsequent survival	Evidence of majority released postcapture and survival	Evidence of some released postcapture and survival	Retained species or majority dead when released Default score for retained species (P1 or P2)

Table VI.5. PSA Susceptibility attributes and scores.

Productivity Attribute	High productivity (Low risk, score=1)	Medium productivity (medium risk, score=2)	Low productivity (high risk, score=3
Average age at maturity	<5 years	5-15 years	>15 years
Average maximum age	<10 years	10-25 years	>25 years
Fecundity	>20,000 eggs per year	100-20,000 eggs per year	<100 eggs per year
Average maximum size (not to be used when scoring invertebrate species)	<100 cm	100-300 cm	>300 cm
Average size at maturity (not to be used when scoring invertebrate species)	<40 cm	40-200 cm	>200 cm
Reproductive strategy	Broadcast spawner	Demersal egg layer	Live bearer
Trophic Level	<2.75	2.75-3.25	>3.25
Density dependence (to be used when scoring invertebrate species only)	Compensatory dynamics at low population size demonstrated or likely	No depensatory or compensatory dynamics demonstrated or likely	Depensatory dynamics at low population sizes (Allee effects) demonstrated or likely

Table VI.6. Weighting of fisheries.

% contribution of catch	Weighting score
0–25	1
25–50	2
50–75	3
75–100	4

Table VI.7. Rules for use of CA or PSA scores.

CA	PSA	Rule
80 or 100	≥80	Score awarded shall be at the midway point between CA and PSA scores.
80 or 100	≥60 and <80	Score awarded for PI shall be less than 80, as near to the midway point between CA and PSA scores as possible.
80 or 100	<60	Fail
60	≥80	Score awarded for PI shall be less than 80, as near to the midway point between CA and PSA scores as possible.
60	≥60 and <80	Score awarded for PI shall be at the midway point between CA and PSA scores.
60	<60	Fail
<60	≥80	Fail
<60	≥60 and <80	Fail
<60	<60	Fail

APPENDIX VII – TASK 5

1. List of CMMs regarding sharks and rays

Table VII.1. List of Conservation and Management Measures (CMMs) for sharks and rays for the various tuna-RFMOs and other advisory or management bodies.

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
IATTC	Res C04-09	2004	Sets out a multi-annual conservation and management program for bigeye and yellowfin tunas in the IATTC area of competence. Includes 40 days fishery closure each year		Bycatch
IATTC	Res C05-03 Res C16-04	2005	Sets out a scientific and management framework on the conservation of sharks caught in association with IATTC managed fisheries. Includes Implementation of National Plan of Action, in accordance with the FAO IPOA, for the conservation and management of sharks, full utilization of shark catches, 5% fin/ body ratio for retained catches, encouragement for release of live sharks captured as bycatch and research implementation (biological/ecological parameters, life-history and behavioural traits, and migration patterns of key shark species, identification mating, pupping, and nursery areas, fishing gear selectivity and improved handling practices to maximise post-release survival)	Concerns about an extensive unregulated shark fishery in the EPO, including shark-fishing vessels slightly smaller than 24 m length overall, about which the Commission has little information.	Target and Bycatch
IATTC	Res C11-10	2012	Sets out a scientific and management framework on the conservation of oceanic whitetip sharks (*Carcharhinus*	Concerns about the recent declining trend in catches of oceanic whitetip shark by	Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
			longimanus) caught in association with IATTC managed fisheries. Includes prohibition of retention, release of live sharks, data report requirements (discards and release through observer programs).	purse seiners	
IATTC	Res C15-04	2016	Sets out a scientific and management framework on the conservation of Mobulid rays caught in association with IATTC managed fisheries. Includes prohibition of retention, release of live rays requirement, data report requirements (discards and release through observer programs)	Mobulid rays are extremely vulnerable to overfishing as they take a long time to reach sexual maturity, have long gestation periods, and often give birth to only a few pups; The giant manta ray (Manta birostris) is considered vulnerable by the IUCN and the Munk's devil ray (Mobula munkiana) and the smoothtail devil ray (Mobula thurstoni) are considered near threatened by the IUCN.	Bycatch
IATTC	Res 16-01	2016	Sets out a scientific and management framework on FAD fishing, including purse seine sets associated to whale sharks. Includes mandatory non entangling FAD design, prohibition of intentional setting on whale shark, safe release of whale shark incidentally encircled and data reporting (encirclement and status of release individual)	Concerned about the potential effects of purse-seine operations on the status of whale sharks when deliberately or accidentally set upon. Recognition that Improved FAD designs, in particular non-entangling FADs, both drifting and anchored, helps reduce the incidence of entanglement of	Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
				sharks, sea turtles and other species.	
IATTC	Res 16-05	2018	Sets out a scientific and management framework on the conservation of sharks caught in association with IATTC managed fisheries. Includes development of workplan for stock assessment (silky and hammerhead sharks), data report requirements (silky and hammerhead sharks), release of live sharks requirement and shark line prohibition	Silky sharks and the hammerhead sharks are the shark species most frequently caught by purse-seine vessels fishing for tuna in its convention area.	Target and Bycatch
IATTC	Res C16-06	2017	Sets out a scientific and management framework on the conservation of silky sharks (*Carcharhinus falciformis*) caught in association with IATTC managed fisheries. Includes prohibition of retention, ban of fishing in silky shark pupping areas, limit in the bycatch of silky shark (20% of the total catch by fishing trip in weight, if not respected prohibition of steel leader for 3 years), limit in the catch of juvenile silky shark for surface longlines fisheries (sharks of TL <100cm should be less than 20% of the total catch of silky shark), data report requirements (discards and release through observer programs) and research implementation (identification of pupping areas, mitigation method for bycatch of sharks, handling practices)	The silky shark is the shark species most commonly caught as bycatch by purse-seine vessels in the Convention Area.	Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
ICCAT	Rec 03-04	2003	Sets out a management framework on the use of large-scale driftnets on the high seas in the Mediterranean sea. Includes prohibition of the use of driftnets for fisheries of large pelagics in the Mediterranean		Target and Bycatch
ICCAT	Res 03-10	2003	Implementation of National Plan of Action, in accordance with the FAO IPOA, for the conservation and management of sharks.		Target and Bycatch
ICCAT	Rec 04-10	2004	Sets out a scientific and management framework on the conservation of sharks caught in association with ICCAT managed fisheries. Includes data report requirements (Task I and II), full utilization of catch, 5% fin/ body ratio for retained catches, encouragement for release of live sharks captured as bycatch and research implementation (identification nursery areas, fishing gear selectivity)		Target and Bycatch
ICCAT	Rec 09-07	2009	Sets out a scientific and management framework on the conservation of Thresher sharks caught in association with ICCAT managed fisheries. Includes directed fishery ban, prohibition of retention of bigeye thresher shark (*Alopias superciliosus*), data report requirements (Task I and II), encouragement for release of live	The 2008 ecological risk assessment conducted by the SCRS concluded that the bigeye thresher shark has the lowest productivity and highest vulnerability of all pelagic shark species investigated.	Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
			sharks and research implementation (identification nursery areas)		
ICCAT	Rec 10-06	2010	Sets out a scientific and management framework on the conservation of Atlantic shortfin mako sharks (*Isurus oxyrinchus*) caught in association with ICCAT managed fisheries. Includes data report requirements (Task I and II), prohibition of retention for CPS that do not report Task I.	Stock depleted to about 50 % of biomass estimated for the 1950s, and some model outcomes indicated that the stock biomass was near or below the level that would support MSY and current harvest levels are above FMSY. The 2008 ecological risk assessment conducted by the SCRS concluded that the shortfin mako shark has low biological productivity, making it susceptible to overfishing even at low levels of fishing mortality.	Target
ICCAT	Rec 10-07	2010	Sets out a scientific and management framework on the conservation of oceanic whitetip sharks (*Carcharhinus longimanus*) caught in association with ICCAT managed fisheries. Includes prohibition of retention, data report requirements (discards and release through observer programs), and recommendation for adoption of minimum size of 200 cm	The oceanic whitetip shark has been ranked as one of the five species with the highest degree of risk in an ecological risk assessment. It also has high at-vessel survival and constitutes a small portion of the shark catch. It is one of the easiest shark species to identify. A significant proportion of the species catch is composed of juveniles.	Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
ICCAT	Rec 10-08	2010	Sets out a scientific and management framework on the conservation of Hammerhead sharks (except *Sphyrna tiburo*) caught in association with ICCAT managed fisheries. Includes prohibition of retention, data report requirements (discards and releases; and task I and II for developing coastal CPCs catching silky shark for local consumption), encouragement for release of live sharks and research implementation (identification nursery areas)	Sustainability concerns for *Sphyrna lewini* and *Sphyrna zygaena*. Difficulty to differentiate between the various species of hammerhead sharks except for the bonnethead (*Sphyrna tiburo*) without taking them on board and that such action might jeopardize the survival of the captured individuals.	Bycatch
ICCAT	Rec 11-01	2012	Sets out a multi-annual conservation and management program for bigeye and yellowfin tunas in the ICCAT area of competence. Includes a FAD moratorium in an area of the eastern Atlantic Ocean for two months each year		Bycatch
ICCAT	Rec 11-08	2011	Sets out a scientific and management framework on the conservation of silky sharks (*Carcharhinus falciformis*) caught in association with ICCAT managed fisheries. Includes prohibition of retention, data report requirements (discards and release through observer programs and task I and II for developing coastal CPCs catching silky shark for local consumption), encouragement for release of live sharks, including additional measures	The 2010 ecological risk assessment conducted by the SCRS concluded that the silky shark has the highest degree of vulnerability of all pelagic shark species investigated.	Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
			needed to increase survival rates of shark incidentally caught by purse seiners and research implementation (identification nursery areas)		
ICCAT	Rec 14-06	2014	Sets out a scientific and management framework on the conservation of Atlantic shortfin mako sharks (*Isurus oxyrinchus*) caught in association with ICCAT managed fisheries. Includes data report requirements (Task I and II), research implementation (biological/ecological parameters, life-history and behavioural traits, identification of potential mating, pupping and nursery grounds) and stock assessment by 2016	SCRS recommendation of a precautionary approach (fishing mortality of shortfin mako sharks should not be increased) until more reliable stock assessment results are available for both the north and south stocks. And high vulnerability ranking of shortfin mako sharks in the 2008 and 2012 Ecological Risk Assessment.	Target
ICCAT	Rec 15-06	2015	Sets out a scientific and management framework on the conservation of Porbeagle Shark (*Lamna nasus*) caught in association with ICCAT managed fisheries. Includes encouragement for release of live sharks, data report requirements (Task I and II) and scientific research encouragement (key biological data and identification of areas of high abundance of important life-history stages)	SCRS estimated in 2015 that the biomass of northwest Atlantic and northeast Atlantic porbeagle shark is depleted to well below BMSY, but recent fishing mortality is below FMSY and in 2009 concluded that data for southern hemisphere stocks were too limited to provide a robust indication on the status of the stocks ICES advice for the North-East Atlantic stock in 2015 recommended on the basis of the precautionary approach	Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
				that no fishing for porbeagle should be permitted and that landings of porbeagle should not be allowed. In 2014, species added to Appendix 2 of the CITES	
ICCAT	Rec 16-12	2016	Sets out a scientific and management framework on the conservation of Atlantic blue sharks (*Prionace glauca*) caught in association with ICCAT managed fisheries. Includes catch limit, data report requirements (Task I and II) and scientific research encouragement (biological/ ecological parameters, life-history, migrations, post-release survivorship and behavioural traits)	Stock assessment undertaken in 2015, shows that despite the positive signs of the stock status of the North Atlantic stock of blue shark, a high level of uncertainty in data inputs and in model structural assumptions remains and, therefore, the possibility of the stock being overfished and overfishing occurring could not be ruled out; Precautionary management measures should be considered for shark stocks for which there are few data and/or greater uncertainty in assessment results.	Target
IOTC	Res 05/05	2005	Sets out a scientific and management framework on the conservation of sharks caught in association with IOTC managed fisheries. Includes data report requirements, full utilization of shark catches, 5% fin/ body ratio for retained		Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
			catches, encouragement for release of live sharks, especially juveniles and pregnant females and research implementation (gear selectivity, identification of shark nursery areas)		
IOTC	Res 12/09	2012	Sets out a scientific and management framework on the conservation of Thresher sharks caught in association with IOTC managed fisheries. Includes prohibition of retention, encouragement for release of live sharks, data report requirements (target and incidental catches and live release), and research implementation (identification nursery areas)	Stock assessments on sharks may not be possible because of data limitations and that it is essential that some stock assessment evaluation should be carried out. The bigeye thresher shark (*Alopias superciliosus*) is particularly endangered and vulnerable. Difficulty to differentiate between the various species of thresher sharks without taking them onboard and that such action might jeopardise the survival of the captured individuals.	Target and Bycatch
IOTC	Res 12/12	2012	Sets out a management framework on the use of large-scale driftnets on the high seas in the IOTC area. Includes prohibition of the use of large-scale driftnets on the high seas and monitoring of large-scale driftnets fishing.	Concerns about vessels continuing to engage in large-scale high seas driftnet fishing in the Indian Ocean area, which are interacting more frequently with highly migratory species, such as tunas, swordfish, sharks. And that associated "ghost fishing" by lost or discarded driftnets	Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
				have serious detrimental effects on these species of concern and the marine environment.	
IOTC	Res 12/13	2010	Sets out a scientific and management framework for the conservation of for bigeye and yellowfin tunas in the IOTC area of competence. Includes a FAD moratorium over main fishing areas (20°N–20°S) of the Western and Central Pacific Ocean for three months each year		Bycatch
IOTC	Res 13/05	2013	Sets out a scientific and management framework on the conservation of whale sharks (*Rhincodon typus*) caught in association with IOTC managed fisheries. Includes prohibition of intentional setting on whale shark, safe release of whale shark incidentally encircled and data reporting (encirclement and status of release individual)	Ecological and cultural significance of whale sharks. Whale sharks are particularly vulnerable to exploitation including from fishing. Concerned about the potential impacts of purse seine operations on the sustainability of whale sharks.	Bycatch
IOTC	Res 13/06	2013	Sets out a scientific and management framework on the conservation of oceanic whitetip sharks (*Carcharhinus longimanus*) caught in association with IOTC managed fisheries. Includes prohibition of retention, encouragement for release of live sharks, data report requirements (target and incidental	The ecological risk assessment by fishing gears made by the IOTC Scientific Committee recognises the oceanic whitetip sharks as a vulnerable species. Oceanic whitetip sharks can	Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
			catches and live release), and research implementation (identification nursery areas)	be easily distinguished from other shark species and can therefore be released before they are taken on board of the vessel.	
IOTC	Res 15-08	2015	Sets out a scientific and management framework on dFAD fishing in the IOTC area of competence. Includes mandatory non entangling FAD design	Recognition non-entangling FADs, helps reduce the entanglement of sharks and marine turtles.	Bycatch
IOTC	Res 16-07	2016	Sets out a management framework on the use of artificial lights to attract fish. Includes prohibition of the use of artificial lights on FAD and vessel for the purpose of aggregating tuna and tuna like species		Bycatch
WCPFC	CMM 2008-04	2008	Sets out a management framework on the use of large-scale driftnets on the high seas in the WCPFC area. Includes prohibition of the use of large-scale driftnets on the high seas and monitoring of large-scale driftnets fishing.	Concerns about vessels continuing to engage in large-scale high seas driftnet fishing in the Pacific Ocean area, which are interacting more frequently with highly migratory species, such as tunas, swordfish, sharks. And that associated "ghost fishing" by lost or discarded driftnets have serious detrimental effects on these species of concern and the marine environment.	Target and Bycatch
WCPFC	CMM 2010-	2010	Sets out a scientific and management framework on the conservation of	Some species of pelagic sharks, (i.e., basking and	Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
	07		sharks caught in association with WCPFC managed fisheries. Includes assessment of need for National Plan of Action, in accordance with the FAO IPOA, data report requirements, full utilization of shark catches, 5% fin/ body ratio for retained catches and encouragement for release of live sharks	great white sharks) included in Appendix II of the CITES.	
WCPFC	CMM 2011-01	2009	Sets out a scientific and management framework for the conservation of tropical tunas stocks in the WCPFC area of competence. Includes a FAD moratorium in an area of the western Indian Ocean for one month each year		Bycatch
WCPFC	CMM 2011-04	2013	Sets out a scientific and management framework on the conservation of oceanic whitetip sharks (*Carcharhinus longimanus*) caught in association with WCPFC managed fisheries. Includes prohibition of retention, encouragement for release of live sharks and data report requirements (incidental catches and live release through observer programs)	Concerns about the steep declining standardized catch rates and size trends of oceanic whitetip in longline and purse seine fisheries in the WCPO. Other species of sharks also show negative trends currently, or others that may in the future. Will to have consistent conservation and management measures with those of the IATTC.	Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
WCPFC	CMM 2012-04	2014	Sets out a scientific and management framework on the conservation of whale sharks (*Rhincodon typus*) caught in association with WCPFC managed fisheries. Includes prohibition of intentional setting on whale shark, safe release of whale shark incidentally encircled and data reporting (encirclement and status of release individual)	Ecological and cultural significance of whale sharks. Whale sharks are particularly vulnerable to exploitation including from fishing. Concerned about the potential impacts of purse seine operations on the sustainability of whale sharks.	Bycatch
WCPFC	CMM 2013-08	2014	Sets out a scientific and management framework on the conservation of Silky shark (*Carcharhinus falciformis*) caught in association with WCPFC managed fisheries. Includes prohibition of retention, encouragement for release of live sharks and data report requirements (incidental catches and live release through observer programs)	Stock assessment for Silky sharks shows declining standardized catch rates in the WCPO, along with a clear finding that the stock of this low productivity species is overfished, and that overfishing is occurring. Stock assessment also concluded that the species was predominantly caught as by-catch in the WCPO, and that the greatest impact on the stock is attributed to bycatch from the longline fishery, but there are also significant impacts from the associated purse seine fishery which catches predominantly Juvenile individuals	Bycatch
WCPFC	CMM 2014-	2015	Sets out a scientific and management framework on the conservation of		Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
	05		sharks caught in association with WCPFC managed fisheries. Includes prohibition of a) wire leaders or b) shark lines for longline fisheries targeting tuna and billfishes, development of management plan (licence, TAC…) for longline fisheries targeting sharks		
NEAFC	Rec 10:2015	2015	Sets out a scientific and management framework on the conservation of sharks caught in association with NEAFC managed fisheries. Includes full utilization of catch, prohibition of "finning", encouragement for release of live sharks captured as bycatch and research implementation (fishing gear selectivity, key biological/ ecological parameters, life history and behavioural traits, migration patterns and identification of potential mating, pupping and nursery grounds)		Target and Bycatch
NEAFC	Rec 7:2016	2016–2019	Sets out a scientific and management framework on the conservation of porbeagle shark (*Lamna nasus*) caught in association with NEAFC managed fisheries. Includes targeted fishery ban for porbeagle shark, encouragement for release of live shark incidentally captured and data report requirements to ICES	Information available is not sufficient to inform on the current status of the stock of porbeagle in the Northeast Atlantic.	Target

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
EU	Council reg. 2015/104	2015	Sets out a scientific and management framework on the conservation of porbeagle shark (*Lamna nasus*) caught by EU vessel in the Atlantic. Includes targeted fishery ban for porbeagle shark, prohibition of retention, encouragement for release of live shark incidentally captured.		Target
GCFM	36/2012/3	2012	Sets out a scientific and management framework on the conservation of sharks and rays in the Mediterranean sea. Includes prohibition of "finning", prohibition of retention of porbeagle shark (*Lamna nasus*)		Target and Bycatch
NAFO	Doc 16/01	2016	Sets out a scientific and management framework on the conservation of sharks caught in association with NAFO managed fisheries. Includes full utilization of catch, 5% fin/ body ratio for retained catches, encouragement for release of live sharks captured as bycatch and research implementation (identification nursery areas, fishing gear selectivity)		Target and Bycatch
SEAFO	CM 04-06	2006	Sets out a scientific and management framework on the conservation of sharks caught in association with SEAFO managed fisheries. Includes full utilization of catch, 5% fin/ body ratio for retained catches, data reporting, encouragement for release of live sharks captured as bycatch and		Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
			research implementation (identification nursery areas, fishing gear selectivity)		
CITES	Appendix II	2016	Sets out strict regulation in the trade of specimens of species included in Appendix II of the CITES. For shark and rays in the pelagic environment, it includes Oceanic whitetip shark (*Carcharhinus longimanus*), Porbeagle shark (*Lamna nasus*), Scalloped hammerhead shark (*Sphyrna lewini*), Smooth hammerhead shark *(Sphyrna zygaena*), Great hammerhead shark(*Sphyrna mokarran*), Whale shark (*Rhincodon typus*), Manta rays (*Manta* spp.)		Target and Bycatch
CMS	Appendix I	2014	Sets out management framework on the conservation of endangered migratory species of wild animals. For shark and rays in the pelagic environment, it includes Spinetail mobula (Mobula japanica), Giant Devil Ray (*Mobula mobular*), Chilean devil ray (*Mobula tarapacana*)		Target and Bycatch
CMS	Appendix II	2014	Sets out management framework on the conservation of migratory species of wild animals which have an unfavourable conservation status. For shark and rays in the pelagic environment, it includes Silky shark (*Carcharhinus falciformis),* Pelagic		Target and Bycatch

RFMO or adv body	CMM reference	Date of implementation	Description	Origin of the CMM adoption (if available)	Shark status (target vs bycatch)
			thresher (*Alopias pelagicus*), Spinetail mobula (*Mobula japanica*), Giant Devil Ray (*Mobula mobular*), Chilean devil ray (*Mobula tarapacana*)		

2. Comparison of existing CMMs

Table VII.2. Comparison of CMMs between oceanic basins for main shark species (red denotes the existence of a CMM for that particular ocean basin).

N°	CMM	Fishery	Species	AO	IO	EPO	WPO	MED
Input and Output Controls								
1	Directed fishery ban	LL	Porbeagle *Lamna nasus*	■				
2	Prohibition of retention	All	Shortfin mako *Isurus oxyrinchus*	■				
		All	Porbeagle *Lamna nasus*	■				■
3	Catch limit	All	Blue shark *Prionace glauca*	■ **N**				
Fishing gear modification								
4	Prohibition of wire or shark line for tuna and billfish directed fishery	LL	Target sharks			■	■	
Fishing practices and strategy								
5	Ban of high sea driftnets	GIL	Target sharks		■		■	■
Incentive to limit finning and discard								
6	Full utilization	All	Target sharks	■	■	■	■	
7	5% fin/body ratio*	All	Target sharks	■	■	■	■	
8	Prohibition of finning*	All	Target sharks	■ **NE**				■

* Note: Fin-attached policy on EU vessels

Table VII.3 Correspondence between the CMM (numbers mentioned in the previous table) and the resolutions or recommendations adopted by RFMOs, international conventions and political administrations regarding main shark species.

N°	Species	ICCAT	IOTC	IATTC	WCPFC	GFCM	NEAFC	SEAFC	EU
1	Porbeagle	Rec 09-07					16/07		2015/104
2	Atlantic shortfin mako	Rec 14-06							
	Porbeagle					36/2012/3			2015/104
3	Atlantic blue shark	Rec 16-12							
4	Sharks			Res C16-05	CMM 2014-05				
5	Sharks	Rec 03-04	Res 12/12		CMM 2008-04				
6	Sharks	Res 04-10	Res 05/05	Res C05-03	CMM 2010-07		16/01	CM 04-06	
7	Sharks	Res 04-10	Res 05/05	Res C05-03	CMM 2010-07		16/01	CM 04-06	
8	Sharks					36/2012/3	15/10		

Table VII.4. Comparison of CMMs between oceanic basin for other shark species that can be incidentally caught by oceanic fisheries (red denotes the existence of a CMM for that particular ocean basin).

N°	CMM	Fishery	Species	AO	IO	EPO	WPO	MED
Input and Output Controls								
1	Prohibition of retention	All	Thresher sharks *Alopiidae*		■			
			Bigeye thresher *Alopias superciliosus*	■				
			Oceanic whitetip *Carcharhinus longimanus*	■	■	■	■	
			Hammerhead sharks *Sphyrnidae* (except *Sphyrna tiburo*)	■				
			Silky shark *Carcharhinus falciformis*	■			■	
		PS	Silky shark *Carcharhinus falciformis*			■		
		All	Mobulid rays			■		
		All	Porbeagle *Lamna nasus*	■				■
2	Bycatch/ catch ratio limit	LL	Silky shark *Carcharhinus falciformis*			■		
3	Limit in the number of juvenile catch	surf LL	Silky shark *Carcharhinus falciformis*			■		
4	Minimum size recommendation	All	Oceanic whitetip *Carcharhinus longimanus*	■				
Fishing gear modification and bycatch mitigation devices								
5	Prohibition of wire for tuna and billfish directed fishery	LL	Sharks				■	
6	Non entangling FAD	PS	Sharks		■	■		
7	Ban of artificial lights on FAD and vessel	PS	Sharks		■			
Fishing practices and strategy								
9	Ban of high sea driftnets	G	Sharks		■		■	■
10	Prohibition of intentional setting on whale shark	PS	Whale shark *Rhincodon typus*		■	■	■	
Spatial and temporal measures								
11	FAD moratorium	PS	Sharks	■	■	■	■	
Incentive to limit finning and discard								
12	Full utilization	All	Sharks	■	■	■	■	
13	5% fin/ body ratio	All	Sharks	■	■	■	■	

14	Prohibition of finning	All	Sharks	**NE**				
15	Encourage release of live sharks	All	Sharks					
			Thresher sharks *Alopiidae*					
			Bigeye thresher *Alopias superciliosus*					
			Hammerhead sharks *Sphyrnidae*					
			Oceanic whitetip *Carcharhinus longimanus*					
			Silky shark *Carcharhinus falciformis*					
			Mobulid rays					
		All	Porbeagle *Lamna nasus*					
16	Release guidance to increase survival	PS	Sharks					
			Whale shark *Rhincodon typus*					
			Mobulid rays					
17	Prohibition/control on international trade	All	Oceanic whitetip *Carcharhinus longimanus*					
			Porbeagle *Lamna nasus*					
			Scalloped hammerhead *Sphyrna lewini*					
			Smooth hammerhead *Sphyrna zygaena*					
			Great hammerhead *Sphyrna mokarran*					
			Whale shark *Rhincodon typus*					
			Manta rays					

Table VII.5. Correspondence between the CMM (number mentioned in the previous table) and the resolutions or recommendations adopted by RFMOs, international conventions and political administrations regarding other shark species that interact with oceanic fisheries.

N°	Species	ICCAT	IOTC	IATTC	WCPFC	GFCM	NEAFC	SEAFC	CITES
1	Thresher sharks		Res 12/09						
	Bigeye thresher shark	Rec 09-07							
	Oceanic whitetip shark	Rec 10-07	Res 13/06	Res C11-10	CMM 2011-04				
	Hammerhead sharks	Rec 10-08							
	Silky shark	Rec 11-08		Res C16-06	CMM 2013-08				
	Mobulid rays			Res C15-04					
	Porbeagle shark	Res C15-04				36/2012/3			
2	Silky shark			Res C16-06					
3	Silky shark			Res C16-06					
4	Oceanic whitetip shark	Rec 10-07							
5	Sharks				CMM 2014-05				
6	Sharks		Res 15/08	Res16-01					
7	Sharks		Res 16/07						
9	Sharks	Rec 03-04	Res 12/12		CMM 2008-04				
10	Whale shark		Res 13/05	Res C16-01	CMM 2012-04				
11	Sharks	Rec 11-01	Res 12/13	Res C04-09	CMM 2011-01				
12	Sharks	Res 04-10	Res 05/05	Res C05-03	CMM 2010-07		16/01	CM 04-06	
13	Sharks	Res 04-10	Res 05/05	Res C05-03	CMM 2010-07		16/01	CM 04-06	

14	Sharks					36/2012/3	15/10	
15	Sharks	Res 04-10	Res 05/05	Res C05-03	CMM 2010-07			
	Thresher sharks		Res 12/09					
	Bigeye thresher shark	Rec 09-07						
	Hammerhead sharks	Rec 10-08						
	Oceanic whitetip shark		Res 13/06	Res C11-10	CMM 2011-04			
	Silky shark	Rec 11-08			CMM 2013-08			
	Mobulid rays			Res C15-04				
	Porbeagle shark	Rec 15-06						
16	Sharks			Res C16-05				
	Whale shark		Res 13/05	Res C16-05	CMM 2012-04			
	Mobulid rays			Res C15-04				
17								App. II

APPENDIX VIII – TASK 6

Table VIII.1 – Advantage and disadvantage of generic management measures (MM, see list of corresponding numbers at the end note) for reducing bycatch of elasmobranchs in tuna and tuna-like fisheries (modified from Poisson et al., 2016).

N° MM	Advantage	Disadvantage	Remark	Reference
1	• Fishing effort and fishing mortality on sharks could be reduced, as numbers retained depend on as fins were a high-value, low volume product • Enables better quantification at the species level at landings	• Fishers argue that the obligation of landings shark carcass with fins reduce on-board storage, increase labour costs and damage the flesh when defrosting is required for removing fins. • Required high rate of observer coverage and/or control at landings • Possible increase of fin transhipments for low level of enforcement at sea	• Finning prohibition divert attention from assessing whether catch levels are sustainable • Issues with compliance and enforcement	(Camhi et al., 2008); (Walsh et al., 2009); (Clarke et al., 2013)
2	• Quotas may help landing limits	• Benefit for stocks only for high survival when catching and low post-release mortality • May incentivize finning or high grading	•	(Poisson et al., 2016)
3	• Reduced fishing mortality on the most vulnerable elasmobranch species • May not have a significant economic impact on the fishing sector	• Efficiency depends on the discard survival • Misidentification of species can occur even with observer on board • May have an economic impact for high valuable species or products	• Prevent scientific knowledge particularly for data-poor species	(Poisson et al., 2016); (Tolotti et al., 2015)
4	• Foster fishing activities on fishing grounds where small fish are less abundant • Encourage gear selectivity improvement to avoid juvenile catches	• Fishers should modify their fishing gear in some fishing grounds • Can hidden the mortality on juveniles if the post release survival is weak	• Post release mortality is higher for juveniles • A better knowledge of nursery grounds is clearly needed	(Carruthers et al., 2009); (Coelho et al., 2012)
5	• Discourage the targeting or retention of large individuals being often females • Foster to displace the fishing effort to avoid fishing grounds with aggregations of adults	• Economic impact as large sharks may have a higher value • Effectiveness depends on the post release mortality • Can hidden the mortality on adults if the post release survival is weak	• May create problems for fishermen to assess the size of the fish being caught alive • Require a tolerance level by enforcers regarding the MaxLS	
6	• Reduction of shark catches and mortality • Foster a co-management with fishermen • Encourage a collaborative work with	• May impact the sustainability of the fishing activity for vessels which cannot reach the goals	• Regulation proposed by authorities or by the fishing industry could have an economic impact on some vessels or fishermen associations when bycatch standards are not	(Gilman, 2011)

	scientists to develop mitigation measure		met • Reducing or withholding any subsidies or increase coast of the permit or license fee • Fisheries may benefit from a sustainable fishery certification	
7	• Reduction of shark catches in the closure area • May have positive impact for other sensitive taxa	• Economic and ecological impact (fuel and ecological printing) to move on other fishing grounds • Can generate problems for fleets with limited carrying capacity (mostly sei-industrial fleets) • Could transfer a negative fishing impact on other fishing grounds • Closed area in distant high sea could promote the presence of IUU vessels	• Need a deep knowledge of the ecology of fishes being protected by the measure • Need to foresee the response of the fleet • Easy to monitor and enforce with vessel monitoring system (VMS) • Regulation in international waters limited to the fisheries of the regulating nation or international agreements	(Alverson et al., 1994); (Dunn et al., 2011); (Senko et al., 2014)
8	• Expected reduction of shark catches • May have positive impact for other sensitive taxa	• Monitoring compliance can be difficult (and costly) to implement and achieve	• Various input controls can be applied such as limiting the number of vessel and/or the carrying capacity of the fleet, the number of hooks, the number of fishing operations, …	(Davis and Worm, 2013)
9	• Expected reduction of shark catches • May have positive impact for other sensitive taxa	• Any measure restricting fishing faces reluctance by the industry • Land-all policies can result in mixed fisheries being closed early when the catch limits for the species with the smallest quota are reached ("choke" species) or if bycatch limits of vulnerable taxa are exceeded	• Several bycatch management approaches have been implemented to reduce waste, bycatch and discarding in fisheries like 1) national of international bycatch policy; 2) bycatch quotas or caps; 3) individual habitat quotas (HQs); 4) bycatch tax system; 5) zero (dead) discard policies	(Davis and Worm, 2013)
10	• Can report real-time observations of bycatch hotspots to be avoided by other vessels • Easy to implement particularly on fisheries where observer programs are implemented • Can be supported by the fishing industry to demonstrate environmental awareness	• Avoiding bycatch hotspots may be compromised by the catch rates of target species • Difficult to monitor without observer programme	• Appropriated measure with strong economic incentives to reduce bycatch • Appropriated measure for large fleets and when interactions with bycatch species are rare events	(Gilman et al., 2008); (Gilman et al., 2006)
11	• Information transfer to crew about resolutions in place regarding the	• Potential for fishers to incur costs and time when attending workshops	• Species identification trainings aim to improve the quality of reported	(Carruthers et al., 2011); (Poisson et al.,

reduction of bycatch and the mitigation measures proposed to assess this issue • Improved safety for crews • Reduced mortality of discarded elasmobranch and others sensitive species • Potential time savings • Raise the fishers' awareness of conservation issues and encourage their involvement in the sustainable management of marine resources	• Some good handling practices may increase the time taken to bring fish onboard or catch processing time	data • Possible support from these measures if fishermen receive some subsidies in return	2014)

List of management measure numbered in the table:

1) Legal constraints in fishery for fin cutting and removal,
2) Quotas for bycatch species,
3) Species retention prohibition,
4) Minimum landing size (MinLS: the minimal length at which it is legal to retain the species),
5) Maximum landing size (MaxLS: the maximum length at which it is legal to retain the species),
6) Compensation mitigation/industry self policing,
7) Spatial/temporal closure,
8) Input control (fishing effort reduction)
9) Bycatch management
10) Real-time fleet communication programme
11) Workshop and training programmes on good handling and fishing practices, and species identification.

APPENDIX IX – TASK 10

1. List of elasmobranchs listed on the CMS and MoU-Sharks

Table IX.1. List of elasmobranchs listed on the CMS and MoU-Sharks. Notes: * Species that are considered to occur in oceanic habitats; **only relates to northern hemisphere populations. Those species listed on CMS Appendix I that are also listed as prohibited under EU fishing regulations (EU, 2018) are indicated in green, and those species listed on CMS Appendix I that are not currently listed under EU fishing regulations as prohibited are indicated in red.

Family	Scientific name	CMS Appendix I	CMS Appendix II	CMS MoU-Sharks Annex	Prohibited species on EU regulations (EU, 2018)
Squalidae	***Squalus acanthias*	–	Yes	Yes	Yes (EU waters of ICES Subareas 2–10; unless on a pilot scheme)
Squatinidae	*Squatina squatina*	Yes (2017)	Yes (2017)	–	Yes (EU waters)
Rhincodontidae	**Rhincodon typus*	Yes (2017)	Yes	Yes	–
Cetorhinidae	**Cetorhinus maximus*	Yes	Yes	Yes	Yes (all waters)
Lamnidae	**Carcharodon carcharias*	Yes	Yes	Yes	Yes (all waters)
	**Isurus oxyrinchus*	–	Yes	Yes	–
	**Isurus paucus*	–	Yes	Yes	–
	**Lamna nasus*	–	Yes	Yes	Yes (all waters)
Alopiidae	**Alopias pelagicus*	–	Yes	Yes	Yes (IOTC Convention area)
	**Alopias superciliosus*	–	Yes	Yes	Yes (ICCAT and IOTC Convention areas)
	**Alopias vulpinus*	–	Yes	Yes	Yes (IOTC Convention area)
Carcharhinidae	**Carcharhinus falciformis*	–	Yes	Yes	Yes (ICCAT and WCPFC Convention areas)
	Carcharhinus obscurus	–	Yes (2017)	–	–
	**Prionace glauca*	–	Yes (2017)	–	–

Sphyrnidae	**Sphyrna lewini*	–	Yes	Yes	Yes (ICCAT Convention area)
	**Sphyrna mokarran*	–	Yes	Yes	Yes (ICCAT Convention area)

Family	Scientific name	CMS Appendix I	CMS Appendix II	CMS MoU-Sharks Annex I	Prohibited species on EU regulations (EU, 2018)
Pristidae	*Anoxypristis cuspidata*	Yes	Yes	Yes	Yes (all waters)
	Pristis clavata	Yes	Yes	Yes	Yes (all waters)
	Pristis pectinata	Yes	Yes	Yes	Yes (all waters)
	Pristis zijsron	Yes	Yes	Yes	Yes (all waters)
	Pristis pristis	Yes	Yes	Yes	Yes (all waters)
Rhinidae	*Rhynchobatus australiae*	–	Yes (2017)	–	–
Rhinobatidae	*Rhinobatos rhinobatos*	–	Yes (2017)	–	–
Mobulidae	**Mobula alfredi* [as *Manta alfredi*]	Yes	Yes	Yes	Yes (all waters)
	**Mobula birostris* [as *Manta birostris*]	Yes	Yes	Yes	Yes (all waters)
	**Mobula hypostoma*	Yes	Yes	Yes	Yes (all waters)
	**Mobula kuhlii*	Yes	Yes	Yes	Yes (all waters)
	**Mobula mobular*	Yes	Yes	Yes	Yes (all waters)
	**Mobula munkiana*	Yes	Yes	Yes	Yes (all waters)
	**Mobula tarapacana*	Yes	Yes	Yes	Yes (all waters)
	**Mobula thurstoni*	Yes	Yes	Yes	Yes (all waters)
	**Mobula japanica* [= *Mobula mobular*]	Yes	Yes	Yes	Yes (all waters)
	**Mobula eregoodootenkee* [= *Mobula kuhlii*]	Yes	Yes	Yes	Yes (all waters)
	**Mobula rochebrunei* [= *Mobula hypostoma*]	Yes	Yes	Yes	Yes (all waters)

2. Progress and future needs in relation to the MoU-Sharks

Table IX.2. Summary of the objectives in the MoU-Sharks and examples of how these have developed by the EU and Member States for *Objective A: Improving understanding of migratory shark populations through research, monitoring and information exchange.*

Activities under the MoU-Sharks		Progress	Future needs
1. *Ecological research, monitoring and data collection*	*1.1 Identify priority research, monitoring and training needs, taking into account regional differences.*	Such work is on-going, and the current study assists with this activity.	Developing a strategy or timetable to start addressing data gaps and research needs, including resourcing, is required.
	1.2 Endeavour to develop capacity in research, data collection, monitoring and facilitate training in data quality.	Such work is on-going to varying degrees within EU Member States. The main EU member states that exploit elasmobranchs send delegates to relevant expert groups and workshops. There have been various workshops (e.g. ICES, ICCAT data preparatory meetings) that help address data quality.	Developing approaches to facilitate 'staff exchange' between relevant expert groups and laboratories to improve collaborative links Facilitation of 'joint meetings' that could address common issues, such as data collation and data quality.
	1.3 Compile relevant data, improve ecological knowledge and conduct baseline studies on shark populations (e.g. populations dynamics, abundance, essential shark habitat; distributional range, aggregations, behaviour, seasonal and spatial migration patterns, taxonomy)	The relevant working Groups within ICES and RFMOs have generally compiled much of the available information (e.g. from national monitoring programmes and published studies) for the main commercial stocks.	The development of a standardised synthesis of such information (e.g. as 'species executive summaries', 'stock annexes', or 'biological synopses') could be usefully considered.

Activities under the MoU-Sharks			Progress	Future needs
	1.4	*Conduct long-term monitoring of shark populations in order to assess their conservation status and trends.*	In general, there is limited or no fishery-independent monitoring of oceanic/pelagic elasmobranchs. Current assessments are usually reliant on fishery-dependent data to provide standardised indices of CPUE, which are used as a proxy index for stock abundance.	Collaborative studies between scientists and fishers to inform on the potential merits of using some dedicated trips on commercial vessels to undertake a more robust, survey-based approach to fishing/sampling could usefully be considered.
	1.5	*Identify and prioritize (with a view to developing conservation measures) critical shark habitats including critical migration routes and critical life stages*	There are generally insufficient data to accurately identify and delineate critical habitats for oceanic sharks, although some important aggregation sites can be identified for some species, and some broader regions in which nursery grounds may occur are documented in the scientific literature.	Studies to collate and analyse distributional data for oceanic sharks (by length, sex and, if available, maturity), including both data held by RFMOs augmented with data from other sources could be undertaken to allow for the preliminary identification of potentially important sites for oceanic sharks (e.g. pupping and nursery grounds, sites if importance to 'threatened' species).
	1.6	*Assess and prioritize threats to sharks from human activities (especially fisheries) and identify the species most vulnerable to them*	Ecological Risk Assessments and/or Productivity-Susceptibility Analyses have been undertaken for some fisheries and species, including high seas fisheries. Information on the threats of shelf-based activities on pelagic sharks that also occur in shelf seas are less-well documented.	Identify which oceanic sharks have greater reliance on shelf seas, and assess threats on these species in such areas.
	1.7	*Establish conservation targets and indicators to assess progress towards*	There are no agreed quantitative, stock-specific reference points for oceanic elasmobranchs.	Species-specific reference points and indicators are required.

Activities under the MoU-Sharks		Progress	Future needs
	reaching these targets at the species population level, and develop species-specific reference points for enhanced conservation measures.		
2. Information exchange	*2.1 Facilitate the timely access to and exchange of information necessary to coordinate conservation and management measures.*	The various activities within 'information exchange' are generally on-going, but are often based on informal links between collaborative scientists and institutes. Various bodies (e.g. RFMOs and ICES) provide access to collated data and have their own protocols for collating data from national administrations, including through expert working groups. The various expert groups within RFMOs and other bodies (e.g. ICES) can often have some scientists in common, which also facilitates knowledge exchange.	Developing approaches to facilitate 'staff exchange' between relevant expert groups (e.g. ICES, GFCM, ICCAT) to improve collaborative links, including more regular 'joint meetings' that could address common issues and allow for best practice to be shared.
	2.2 Recommend standard methods and set minimum levels of data collection and adopt or develop a recommended set of protocols for research, monitoring, and information exchange.		
	2.3 Determine and, where appropriate, develop the most suitable methods for information dissemination.		
	2.4 Regularly exchange scientific and technical information and expertise among national governments, scientific institutions etc.,		

Activities under the MoU-Sharks		Progress	Future needs
	in order to develop and implement best practice approaches to the conservation of sharks and their habitats.		
	2.5 Create a directory of experts and organizations concerned with shark conservation on a regional and global level.	Not currently available.	Such a directory should be developed.
	2.6 Disseminate traditional knowledge on sharks and their habitats.	Collating 'traditional knowledge', which includes fisher knowledge, is variable across the scientific community. Whilst some expert group meetings allow members of the fishing industry to attend (often as observers), not all expert groups do. There are also other fora (e.g. Advisory Councils in EU waters) which engage with both scientists and the fishing industry. Better methods for inclusion of fishery-dependent information and data are needed.	Traditional knowledge on sharks and their habitats could usefully be collated, both nationally and then regionally.

Table IX.3. Summary of the objectives in the MoU-Sharks and examples of how these have developed by the EU and Member States for *Objective B: Ensuring that directed and non-directed fisheries for sharks are sustainable – In pursuing activities described under this objective Signatories should endeavour to cooperate through RFMOs, the FAO, RSCAPs and biodiversity-related MEAs as appropriate.*

Activity	Activities	Progress	Future needs
3. Fisheries-related research and data collection	*3.1 Promote stock assessments and related research.*	Sharks are of increasing focus for the main tuna RFMOs, and there have been gradual improvements to the process (e.g. an increase in the number of stocks being assessed and the quality of the assessments)	The quality and availability of data can be highly variable. Workshops to better appraise data and to estimate catch data for stock assessment scientists are required. Training workshops to better develop capacity in stock assessment methods.
	3.2 Develop programmes to establish baseline data and facilitate reporting at a species-specific level on (for example) shark catch rates, landings, discards, biological composition etc.	Such data are generally reported either annually, or when there is a specific data call or data preparatory meeting.	
4. Ecologically sustainable management of shark populations, including monitoring, control and surveillance	*4.1 Develop and adopt best practice guidance for the conservation and management of shark populations based on the best available scientific knowledge and following a precautionary and ecosystem approach.*	This is a policy issue and is not addressed here.	
	4.2 Develop programmes to monitor directed shark fisheries and shark bycatch, including programmes such as vessel monitoring systems, inspections and on-board observer or monitoring programmes.	There is a degree of observer coverage on EU-vessels operating on the high seas, and market sampling of some of the catch. In general, tRFMOs require a minimum of 5% scientific observer coverage, and in some cases, like large purse seine	These should be developed on a case-by-case basis, depending on the data requirements and other issues identified by the relevant stock assessment and management groups.

Activity	Activities	Progress	Future needs
		fleets, the coverage can reach values close to 100%. There are pilot studies for trials on electronic monitoring systems, especially for fisheries, where deploying scientific observers is difficult (e.g. vessels/fleets with limited space or conditions to take extra persons onboard). VMS and port-inspection also take place through tRFMOs, but are separate programs linked with compliance issues rather than with the scientific sampling schemes.	
	4.3 Prohibit the taking of species in accordance with paragraph 13 i of the MoU.	The species listed on CMS Appendix I of the CMS (angel shark, white shark, basking shark, manta/mobulid rays and sawfish) are listed as 'prohibited species' on EU Fishing Regulations.	Whale shark was listed on CMS Appendix I in 2017, but is not currently a prohibited species on EU fishing regulations.
	4.4 Ensure that mortality rates arising from fishing activities do not exceed levels resulting in a significant decline of populations following the precautionary approach in proactively setting conservation and management measures at all times.	Mortality rates uncertain. Only a limited number of oceanic shark stocks have stock assessments. Whilst some oceanic sharks are 'prohibited species', an unknown degree of fishing mortality is likely to occur, and this can be hard to quantify.	Studies to better estimate the quantity of bycatch and both the at-vessel and post-release mortality of prohibited species are required, in order to gauge whether additional technical or management measures would be required.
	4.5 Encourage relevant bodies to set	This is a policy issue and is not addressed here.	

Activity	Activities	Progress	Future needs
	targets for fish quotas, fishing effort and other restrictions to help achieve sustainable use in line with the best available scientific advice and using the precautionary approach to ensure that all shark catch is within sustainable limits.		
	4.6 Consider the development or application of certification systems for sustainable shark products.	This is a policy issue and is not addressed here.	
	4.7 Encourage the consideration of including shark conservation criteria in existing certification systems for sustainable fisheries.	This is an issue for other stakeholder groups and is not addressed here.	
	4.8 Encourage no increase in and minimize the use of plastics and non-degradable materials in fishing operations.	This is a policy issue and is not addressed here.	
	4.9 Encourage the participation of indigenous and local communities (ILC) in the fishery management process.	This is a policy issue and is not addressed here.	
	4.10 Ensure that the global moratorium on all large-scale pelagic driftnet fishing is fully implemented on the high seas of the world's oceans and seas, including enclosed seas and semi-enclosed seas, in accordance to UN General Assembly Resolution 46/2158.	This is a policy issue and is not addressed here. However, it is noted that particularly in the Indian Ocean, the IOTC Scientific Committee has identified drifting gillnets as a major issue multiple times, due to the large number of drifting gillnets still operating in that ocean. Better enforcement and monitoring needed.	
5. Bycatch	*5.1 To the extent practicable, develop*	There have been several studies on	In the short-term, further

Activity	Activities	Progress	Future needs
	and/or use selective gear, devices, and techniques to ensure that the take of sharks in fisheries is sustainable and appropriately managed and that mortality of non-utilized catches is minimized to the greatest extent possible.	technical mitigation measures (e.g. Poisson *et al*., 2016), but the efficacy of potential measures can vary between fleets and species.	studies on technical mitigation could usefully focus on those bycatch species that have higher capture mortality, including hammerhead and thresher sharks.
	5.2 Liaise and coordinate with fishing industries, fisheries management organizations, academic institutions and environmental non-governmental organizations (NGOs) to develop and implement incidental capture mitigation mechanisms in national waters and on the high seas, prioritizing work to avoid the capture of protected sharks in accordance with paragraph 13 i of the MoU.	This is a policy issue and is not addressed here.	
	5.3 Promote capacity building for the safe handling and release of sharks.	Safe handling guidelines have been developed for some fisheries (e.g. Poisson *et al*., 2014). The adoption of safe handling guidelines may be variable.	Safe handling guidelines should be trialled in representative fisheries, with a view to ensuring their appropriateness for those fleets, and encouraging fishers to develop the most effective solutions.
6. Cooperation through RFMOs, RSCAPs and FAO	*6.1 Encourage implementation of conservation and management measures adopted by RFMOs, RSCAPs, biodiversity-related MEAs and FAO.*	This is a policy issue and is not addressed here.	
	6.2 Develop and implement National Plans of Action for Sharks - NPOA-Sharks - to	Globally, some, but not all, relevant nations have NPOA-Sharks. Some	Reviews of NPOAs could usefully be undertaken, so as

Activity	Activities	Progress	Future needs
	manage sharks within a State's jurisdictional waters and for the regulation of the activities of States' fleets fishing on the High Seas in accordance with FAO's voluntary IPOA-Sharks - also taking into account UN General Assembly Resolutions 59/259 and 61/10510.	existing NPOAs have not been updated.	to highlight progress, identify limitations, and identify future needs for subsequent NPOAs.
	6.3 Promote practical and enforceable conservation recommendations based on the best available science within relevant RFMOs, RSCAPs, biodiversity-related MEAs and FAO.	This is a policy issue and is not addressed here.	
7. Policy, legislation and law enforcement	*7.1 Review of domestic policy*	The various elements of this activity are policy issues and are not addressed here.	
	7.2 International trade		
	7.3 Finning		
	7.4 Law enforcement		
8. Economic incentives	*8.1 Work to reform, phase out and eliminate subsidies resulting in unsustainable use of sharks.*	The various elements of this activity are policy issues and are not addressed here.	
	8.2 Develop opportunities for alternative livelihoods for and together with local communities.		

Table IX.4. Summary of the objectives in the MoU-Sharks and examples of how these have developed by the EU and Member States for *Objective C: Ensuring to the extent practicable the protection of critical habitats and migratory corridors and critical life stages of sharks.*

Activity	Activities	Progress	Future needs
9. Conservation activities	*9.1 Designate and manage conservation areas, sanctuaries or temporary exclusion zones along migration corridors and in areas of critical habitat, including those on the high seas in cooperation with relevant RFMOs and RSCAPs where appropriate, or take other measures to remove threats to such areas.*	There are generally insufficient data to accurately identify and delineate migration corridors and other critical habitats for oceanic sharks, although some important aggregation sites can be identified for some oceanic species. There have been some recent studies using observer data from multiple fleets and fisheries to identify distribution patterns of pelagic sharks on oceanic scales (e.g., Fernandez-Carvalho et al., 2015, Coelho et al., 2018), but such studies have not been undertaken for most species. Consequently, there are limited options for spatial management for most oceanic elasmobranchs. There may be more relevance to considering the utility and efficacy of spatio-temporal management for those species occurring in shelf seas, or where there are discrete and well-defined pupping or nursery grounds.	Spatial information from relevant data sources needs to be collated by life-history stage, in order to identify the locations of nominal pupping and nursery grounds (and other critical habitats where required). Appropriate field surveys to validate the current use of such sites, determine the degree of inter-annual utilization, and establish whether such sites are critical habitats. Evaluate the human activities occurring in any critical habitats, to determine whether such activities are resulting in mortality that impacts on the population, and develop appropriate spatial management framework.
	9.2 Integrate shark and shark habitat protection in environmental impact or risk assessments for marine and coastal development projects.		
	9.3 Develop, implement and assess spatial and/or seasonal closures of fishing areas to reduce incidental capture of sharks, particularly to protect nursery grounds as well as aggregation areas for mating and pupping.		
	9.4 Promote the protection of the marine environment from land-based and maritime pollution that may adversely affect shark populations.	This activity is not-specific to elasmobranchs, and so is not addressed here.	

Activity	Activities	Progress	Future needs
	9.5 Avoid the mortality of juvenile sharks and fecund females in order to maintain population levels and to ensure population viability.	Reducing the mortality on juvenile sharks and large fecund females may be achieved through spatio-temporal management and/or size restrictions. There are currently no such restrictions for oceanic elasmobranchs.	Demographic modelling to demonstrate the efficacy of minimum and/or maximum size limits of relevant species. Studies on AVM and PRM by species and length class, in order to determine whether there are ontogenetic differences in capture mortality. Collation of spatial data relating to gravid (term and near-term) females and neonates, and establish the degree of inter-annual variation in the use of such habitats (i.e., are they used regularly by the stock, or are they 'transient features').
10. Legislation	*10.1 Contribute to developing legislation to protect species and their critical habitats and ensure implementation of regulations and policies on national, regional and global scale.*	This is a policy issue and is not addressed here.	
11. Economic incentives	*11.1 Develop incentives for adequate protection of areas of critical habitats inside and outside protected areas.*	This is a policy issue and is not addressed here.	

Table IX.5. Summary of the objectives in the MoU-Sharks and examples of how these have developed by the EU and Member States for *Objective D: Increasing public awareness of threats to sharks and their habitats, and enhance public participation in conservation activities*

Activity	Activities	Progress and future needs
12. Awareness raising	*12.1 Increase knowledge of the ecosystem services provided by sharks and knowledge about sharks in their marine environment.*	Whilst individual scientists may contribute to awareness raising, such activities are typically the remit of other bodies (e.g. education and conservation bodies) and so is not addressed here.
	12.2 Raise public awareness of threats to sharks and their habitats.	
	12.3 Raise public awareness of this Memorandum of Understanding and its objectives.	
13. Stakeholder participation	*13.1 Encourage the participation of relevant stakeholders (e.g. government institutions; non-governmental organizations; local communities; commercial and recreational fishing communities; scientists; academia) in the implementation of this Conservation Plan*	Whilst individual scientists and expert groups may be involved in stakeholder participatory meetings, the further development of such activities would be the remit of the relevant bodies, and so is not addressed here.
	13.2 Develop and apply methods of co-management and/or public participation with local fishery communities in shark fishing.	

Table IX.6. Summary of the objectives in the MoU-Sharks and examples of how these have developed by the EU and Member States for *Objective E: Enhancing national, regional and international cooperation*

Activity	Activities	Progress and future needs
14. Cooperation among governments	*14.1 Identify specific management issues where cooperation among States is required for successful conservation and management.*	The various elements of this activity are policy issues and are not addressed here.
	14.2 Enhance institutional capacities and competencies in shark identification, management and conservation techniques to generate technical support for the implementation of the MoU at the national, regional and international level.	
	14.3 Strengthen existing and develop new mechanisms, where required, for cooperation and effective consultations involving stakeholders in research, management among coastal and fishing states, as well as with relevant IGOs and RFMOs and regional seas conventions, at the sub-regional level.	
	14.4 Develop networks, including those for information and data, for cooperative management of shared populations, within or across sub-regions, and, where appropriate, formalize cooperative management arrangements.	
	14.5 Cooperate, where possible, in the establishment of transboundary marine protected areas using ecological rather than political boundaries.	
	14.6 Conduct collaborative studies and monitoring in pursuing activities described in objective A and B above where appropriate.	
15. Cooperation with existing instruments and organizations	*15.1 Cooperate, as appropriate with, for example, the fisheries industry, FAO, RFMOs, UN bodies and biodiversity-related MEAs (e.g. CBD, CITES and Ramsar), IGOs and NGOs engaged with shark conservation, and other international organizations that deal with*	This activity is a policy issue and is not addressed here.

Activity	Activities	Progress and future needs
related to shark conservation	*fisheries.*	
16. Accession to international instruments relevant for the conservation and management of sharks	*16.1 Ratify or accede to those international instruments relevant to the conservation and management of migratory sharks and their habitats in order to enhance the legal protection of migratory shark species.*	The various elements of this activity are policy issues and are not addressed here.
	16.2 Encourage Signatories that have not already done so to become Parties to the Convention on Migratory Species (CMS); global fisheries agreements such as the UN Fish Stocks Agreement (1995), the FAO Compliance Agreement (1993), the FAO Port State Measures Agreement (2009) and other relevant international instruments.	
	16.3 Encourage Signatories to implement the FAO Code of Conduct for Responsible Fisheries (1995).	

3. Data availability on capture mortality

Table IX.7. Availability of published data on at-vessel mortality (AVM) and post-release mortality (PRM). NA = Not Available (indicating where data are not currently available), '–' indicates where interactions between a gear/fishery and a species are considered minimal. Adapted from Ellis *et al.* (2017).

Species	Mortality	Longline	Gillnet	Purse seine
Whale shark *Rhincodon typus*	AVM	–	N/A	Capietto et al. (2014)
	PRM	–	N/A	N/A
Bigeye sand tiger *Odontaspis noronhai*	AVM	N/A	N/A	–
	PRM	N/A	N/A	–
Crocodile shark *Pseudocarcharias kamoharai*	AVM	Musyl et al. (2011) Afonso et al. (2012) Bromhead et al. (2012) Coelho et al. (2012) Fernandez-Carvalho et al. (2015) Gilman et al. (2015)	–	–
	PRM	N/A	–	–
Megamouth shark *Megachasma pelagios*	AVM	–	–	–
	PRM	–	–	–
Pelagic thresher *Alopias pelagicus*	AVM	Musyl et al. (2011) Bromhead et al. (2012) Gilman et al. (2015)	–	–
	PRM	–	–	–
Bigeye thresher *Alopias superciliosus*	AVM	Beerkircher et al. (2004) Coelho et al. (2011, 2012)	–	–

Species	Mortality	Longline	Gillnet	Purse seine
		Musyl et al. (2011) Bromhead et al. (2012) Fernandez-Carvalho et al. (2015) Gallagher et al. (2014a) Gilman et al. (2015)		
	PRM	–	–	–
Common thresher *Alopias vulpinus*	AVM	Bromhead et al. (2012) Coelho et al. (2012) Gilman et al. (2015)	Walker et al. (2005) Braccini et al. (2012)	–
	PRM	N/A	N/A	–
Thresher sharks *Alopias* spp.	AVM	Boggs (1992)	Reid & Krogh (1992)	–
	PRM	–	–	–
Basking shark *Cetorhinus maximus*	AVM	–	N/A	–
	PRM	–	N/A	–
White shark *Carcharodon carcharias*	AVM	N/A	Reid & Krogh (1992)	–
	PRM	N/A	N/A	–
Shortfin mako *Isurus oxyrinchus*	AVM	Francis et al. (2001) Megalofonou et al. (2005) Beerkircher et al. (2004) Coelho et al. (2011, 2012) Musyl et al. (2011) Bromhead et al. (2012) Epperly et al. (2012) Gallagher et al. (2014a) Gilman et al. (2015)	Walker et al. (2005) Braccini et al. (2012)	–

Species	Mortality	Longline	Gillnet	Purse seine
		Campana et al. (2016)		
	PRM	Campana et al. (2016)	N/A	–
Longfin mako *Isurus paucus*	AVM	Coelho et al. (2012) Gallagher et al. (2014a) Gilman et al. (2015)	–	–
	PRM		–	–
Mako sharks *Isurus* spp.	AVM	Afonso et al. (2012)	Reid & Krogh (1992)	
	PRM	-	–	
Salmon shark *Lamna ditropis*	AVM	N/A	N/A	–
	PRM	N/A	N/A	–
Porbeagle *Lamna nasus*	AVM	Francis et al. (2001) Coelho et al. (2012) Epperly et al. (2012) Gallagher et al. (2014a) Campana et al. (2016)	Bendall et al. (2012)	–
	PRM	Campana et al. (2016)	N/A	–
Silky shark *Carcharhinus falciformis*	AVM	Beerkircher et al. (2004) Afonso et al. (2011) Coelho et al. (2011, 2012) Musyl et al. (2011) Scott-Denton et al. (2011) Afonso et al. (2012) Bromhead et al. (2012)	–	Poisson et al. (2014a) Hutchinson et al. (2015) Eddy et al. (2016)

Species	Mortality	Longline	Gillnet	Purse seine
		Serafy et al. (2012) Gallagher et al. (2014a) Gilman et al. (2015) Gulak et al. (2015)		
	PRM	N/A	–	Poisson et al. (2014a) Hutchinson et al. (2015) Eddy et al. (2016)
Galapagos shark *Carcharhinus galapagensis*	AVM	Bromhead et al. (2012) Gilman et al. (2015)	N/A	–
	PRM	N/A	N/A	–
Oceanic whitetip shark *Carcharhinus longimanus*	AVM	Beerkircher et al. (2004) Poisson et al. (2010) Afonso et al. (2011) Musyl et al. (2011) Afonso et al. (2012) Bromhead et al. (2012) Coelho et al. (2012) Fernandez-Carvalho et al. (2015) Gallagher et al. (2014a) Gilman et al. (2015)	–	–
	PRM	Musyl et al. (2011)	–	–
Tiger shark *Galeocerdo cuvier*	AVM	Beerkircher et al. (2004) Morgan & Burgess (2007) Afonso et al. (2011) Scott-Denton et al. (2011) Afonso et al. (2012) Bromhead et al. (2012) Coelho et al. (2012)	Reid & Krogh (1992)	–

Species	Mortality	Longline	Gillnet	Purse seine
		Gallagher et al. (2014a) Butcher et al. (2015) Gilman et al. (2015) Gulak et al. (2015)		
	PRM	Afonso & Hazim (2014) Gallagher et al. (2014b)	N/A	–
Blue shark *Prionace glauca*	AVM	Francis et al. (2001) Beerkircher et al. (2004) Diaz & Serafy (2005) Megalofonou et al. (2005) Moyes et al. (2006) Campana et al. (2009, 2016) Poisson et al. (2010) Afonso et al. (2011) Coelho et al. (2011, 2012) Musyl et al. (2011) Afonso et al. (2012) Bromhead et al. (2012) Epperly et al. (2012) Serafy et al. (2012) Gallagher et al. (2014a) Gilman et al. (2015)	N/A	–
	PRM	Campana et al. (2016)	N/A	–
Scalloped hammerhead *Sphyrna lewini*	AVM	Beerkircher et al. (2004) Afonso et al. (2011) Scott-Denton et al. (2011) Bromhead et al. (2012) Coelho et al. (2012) Gallagher et al. (2014a)	N/A	N/A

Species	Mortality	Longline	Gillnet	Purse seine
		Butcher et al. (2015) Gulak et al. (2015)		
	PRM	N/A	N/A	N/A
Great hammerhead *Sphyrna mokarran*	AVM	Bromhead et al. (2012) Coelho et al. (2012) Butcher et al. (2015) Gulak et al. (2015)	N/A	N/A
	PRM	Gallagher et al. (2014b)	N/A	
Smooth hammerhead *Sphyrna zygaena*	AVM	Coelho et al. (2011, 2012) Fernandez-Carvalho et al. (2015) Butcher et al. (2015)	Walker et al. (2005) Braccini et al. (2012)	N/A
	PRM	N/A	N/A	N/A
Hammerhead sharks Sphyrnidae	AVM	–	Reid & Krogh (1992) Manire et al. (2001) Hueter et al. (2006) Thorpe & Frierson (2009)	Eddy et al. (2016)
	PRM	–	N/A	Eddy et al. (2016)
Pelagic stingray *Pteroplatytrygon violacea*	AVM	Boggs (1992) Carruthers et al. (2009) Poisson et al. (2010) Coelho et al. (2011, 2012) Afonso et al. (2012) Bromhead et al. (2012) Gilman et al. (2015)	–	N/A
	PRM	N/A	–	N/A

Species	Mortality	Longline	Gillnet	Purse seine
Alfred manta *Mobula alfredi*	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	N/A
Manta ray *Mobula birostris*	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	N/A
Lesser devil ray *Mobula hypostoma*	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	N/A
Shortfin devil ray *Mobula kuhlii*	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	N/A
Giant devilray *Mobula mobular* (including *M. japanica*)	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	Francis & Jones (2016)
Munk's devil ray *Mobula munkiana*	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	N/A
Chilean devilray *Mobula tarapacana*	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	N/A
Smoothtail mobula *Mobula thurstoni*	AVM	N/A	N/A	N/A
	PRM	N/A	N/A	N/A
Mobulid rays Mobulidae	AVM	Coelho et al. (2011, 2012) Mas et al. (201	–	–
	PRM	–	–	–

APPENDIX X – TASK 12

Executive summary sheets for the blue shark and shortfin mako shark.

Prionace glauca (Linnaeus, 1758) Blue shark – FAO code: BSH

FAO code	Scientific name & English name	IUCN. Red List. Global assessment	IUCN. Red List. Regional assessments
BSH	*Prionace glauca.* Blue shark	NT (2009)	VU : MED

Age & growth

Prionace glauca (Linnaeus, 1758) Blue shark FAO code: BSH	Atlantic Ocean	Ref.	Mediterranean Sea	Ref.	Indian Ocean	Ref.	West Pacific	Ref.	East Pacific	Ref.
L∞ for female in cm	L∞=310 FL L∞=394 L∞=423 L∞=311.6 TL	13 21-23 21-34 50			L∞=311.6 TL	50	L∞=235.5 L∞=304 L∞=243.3	7 21 16-29	L∞=237.5 TL L∞=241.9 L∞=243.3	12 12-14 16-29

Prionace glauca (Linnaeus, 1758). Blue shark – FAO code: BSH

K for female /year	k=0.16 k=0.13 k=0.11 k=0.12	13 21-23 21-34 50			k=0.12	50	k=0.2297 k=0.16 k=0.144	7 21 16-2	k=0.15 k=0.25 k=0.144	12 12-14 16-29
t_o for female in years	t_0=-1.56 t_0=-0.80 t_0=-1.04 t_0=-1.66	13 21-23 21-34 50			t_0=-1.66	50	t_0=-1.01 t_0=-0.849	21 16-29	t_0=-2.15 t_0=-0.79 t_0=-0.849	12 12-14 16-29
L∞ for male in cm	L∞=282 FL L∞=394 L∞=423 L∞=311.6 TL	13 21-33 21-34 50			L∞=311.6 TL	50	L∞= 297.18 L∞=369 L∞=289.7	7 21 16-29	L∞=299.85 TL L∞=295.3 TL L∞=289.7	12 12-14 16-29
K for male /year	k=0.18 k=0.13 k=0.11 k=0.12	13 21-33 21-34 50			k=0.12	50	k=0.1650 k=0.1 k=0.129	7 21 16-29	k=0.10 k=0.18 k=0.129	12 12-14 16-2
t_o for male in years	t_0=-1.35 t_0=-0.80 t_0=-1.04 t_0=-1.66	13 21-33 21-34 50			t_0=-1.66	50	t_0=-1.38 t_0=-0.756	21 16-29	t_0=-2.44 t_0=-1.11 t_0=-0.756	12 12-14 16-29
Longevity in years	>20 16-20	1-3 13	>20	1-3	>20	1-3	>20 22.76 (males) 19.73 (females)	1-3 7 7	>20	1-3
Maximum size TL in cm	383 396.2	2 30	383 396.2	2 30	383 396.2	2 30	383 396.2	2 30	383 396.2	2 30
Common size (FL) in cm	335 93-387 TL 240 FL 156-250	3 20 22 25	335 180-240 FL	3 22	335 170-330 (males) 130-330 (females) 180-240FL	3 22-23 22-23 22	335 180-240 FL	3 22	335 180-240 FL	3 22
Maximum weight in kg										

Prionace glauca (Linnaeus, 1758). Blue shark – FAO code: BSH

Reproduction

Female maturity size in cm	221 >185 228 TL 180 FL (50%) 194.4 TL 171.1 FL	1 19 25-28 35 50 56	221	1	221 194.4 TL	1 50	221 170-190 FL 170-195 FL 186-212 199.2 TL (50%)	1 6 7 16-17 58	221 186-212 199.2 TL (50%)	1 16 58
Female maturity age in years	5-6 6 5-7 5 6 5-6	1 19 28-29 25-28 50 56	5-7	28-29	5-7 6	28-29 50	5-7 7-9 5-6	28-29 7 16-17	5-6 5-7	16-17 28-29
Male maturity size in cm	182-281? 193-210 FL (50%) 183 FL 225 FL L_{95}=205 FL 201.4 TL 185-241 FL 180.2 FL	1-3 17-18 19 25-28 36 50 52 56	182-281?	1-3	182-281? 201.4 TL 207 TL (50%)	1-3 50 57	182-281? 190-195 FL 203 190.3 TL (50%)	1-3 6-7 16-17 58	182-281? 203 190.3 TL (50%)	1-3 16-17 58
Male maturity age in years	4-5 4-6 7	1 28-29 50	4-6	28-29	4-6	28-29	4-6 8 4-5	28-29 7 16-17	4-6 4-5	28-29 16-17
Birth size TL in cm	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50	1-19 29 47-47	35-44 35-50 40-50 43.5	1-19 29 46-47 14-30
Sex ratio	1:1 (embryos)	17-35			1:1 (embryos)	1	1:1 (embryos) 4:5	17 46	1:1 (embryos)	17
Mode of development	placental viviparous	1-19	placental viviparous	1-19	placental viviparous	1-19	placental viviparous	1-19	placental viviparous	1-19

Prionace glauca (Linnaeus, 1758). Blue shark – FAO code: BSH

Gestation period in months	9-12	1-19-29	9-12	1-29	9-12	1-29	9-12	1-29	9-12	1-29
Spawning & mating periods	Spring to early Summer December/ July pupping group off Azores	1-7 36 54	Spring to early Summer	1	Spring to early Summer	1	Spring to early Summer	1-7	Spring to early Summer	1-7
Fecundity: number of embryos per litter	4-135 4-63 up to 82 30 in average 43-55 33 (median litter)	1 2 3 19 50 56	4-135 4-63 up to 82 30 in average	1 2 3 19	4-135 4-63 up to 82 30 in average 43-55	1 2 3 19 50	4-135 4-63 up to 82 30 in average 1-62 4-57	1 2 3 19 16-17 46	4-135 4-63 up to 82 30 in average 1-62	1 2 3 19 16-17
Nursery ground	nursery in central North Atlantic where juveniles stay up to 2 years									

Conversion factors

Length / Weight relationships	LogW=-5.396 + 3.134logTL $WT=0.0110*TL^{2.828}$ $WT=3.1841*10^{-6}*FL^{3.1313}$ $WT=0.392*10^{-6}*TL^{3.41}$ (males) $WT=0.131*10^{-5}*TL^{3.20}$ (females)	1 9 10 34-37 34-37	LogW=-5.396 + 3.134logTL		LogW=-5.396 + 3.134logTL $WT=0.159*10^{-4}*LF^{2.84554}$	1 26	LogW=-5.396 + 3.134logTL $WT=3.8838*10^{-6}*TL^{3.174}$ (males) $WT=2.328*10^{-6}*PCL^{3.294}$ (females) $W=3.113*10^{-6}*TL^{3.04}$	1 37-38 37-38 46	LogW=-5.396 + 3.134logTL WT= 3.8838*10-6 *TL3.174 (males) WT= 2.328*10-6*PCL3.294 (females) $WT=2.57*10^{-5}*TL^{3.05}$	1 37-38 37-38 37-40
Wet weight / dressed weight ratio										

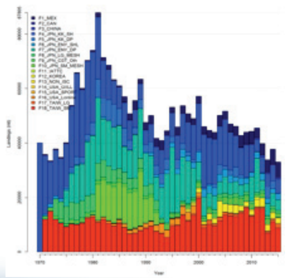
TL / FL	FL=0.8313TL+ 1.3908 FL=1.73872 + 0.82995TL TL=1.175*FL +4.103 FL=11.27 + 0.78TL (males) FL=23.52 + 0.73TL FL=-1.2+0.842TL TL=3.8+1.17FL FL=-1.061 + 0.8203TL TL=1.716 + 1.2158FL FL=1.837 + 1.091*PCL males FL=1.837 + 1.086*PCL females TL=2.045 + 1.200*FL males TL=1.694 +1.200*FL females	10 19 22 37-39 37-39 27 27 35 35 55 55 55 55					FL= $-1.615+0.838TL_{nat}$	6	FL= $-1.615+0.838TL_{nat}$	6
TL/PCL	PCL= 3.92 + 0.74TL (males) PCL= 28.95 + 0.63TL (females)	27-39			ratio 2.40- 2.47	20	PCL=0.762TL - 2.505	37-38		
Fins / carcass ratios	FW=65.84BW/0.0888	27	FW/BW=5.65	48	FW/BW=5.65	48	FW/BW=5.65	48	FW/BW=5.65	48
Stables isotopes N^{15} & C^{14}										

Population dynamics

Stock delineation/range							catch rate declining 5%/ year horizontal & vertical sex-size segregation	59 60	catch rate declining 5%/ year horizontal & vertical sex-size segregation	59 60
Natural mortality										
Stepness										
Intrinsic rate of increase (λ or r) (year^{-1})	0.278	61								
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.1 4.8	32 51	4.1	32	4.1	32	4.1	32	4.1	32

Prionace glauca (Linnaeus, 1758). Blue shark – FAO code: BSH

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean	
			West Pacific Ocean (WCPFC)	East Pacific Ocean (IATTC)
Stock structure	ICCAT separates North and South Atlantic blue shark stocks at 5°N latitude based on tagging and catch data. It is also assumed that the Mediterranean constitutes a separate stock.	IOTC assumes a single stock of Blue shark in the Indian Ocean.	There is evidence for two stocks: North and South.	No information available.
Fishery and Catches	Although global statistics on blue shark catches included in the ICCAT database have improved recently (especially since the mid-90s), they are still insufficient to permit the ICCAT Standing Committee Research and Statistics (SCRS) to provide full quantitative advice on stock status with sufficient precision to guide fishery management toward optimal harvest levels. The first official catch records for blue shark in ICCAT starts in 1978 and 1991 for Northern and Southern stocks, respectively. For the Northern stock, the official catch statistics increased from around 3,000 t in 1990, to around 8,000 in 1996, reaching around 30,000 t. in 1997. Since then, the catches fluctuated between 20,000 t. and 30,000 t to increases of up to 39,500 t. in 2011. In the Southern stock a similar trend is observed, starting with 1,500 t. in 1994, 8,000 t. in 1997, 20,000 in 2005, and 35,000 t. in 2011. The catches for both stocks in 2011 are the highest records in the historic time series. However, the ICCAT official catches are considered to represent only a portion of the total removals and, thus, the SCRS has estimated a time series of blue shark catch based on the ratio of shark catches to tunas from fisheries where more reliable information was available. The catch estimation followed a similar pattern to ICCAT task I official catches since the mid-90s. The catch estimation for the northern stock showed an increasing trend reaching the highest catch level of around 60,000 t. in 1987, then decreasing until 2002, followed by another increase until 2011 and being stable since then. In contrast, the estimated catch trend for the southern stock showed an increasing trend, with a peak in 2011, and decreasing thereafter (Figure 1). For the Mediterranean Sea, the official catch statistics and data quality are extremely poor throughout the entire time series.	It appears that significant catches of sharks have gone unrecorded in several countries. Furthermore, many catch records probably under-represent the actual catches of blue shark because they do not account for species identification, discards (i.e. do not record catches of sharks for which only the fins are kept or of sharks usually discarded because of their size or condition) or they reflect dressed weights instead of live weights. FAO also compiles landings data on elasmobranchs, but the statistics are limited by the lack of species-specific data and data from the major fleets. There is little information on the fisheries prior to the early 1970's, and some countries continue not to collect shark data while others do collect it but do not report it to IOTC.The catch estimates for blue shark are highly uncertain and few Members countries have reported detailed data on blue shark catches. As such, IOTC official catches are considered to represent only a portion of total removals. The first officials catch records for blueshark in IOTC dated back to 1986, it increased up to the highest records in the series of around 11,000 tonnes in 2005, and since then it slightly decreased to be at around 10,000 during last years. A range of alternative estimated catch histories for Indian Ocean blue shark were presented for the 2017 stock assessment of blue shark in the Indian Ocean. The GAM-based estimates were used as the catch series applied for the base-case assessment scenario, while the EUPOA (based on a methodology used in an EU project; EASME/EMFF/2016/008-SC01), the trade based catch series as well as the nominal catches were used for sensitivity runs.	Catch records for BSH in the North Pacific are limited and, where lacking, have been estimated using statistical models and information from a combination of historical landings data, fishery logbooks, observer records and research surveys. In these analyses, estimated BSH catch data refer to total dead removals, which includes retained catch and dead discards. Catch data to carry out this assessment were gathered from Japan, U.S., Taiwan, Republic of Korea, China, Canada, Mexico, IATTC and the Secretariat of the Pacific Community. Eighteen different fisheries are defined. There is little information on the fisheries prior to the early 1970's. The catch estimates were highest from 1976 to 1989 with a peak estimated catch of approximately 88,000 mt in 1981. Since then the catches have declined until 1995, being more or less stable thereafter with a few peaks in specific years. In the most recent years, estimated catch has been between 30,000 and 40,000 tonnes.  Figure 1. Catches by fishery from 1971-2015. Note: Catch in 1970 is an assumed level of catch used to derive equilibrium conditions.	No information available.

Prionace glauca **(Linnaeus, 1758). Blue shark – FAO code: BSH**

Stock Status Executive Summary

Fishery and Catches

Atlantic Ocean and Mediterrenean Sea (ICCAT)

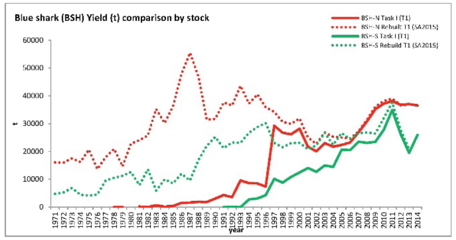


Figure 1 - Blue shark catches reported to ICCAT (Task I) and estimated by the SCRS.

Indian Ocean (IOTC)

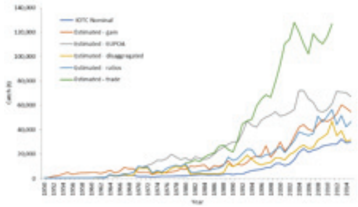


Figure 1 - IOTC nominal catches and a range of alternative estimated catch histories for Indian Ocean blue shark, noting the high uncertainty associated with the reported catches.

Pacific ocean

West Pacific Ocean (WCPFC)

East Pacific Ocean (IATTC)

State of the Stock

Atlantic Ocean and Mediterrenean Sea (ICCAT)

The last full stock assessment for northern and southern stocks of blue shark were conducted in 2015, applying Bayesian surplus production models (BSP and SS-BSP) and a length-based age-structured model (Stock Synthesis) to the available catch data through 2013. Various series of CPUE were available (8 for Northern stock and 6 for Southern stock).

Considerable progress was made on the integration of new data sources, in particular size data, and modelling approaches, particularly model structure, in the 2015 assessment of the status of the stock of North Atlantic blue shark. For both the North and South Atlantic stocks, uncertainty in data inputs and model configuration was explored through sensitivity analysis. Although sensitivity analyses did not cover the full range of possible uncertainty, they revealed that results were sensitive to structural assumptions of the models. Overall, assessment results were uncertain (e.g. the level of absolute abundance varied by an order of magnitude between models with different structures) and should be interpreted with caution.

Indian Ocean (IOTC)

The last full stock assessment for blue shark was conducted in 2017, applying a data-limited catch only model (SRA), two Bayesian biomass dynamic models (JABBA with process error and a Pella-Tomlinson production model without process error) and an integrated age-structured model (Stock Synthesis) to the available catch data through 2015. Manage advice was based on Stock Synthesis. Seven series of CPUE were available, but due to conflicting trends in the series and to avoid model misspecification only three series were used for the base model runs, while the others were used in sensitivity analysis.

Considerable progress was made since the last Indian Ocean blue shark assessment on the integration of new data sources and modelling approaches. Major uncertainties identified in the current model are catches and CPUE indices of abundance. Model results were explored with respect to their sensitivity to the major axes of uncertainty identified.

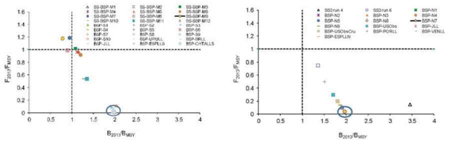
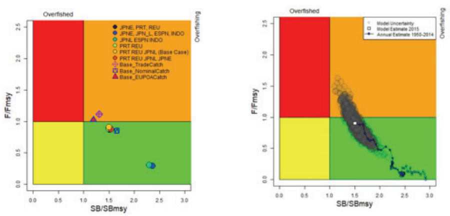
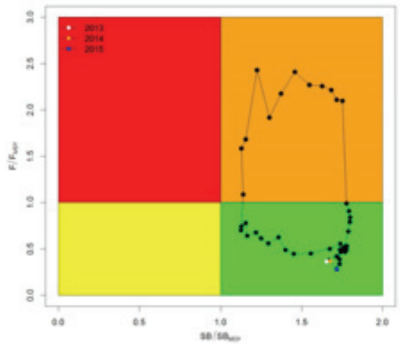
Pacific ocean

The last full stock assessment for northern Pacific blue shark was conducted in 2017, applying an integrated age-structured model (Stock Synthesis) to the available catch data through 2015. A Bayesian State-Space Surplus Production reference case model was also conducted to facilitate comparison with the previous (2014) assessment. Six series of CPUE were available. Of those, two series were used for the base model runs due to their broader spatial temporal coverage in the core distribution of the stock and the statistical soundness of the standardizations.

The assessment used a fully integrated approach in Stock Synthesis with model inputs that have been greatly improved since the previous assessment. Due to uncertainty in the input data and life history parameters, multiple models were run with alternative data/parameters including the abundance indices used in the analyses, initial catch level, natural mortality schedule, and the stock recruitment relationship and shape. In total, 14 SS models representing different combinations of input datasets and structural model hypotheses were used to assess the influence of these uncertainties on biomass trends and fishing mortality levels for North Pacific BSH.

Prionace glauca **(Linnaeus, 1758). Blue shark – FAO code: BSH**

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean: West Pacific Ocean (WCPFC)	Pacific ocean: East Pacific Ocean (IATTC)
Biomass	For the Northern stock, the biomass in 2013 was estimated to be above the biomass at MSY and, thus, most models suggested that stocks were not overfished and that biomass was estimated to be above the ICCAT Convention Objective. For the Southern stock, BSP estimated biomass to be above the biomass at MSY, while SS-BSP runs were generally less optimistic, predicting that biomass could be lower than biomass at MSY (Figure 2).	The biomass in 2015 was estimated to be above the biomass at MSY and, thus, all models suggested that stocks are not overfished, but with the trajectories showing consistent trends towards the overfished quadrant of the Kobe plot (Figure 2). If the alternative CPUE groupings were used then the stock status was somewhat more positive, while if the alternative catch series were used then the estimated stock status resulted in a lower estimated biomass than if the GAM-based estimates were used.	While the results varied depending upon the input assumptions, extensive model explorations showed that the reference run had the best model performance and showed fits most consistent with the data. The biomass in 2015 was estimated to be above the biomass at MSY and, thus, the model suggested that stocks are not overfished (Figure 2).	
Fishing mortality	For the Northern stock, fishing mortality rate was estimated to be below the fishing mortality at MSY and, thus, most models concluded that overfishing was not occurring. For the Southern stock BSP estimated that fishing mortality rate was estimated to be below the fishing mortality at MSY, while SS-BSP were generally less optimistic, predicting that fishing mortality could be higher than the fishing mortality at MSY (Figure 2).  Figure 2 – Top panel: Phase plots summarizing scenario outputs for the current (for 2013) stock status of North Atlantic blue shark. BSP=Bayesian surplus production model; SS3=Stock synthesis model. The circle denotes common status for several BSP runs. Note that the x-axis values for SS3 are SSF2013/SSFMSY. Bottom panel: Phase plots summarizing scenario outputs for the current (for 2013) stock status of South Atlantic blue shark. BSP=Bayesian surplus production model; SS-BSP=State-space Bayesian surplus production model. The circle denotes common status for several BSP runs.	The fishing mortality rate was estimated to be below the fishing mortality rate at MSY and, thus, all models concluded that overfishing was not occurring, but with trajectories showing consistent trends towards the subject to overfishing quadrant of the Kobe plot (Figure 2). If the alternative CPUE groupings were used then the stock status was somewhat more positive, while if the alternative catch series (trade and EUPOA) were used then the estimated stock status resulted in the fishing mortality rate being estimated to be above the fishing mortality rate at MSY and, thus, subject to overfishing.  Figure 2 – Blue shark: Aggregated Indian Ocean stock assessment Kobe plot for the 2017 estimate based on the base case model and a range of sensitivity models explored with several catch reconstructions and fits to CPUE series. Top panel: terminal year estimates of the sensitivity model runs; Bottom panel: base case model with trajectory and MCMC uncertainties in the terminal year. All models shown are run using Stock Synthesis 3.	The recent annual fishing mortality (F2012-2014) was estimated to be below the fishing mortality at MSY and, thus, it was concluded that overfishing was not occurring (Figure 2).  Figure 2 – Kobe plot of the trends in estimates of relative fishing mortality and spawning biomass of North Pacific blue shark between 1971-2015 for the reference case of the SS stock assessment model.	

Prionace glauca (Linnaeus, 1758). Blue shark – FAO code: BSH

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean: West Pacific Ocean (WCPFC) / East Pacific Ocean (IATTC)
Recommendation	Considering the uncertainty in stock status results for the South Atlantic stock of blue sharks, the SCRS strongly recommended that the Commission considers a precautionary approach for this stock. If the Commission chose to use the same approach taken for the North Atlantic stock, the average catch of the final five years used in the assessment model (28,923 t for 2009-2013) could be used as a limit. For the North Atlantic stock, while all model formulations explored predicted that the stock was not overfished and that overfishing was not occurring, the level of uncertainty in the data inputs and model structural assumptions was high enough to prevent the SCRS from reaching a consensus on a specific management recommendation.	Even though the blue shark in 2017 was assessed to be not overfished nor subject to overfishing, maintaining current catches is likely to result in decreasing biomass and the stock becoming overfished and subject to overfishing in the near future. If the Commission wishes to increase the probability of maintaining stock biomass above MSY reference levels (B>BMSY) over the next 8 years, then a reduction of a least 10% in catches is advised. The stock should be closely monitored. Mechanisms need to be developed by the Commission to improve current statistics, by ensuring CPCs comply with their recording and reporting requirement on sharks, so as to better inform scientific advice in the future.	Target and limit reference points have not yet been established for pelagic sharks by the WCPFC or the IATTC, the organizations responsible for management of pelagic sharks caught in international fisheries for tuna and tuna-like species in the Pacific Ocean. The 2015 biomass exceeds biomass at MSY and F2012-2014 is below FMSY. Future projections under different fishing mortality (F) harvest policies show that median BSH biomass in the North Pacific will likely remain above BMSY in the foreseeable future. Other potential reference points were not considered in these evaluations.

Blue Shark	Northern Stock	Southern Stock
Assessment Year	2015	
Data available	2013	
MSY		
B_{2013}/B_{MSY}	1.35-3.45	0.78-2.03
F_{2013}/F_{MSY}	0.04-0.75	0.01-1.19

Blue Shark	Indin Ocean
Assessment Year	2017
Data available	2015
MSY	-
B_{2013}/B_{MSY}	1.541 (1.368 - 1.721)
F_{2013}/F_{MSY}	0.866 (0.670 - 1.093)

Blue Shark	Northern Stock
Assessment Year	2017
Data available	2015
MSY	-
B_{2015}/B_{MSY}	1.69 (1.39-2.59)
$F_{2012\text{-}2014}/F_{MSY}$	0.38 (0.15-0.50)

Prionace glauca (Linnaeus, 1758). Blue shark – FAO code: BSH

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean West Pacific Ocean (WCPFC)	East Pacific Ocean (IATTC)
Sources of Information	Anon. 2015a. Report of the 2015 ICCAT blue shark data preparatory meeting. 23-27 March 2015, Tenerife, Spain. 33 pp. Anon. 2015b. Report of the 2015 ICCAT blue shark stock assessment session. 27-31 July 2015, Oceanário de Lisboa, Lisbon, Portugal. 116 pp. Anon. 2017. Report of the Standing Committee on Research and Statistics (SCRS). 2-6 October, Madrid, Spain. 465 pp.	IOTC. 2017. Report of the Thirteenth Session of the IOTC Working Party on Ecosystems and Bycatch. 4-8 September. San Sebastián, Spain. IOTC–2017–WPEB13–R[E]. 125 pp.	ISC. 2017. Stock assessment and future projection of blue shark in the North Pacific Ocean through 2015. 17th Meeting of the ISC, 12–17 July 2017, Vancouver, Canada. ISC17/SHARKWG Annex 13. 96 pp. WCPFC. 2017. Summary Report of the Thirteenth Regular Session of the Scientific Committee. 9-17 August 2017, Rarotonga, Cook Islands. 280 pp.	

General Recommendations

Data collection

In general, there is a scarcity of data and limited data availability for major fleets and countries in tuna-RFMOs. Attending to historical data, several countries were not collecting fishery statistics, especially in years prior to the development of tuna and tuna-like fisheries in early 1970s. It is thought that important catches of sharks might have gone unrecorded in many countries and fleets. This problem worsens in the case of developing states and, especially, for historical data. Furthermore, many catch records probably under-represent the actual catches of blue shark because they do not account for discards (i.e., do not record catches of sharks for which only the fins are kept or of sharks usually discarded because of their size, condition or low value) or they may reflect dressed weights instead of live weights.

Typically, catches of sharks were not recorded by gear and/or species, and often are not disaggregated at the required level for each species by area and fleet. Major shark species such as blue shark and shortfin mako shark have been better reported that other species but still there are inconsistencies and data gaps. Misidentification of shark species is also a common problem. The identification of sharks in port is usually compromised by the way in which the different species of sharks are processed before being landed. Generally, no indication is given on the type of processing that the different specimens underwent. Then, the identification of sharks unloaded as shark carcasses, shark fins or other shark products is difficult. The fins-attached policy adopted for some countries and fleets is improving this situation.

In order to improve the stock assessments of blue shark harvested in tuna-RFMO fisheries, the tuna-RFMOs also recommended that member countries submit the corresponding statistics of all fisheries capturing blue sharks, including recreational and artisanal fisheries. Countries are required to report all catches of blue shark, including available historical data according to data reporting procedures of the specific RMFOs. Particular reporting requirements apply to shark species in each region. Countries are also urged to report steps taken to improve data collection. It is considered that for a correct assessment of the status of the stocks and management of those species a solid basis to estimate total removals (total catches including discards) is necessary.

The data available by flag in the public domain is scarce in RFMO countries. In some cases due to confidentiality issues it is difficult to get the basic fishery information regarding the fleet activity catching blue shark, especially for historical data. It is difficult to extract disaggregated and aggregated data for some fleets, especially for coastal fisheries. Attempts should be made to allow the Scientific Committees of the tuna-RFMOs to access the available data for improving stock assessments.

Observer programmes

In tuna-RFMOs, data is mostly reported as the nominal catch data (landings and discards by species, stock, gear, fleets and year) which is the basic information used in most stock assessments, but also data on catch/effort and size data are provided, which are more detailed in terms of time and geographic area information. Although the objectives of Observer Programs can vary widely, in general in the case of sharks their objective is to collect basic fishery statistics such as catch and effort data as well as to conduct biological sampling. Fishery observers therefore offer one of the few methods appropriate to obtain accurate location, catch and effort information for sharks caught in tuna fisheries.

Although the objectives of the observer programmes can be diverse, observer programs will generally require high or moderate levels of precision if the purpose of the observer program is to provide adequate information to improve fisheries stock assessments, endangered species protections, and ecosystem management. In tuna-RFMOs, when the goal is to monitor the total tuna catch and/or bycatch/discards, the coverage agreed range between 5 % and 20 %. As such, in relation to the estimation of shark catches, the different coverage agreed have a clear effect on the ability to obtain accurate data of both shark catch estimates and status (alive or dead) of sharks discarded.

Although the level of observer coverage for the estimation of shark mortality depends on species and fleets specific cases, it is important that the observer programme has the following characteristics:

- Sufficient coverage to provide statistically accurate estimates of catch, bycatch and discards. A preliminary aim is to have observer coverage of 20% or above, noting, however, that currently even the 5% coverage is not achieved by the majority of the countries and fleets that operate under the various tuna-RFMOs.
- Sufficient spatial/temporal coverage of the main fleets.
- Sufficiently trained observers: to develop an observer training programme in order for observers to be sufficiently competent to record the data required by the tuna-RFMOs for management purposes.
- Species identification guides: species identification is a major problem with regard to shark bycatch data collection and, thus, species identification guides need to be available.
- Data forms: harmonized data forms to collect the shark bycatch and discard information (sex, size, additional biological information as reproductive stage, and condition status: alive or dead upon retrieval of the gear and at time of discarding).
- Database: database for recording of all observer data as well as well-designed protocols for accessing the data, taking into account data confidentiality and ownership.

Alternative ways to improve the collection of fishery statistics could be the use of "self-sampling" and Electronic Monitoring (EM).

Self-sampling methodology uses fisheries scientists and/or technicians to collect information on commercial catches

General Recommendations

which is a cost effective method. Therefore, currently there is ongoing effort worldwide to develop programmes to use fishers to self-sample their catches. Such programmes have generally two major objectives: i) reduce costs and increase efficiency on the collection of commercial fishery data; and, ii) to involve fishing industry in the assessment process by having them work closely with the scientists. Thus, the overall purpose of the programmes is to improve data collection and consequently reduce stock assessments uncertainty.

One of the major recognized problems with self-sampling is that some scientists do not see the data as fully scientific or valid. In order to shift this attitude it is necessary to properly verify the usability, high quality of data and cross-validated the data collected by self-sampling with data compiled by traditional observer programs. Moreover, for a successful program of self-sampling the willingness and collaboration from industry is necessary. Therefore, they should rely on the development of guidelines of best practice and general recommendations to assist in the initiation and execution of self-sampling and self-reporting programmes. Moreover, such schemes should rely on good collaboration between scientists and fishers, aiming to define clear aims and generate high quality data.

Confidentiality is another important issue that should be assured on these programmes, namely by ensuring that when used the data is presented in an anonymous and aggregated way. This is particularly important as some data sets might be used for enforcement purposes, and therefore might endanger trust between scientists and fishers.

Electronic monitoring (EM) systems are being used in some fisheries as an alternative, or a complement to human observers. The EM systems consist of a centralized computer combined with several sensors and cameras, which can be deployed on fishing vessels to monitor a range of fisheries issues, including: fishing location, catch, catch handling, fishing methods, protected species interactions, and mitigation measures. The efficacy of EM for monitoring issues varies according to fishing methods and other factors. Over the past decade, pilot studies have been carried out in more than 25 fisheries to test the efficacy of this technology, being involved different countries, gears and target species.

During 2012, the first trial with EM on a tropical tuna purse seine was performed in the Atlantic Ocean and this study suggested that EM is a viable tool for monitoring effort, set-type and tuna catch within the tropical tuna purse seine fishery. However, some limitations exist for the monitoring of the bycatch and especially for reliably estimation and identification of some shark species. Furthermore, observers constantly identified sharks to a higher taxonomic level, as 100 % of the shark species were identified by the observer, EM system provided limited identification (e.g. often only to family level). However, the problems observed with this first trial on the tuna purse seine fleet can be easily solved with some adjustments on the system such as the use of digital cameras and some modification on the crew catch handling behaviour.

Similar to the self-sampling programmes, the success of an EM program would depend on the good collaboration between fishers and scientist as it requires that the vessel owners and crew understand the importance of standardized catch handling protocols. EM systems are designed to be flexible enough to accommodate a variety of catch handling methods, but handling must be consistent and standardized in order to collect reliable data. For example, if a camera is installed above the discard handling area, and discarding handling is moved to another area of the vessel, the camera will no longer capture discarding events. This example illustrates the importance of having strong support from the vessel owners, officers and crew to achieve monitoring objectives.

It is also possible to apply such EM systems to gillnet and longline fleets. For example, a study on a gillnet fishery shows that EM offers opportunities for monitoring shark gillnet fishing activity. Overall, the high quality of imagery, the ability to identify most catch items, and no missing imagery in the data set, indicated that EM equipment was reliable and suitable for shark gillnet vessels. In the particular case of gillnet tuna fisheries, due to size of the fleet and the artisanal nature of the fisheries, it could be quite difficult a full-implementation of the EM sampling program. However, taking into account the complete lack of data and non existence of observers programs in gillnets tuna fisheries, the application of EM in a pilot observer vessels (100 % EM coverage of few vessels of the gillnet fishery) can be considered a suitable approach for collecting shark bycatch statistics on artisanal and coastal gillnet fisheries. In the case of longliners, it might be worthy and easier to implement such system.

Management measures

Management measures are essential when a given stock is seriously affected by the fishing activity and are aimed at limiting the impact of this activity. The election of a measure will depend on the stock status, on the behavior of the species, on the species being target or not, etc.

The main problem for pelagic shark's management is that there are few targeted fisheries. In the case of blue shark it can be considered that some of the longline fisheries catching sharks are targeting specifically blue shark, at least in some areas and seasons of the year.

In general for sharks, all tuna-RFMOs recommend that precautionary management measures are needed for stocks where there is the greatest biological vulnerability and conservation concern, and for which there are very few data. Taking into consideration the results of the modeling approaches used in the assessment, the associated uncertainty, and that maintaining or increasing effort will probably result in further declines in biomass and productivity, it can be recommended that the fishing mortality of blue sharks should not be increased.

And for the application of these recommendations several management measures can be recommended, such as:

General Recommendations

TACs

Total allowable catches (TACs) are catch limits that are set for most significant commercial fish stocks, and is widely used as the main management measure for several exploited stocks. Although blue sharks are also caught as bycatch, there are fisheries directly targeting blue shark. In the case where the productivity of the stocks and the impact of the fisheries can be adequately assessed, the establishment of TACs can ensure these populations are kept at levels that do not significantly affect their productivity. This could be the case of blue shark stocks for which an assessment and management advice is provided (e. g. ICCAT and IOTC cases).

Spatial/temporal closures

Time and/or area closures have been widely used as management measures to prevent overfishing and to protect certain marine habitats. Although there are very few examples on the use of this kind of measures to reduce shark bycatch, the development of protected areas or time closures, focused on shark "hot spots" or in critical habitats (e.g. nursery grounds) might have great conservation potential. A measure of this kind must take into account the effect of effort reallocation to adjacent areas, as well as the possible reduction in target species catch.

However, for applying those measures it is first necessary to investigate possible spawning/nursery areas of great conservation potential. Until those studies are available the application of these types of management measures will not be possible and/or might result in choosing inappropriate areas. Moreover, while the monitoring, surveillance and control of this kind of regulations can be easily enforced in industrial fisheries (e.g., by using VMS systems), it is much more difficult for the artisanal fleets, typically smaller vessels without VMS systems implemented.

No retention polices

Taking into account that the blue shark can be considered one of the few species of sharks for which a directed fishery exists, the "no retention policies" are not considered appropriate management measures. In the case of fisheries by-catching blue shark the "no retention policies" can be applied (see mitigation measures and post-release mortality tables).

Finning

Finning is the practice of slicing off fins and dumping carcasses at sea. Although shark finning has been banned in the four main tuna-RFMOs, discussion is now focused on the enforcement of this regulation. Most of the current measures allow for a 5% shark fin to body weight ratio, but this ratio is highly dependent on the fin usage (primary fin sets vs all fins), on the species, on the type of processing of the fins (dried or fresh fins) and on the way the body weight is computed (whole, dressed, etc) and can therefore lead to finning going undetected. Because of those concerns, several nations have established the fins-attached policy, that besides the previously mentioned issues also addresses other issues such as difficulties in species identification for processed carcasses. This policy is now established for some particular fleets (e.g., EU fleets), as well as in one particular case within the tuna-RFMOs, specifically in IOTC for fleets that land fresh sharks. It would be highly advisable to promote and expand this measure within all tuna-RFMOs and for all fleets.

Prionace glauca (Linnaeus, 1758). Blue shark – FAO code: BSH

References

1 – Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. *FAO Fish. Synop.,* 125(4/2): 251-655. Rome, FAO.

2 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome, 716 pp.

3 – Fishbase. 2017. *Prionace glauca*. http://www.fishbase.org/summary/speciessummary.php?id=898

4 – IGFA. 2001. Database of IGFA angling records until 2001. IGFA, Fort Lauderdale, USA.

5 – ICES. 1997. Demersal Fish Committee, 1997 Report of the Study Group on Elasmobranchs. ICES CM /G:2: 123 pp.

6 – Francis, M., Duvy, C. 2005. Length at maturity in three pelagic sharks (*Lamna nasus*, *Isurus oxyrinchus* and *Prionace glauca*) from New Zealand. *Fish. Bull.,* 103: 489-500.

7 – Manning, M. 2005. Age and growth of blue shark (*Prionace glauca*) from New Zealand Exclusive Economic Zone. New Zealand Fisheries Fisheries Assessment Report 2005/26: 52 pp.

8 - Florida Museum of Natural History. Biological profiles: blue shark. Ichthyology at the Florida Museum of Natural History: Education-Biological Profiles. FLMNH, University of Florida. http://www.flmnh.ufl.edu/fish/Gallery/Descript/BlueShark/BlueShark.html

9 – Frota, L., Costa, P., Braga, A. 2004. Length-weight relationships of marine fishes from the central Brazilian coast. *NAGA WorldFish Center Q*., 27: 20-26.

10 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

11 – McCord, M., Campana, S. 2003. A quantitative assessment of the diet of the blue shark (*Prionace glauca)* off Nova Scotia, Canada. *J. Nthwest. Atl. Fisher. Sci.*, 32: 57–63.

12 - Blanco-Parra, M., Galvan-Magana, F., Marquez-Farias, F. 2008. Age and growth of the blue shark, *Prionace glauca* Linnaeus, 1758, in the Northwest coast off Mexico. *Revist. Biol. Mar. Oceanog.*, 43(3): 513-520.

13 – Skomal, G., Natanson, L. 2003. Age and growth of the blue shark, *Prionace glauca*, in the North Atlantic Ocean. *Fisher. Bull.,* 101(3): 627-639.

14 – Caillet, G., Martin, L., Kusher, D., Wolf, P., Welden, B. 1983. Preliminary studies on the age and growth of the blue, *Prionace glauca*, common thresher, *Alopias vulpinus*, and shortfin mako, *Isurus oxyrinchus*, sharks from California waters. In Prince E. & Pulos L. (eds). Proceedings of the International workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. *NOAA Tech. Rep. NMFS,* 8: 179-188.

15 – Nakano, H., Nagasawa, K. 1996. Distribution of pelagic elasmobranchs caught by salmon research gillnets in the North Pacific. *Fisher. Sci.,* 62(6): 860-865.

16 – Nakano, H. 1994. Age, reproduction and migration of blue shark in the North Pacific Ocean. *Bull. Natl. Res. Inst. Far Sea Fisher*., 31: 141-256.

17 - Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2006. Assessment and Status Report on the Blue Shark, *Prionace glauca*, Atlantic Population, Pacific Population, in Canada. COSEWIC, Ottawa, ON.

18 – Campana, S., Marks, L., Joyce, W., Kohler, N. 2004. Influence of recreational and commercial fishing on the blue shark (*Prionace glauca*) population in Atlantic Canadian Waters. Canadian Science Advisory Secretariat Research Document 2004/069: 67 pp.

19 – Pratt, H. 1979. Reproduction in the blue shark, *Prionace glauca*. *Fish. Res. Bull,*. 77: 445-470.

20 – Arocha, F., Tavares, R., Silva, J., Marcano, L. 2005. Blue shark, *Prionace glauca*, length composition from the Venezuelan longline fleet in the northwestern Atlantic: Period 1994-2003. *Collect. Vol. Sci. Pap. ICCAT*, 58: 942-950.

21 – Tanaka, S., Cailliet, G., Yudin, K. 1990. Differences in growth of the blue shark, *Prionace glauca*: technique or population? 177-187 pp. In Pratt, H.Jr., Gruber, S., Taniuchi, T. (eds), Elasmobranchs as Living Resources: Advances in the Biology, Ecology, Systematics, and Status of the Fisheries. *NOAA Tech. Rep.,* 90.

22 – IOTC. 2007. Compilation of information on blue shark (*Prionace glauca*), silky shark (*Carcharhinus falciformis*), oceanic whitetip shark (*Carcharhinus longimanus*), scalloped hammerhead (*Sphyrna lewini*) and shortfin mako (*Isurus oxyrinchus*) in the Indian Ocean. 3rd Working Party on Ecosystems and Bycatch, 11-13 July 2007, Victoria, Seychelles. IOTC document IOTC-2007-WPEB-INF01: 18 pp.

23 – Gubanov, Y., Grigoryev, V. 1975. Observations on the distribution and biology of the blue shark *Prionace glauca* (Carcharhinidae) of the Indian Ocean. *J. Ichthyol.,* 15: 37–43.

24 - Santos, M. Garcia, A. 2005. Factors for conversion of fin weight into round weight for the blue shark (*Prionace glauca*). *Collect. Vol. Sci. Pap. ICCAT,* 58(3): 935-941.

25 – Hazin, F., Boeckman, C., Leal, E., Lessa, R., Kihara, K., Otsuka, K. 1994. Distribution and relative abundance of the blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean. *Fish. Bull.,* 92: 474-480.

26 – IOTC. 2011. Etat de la ressource du requin peau bleue (*Prionace glauca*). 14th Scientific Committee, 12-17 December 2011, Victoria, Seychelles. IOTC document IOTC-2011-SC14-26.

27 – Campana, S., Marks, L., Joyce, W., Kohler, N. 2005. Catch, by-catch and indices of population status ofblue shark (*Prionace glauca*) in the Canadian Atlantic. *Collect. Vol. Sci. Pap. ICCAT,* 58(3): 891-934.

28 – ICCAT. Manuel de l'ICCAT : Requin peau bleue. 2.2.1.1 BSH.

29 – Nakano, H., Stevens, J. 2008. The biology and ecology of the blue shark, *Prionace glauca*. 140-151 pp. In Camhi, M., Pikitch, E., Babcock, E. (Eds.). Sharks of the open ocean, Biology, Fishery and Conservation. Blackwell Publishing, Oxford UK.

30 – Cailliet, G., Bedford, D. 1983. The biology of three pelagic sharks from California waters, and their emerging fisheries: a review. *Calif. Coop. Oceanic Fish. Invest. Rep.*, 24: 57–69.

31 – Stevens, J., Brown, B. 1974. Occurrence of heavy metals in the blue shark (*Prionace glauca)* and selected pelagic in the N.E. Atlantic Ocean. *Mar. Biol.*, 26: 287–293.

32 – Cortés, E. 1999 Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.,* 56: 707-717.

References

33 – Aasen, O. 1966. Blahaien, *Prionace glauca* (Linnaeus), 1758. *Fisken Havet*, 1:1-15.

34 – Stevens, J. 1975. Vertebral rings as a means of age determination in the blue shark *(Prionace glauca* L.). *J. Mar. Biol. Assoc. U.K.*, 55: 657-665.

35 – Castro, J., Mejuto, J. 1995. Reproductive parameters of blue shark, *Prionace glauca*, and other sharks in the Gulf of Guinea. *Mar. Freshw. Res.,* 46: 967-973.

36 – Hazin, F., Boeckmann, C., Leal, E., Otsuka, K., Kihara, K. 1994. Reproduction of the blue shark, *Prionace glauca*, in the southwestern equatorial Atlantic Ocean. *Fish. Sci.,* 60: 487-491.

37 – Nakano, H., Seki, M. 2002. Synopsis of biological data on the blue shark, *Prionace glauca* Linnaeus. *Bull. Fish. Res*., 6: 18-55.

38 – Nakano, H. Makihara, M., Himazaki, K. 1985. Distribution and biological characteristics of the blue shark in the central North Pacific. *Bull. Fac. Fisher., Hokkaido Univ.,* 36(3): 99-113.

39 – Hazin, F., Lessa, R., Ishio, M., Otsuka, K., Kihara, K. 1991. Morphometric description of the blue shark, *Prionace glauca*, from the Southwestern equatorial Atlantic. *Tokyo Suisandai Kempo*, 78: 137-144.

40 – Harvey, J. 1989. Food habits, seasonal abundance, size, and sex of the blue shark, *Prionace gluaca*, in Montery Bay, California. *Calif. Fish & Game,* 75(1): 33-44.

41 – Walker, T. 1988, Mercury concentrations in edible tissues of elasmobranchs, teleosts, crustaceans and mollusks from south-eastern Australian waters. *Austr. J. Mar. Freshw. Res.,* 39: 39-49.

42 – Branco, V., Canario, J., Vale, C., Raimundo, J., Reis, C. 2004. Total and organic mercury concentrations in muscle tissue of the blue shark (*Prionace glauca* L.1758) from the Northeast Atlantic. *Mar. Pol. Bull.,* 49: 871–874.

43 – Davenport, S. 1995. Mercury in blue sharks and deepwater dogfish from around Tasmania. *Austr. Fish.,* 54 (3): 20–22.

44 – Storelli, M., Giacominelli-Stuffer, R., Marcotrigiano, G. 2001. Total mercury and methylmercury in tuna fish and sharks from the South Adriatic sea. *Ital. J. Food Sci.*, 13 (1): 101–106.

45 – Bowman, R., Stillwill, C., Michaels, W., Grosslein, M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dept. Commer., *NOAA Tech. Mem. NMFS NE*, 155: 1-137.

46 – Stevens, J. 1984. Biological observation on sharks caught by sport fishermen off New South Wales. *Aust. J. Mar. Freshw. Res.,* 35: 573–590.

47 – Bass, A., D'Aubrey, J., Kistnasamy, N. 1973. Sharks of the east coast of southern Africa. I. The genus *Carcharhinus* (Carcharhinidae). *Invest. Rep. Oceanogr. Res. Inst.* 33: 1-168.

48 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

49 – Rabehagasoa, N., Lorrain, A., Bach, P., Potier, M., Jaquemet, S., Richard, P., Ménard, F. 2012. Isotopic niches of the blue shark *Prionace glauca* and the silky shark *Carcharhinus falciformis* in the southwestern Indian Ocean. *Endang. Spec. Res*., 17: 83-92.

50 – Jolly, K.A., da Silva, C., Attwood, C.G. 2013. Age, growth and reproductive biology of the blue shark *Prionace glauca* in South African waters. *Afr. J. Mar. Sci., 35*(1): 99-109.

51 – Biton, S. 2015. Biologie, écologie et conservation du requin peau bleue (*Prionace glauca*) et du requin mako (*Isurus oxyrinchus*) en Atlantique nord-est. Thèse doctorat Océanographie, Université de Marseille. 20 Novembre 2015.

52 – Calich, H.J., Campana, S.E. 2015. Mating scars reveal size in immature female blue shark *Prionace glauca. J. Fish Biol.*, 86 (6): 1845-1851.

53 – Vandeperre, F., da Silva, A.A., Fontes, J., Dantos, M., Santos, S.S., Afonso, P. 2014. Movements of Blue Sharks (*Prionace glauca*) across their life history. *PLOS one*, 9(8): e103538.

54 – Vandeperre, F., da Silva, A.A., Santos, M., Ferreira, R., Bolten, A.B., Santos, R.S., Afonso, P. 2014. Demography and ecology of blue shark (*Prionace glauca*) in the central North Atlantic. *Fish. Res.*, 153: 89-102.

55 – Mas, F., Forselledo, R., Domingo, A. 2014. Length-Length relationships for six pelagic shark species commonly caught in the southwestern Atlantic Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 70(5): 2441-2445.

56 - Montealegre-Quijano, S., Cardosos, A.T.C., Silva, R.Z., Kinas, P.G., Vooren, C.M. 2014. Sexual development, size at maturity, size at maternity and fecudity of the blue shark *Prionace glauca* (Linnaeus, 1758) in the Southwest Atlantic. *Fish. Res.*, 160: 18-32.

57 – Verghese, S.P., Unnikrishnan, N., Deepak, K.G., Ayoob, A.E. 2017. Size, sex and reproductive biology of seven pelagic sharks in the esatern Arabian Sea. *J. Mar. Biol. Assoc. UK,* 97(1): 181-196.

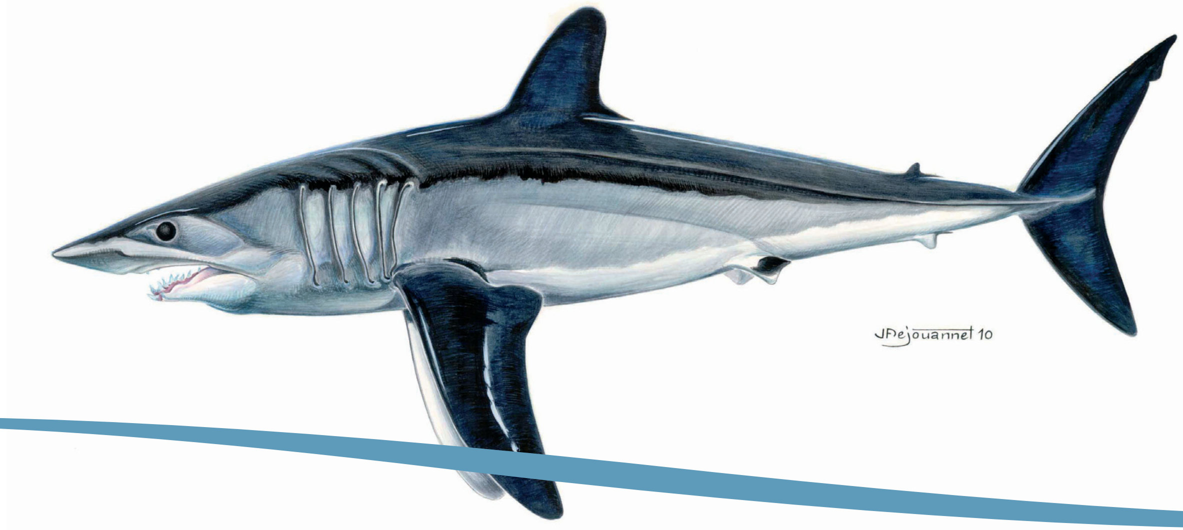
58 – Bustamante, C., Bennett, M.B. 2013. Insights into the reproductive biology and fisheries of two commercially exploited species, shortfin mako (*Isurus oxyrinchus)* and blue shark *(Prionace galuca)* in the south-east Pacific Ocean. *Fish. Res.,* 143: 174-183.

59 – Clarke, S.C., Harley, S., Hoyle, S.D., Rice J.S., 2013. Population trends in Pacific Oceanic sharks and the utility of regulations on shark finning. *Conserv. Biol.,* 27(1): 197-209.

60 – Vögler, R., Beier, E., Ortega-Garcia, S., Santana-Hernandez, H., Valdez-Flores, J.J. 2012. Ecological patterns, distrtibution and populations stucture of *Prionace glauca* in the tropical-subtropical transition zone of the northeastern Pacific. *Mar. Environ. Res*., 73: 37-52.

61 – Au, D.W., Smith, S.E., Show, C. 2015. New abbreviated calculation for measuring intrinsic rebound potential inexploited fish population - example for sharks. *Can. J. Fish. Aquat. Sci*., 72: 767-773.

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA



FAO code	Scientific name. English name	IUCN. Red List. Global assessment	IUCN. Red List. Regional assessments	CMS	Barcelona Convention	GFCM
SMA	*Isurus oxyrinchus.* Shortfin mako	VU (2009)	VU : NEA CR : MED NT : ENP VU : IWP	App. II + MoU	App. II (2012)	35/2012/7B 36/2012/3

Biology

	396 estimated: 408 [1] 396.2 [2] [25]	396 estimated: 408 [1]	396 estimated: 408 [1]	396 estimated: 408 [1]	396 estimated: 408 [1] 350.7 [2] [26]
	commonly to 207 [8]	commonly to 207 [8]	commonly to 207 [8]	commonly to 207 [8]	commonly to 207 [8]
	505.8 [9]	505.8 [9]	505.8 [9]	505.8 [9]	505.8 [9]

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA

Age & growth

	Atlantic Ocean	Ref.	Mediterranean Sea	Ref.	Indian Ocean	Ref.	West Pacific	Ref.	East Pacific	Ref.
L∞ for female in cm	L∞=366 FL L∞=345 FL L∞=247.75	10 10-11 38			L∞=285.4	41-44	L∞=732.41 FL L∞=403.62 FL L∞=349 FL L∞=308.3 FL L∞=239.4 PCL	15 10-16 17 24 50	L∞=321 T L∞=411 TL	2-12 13
K for female /year	k=0.087 k=0.203 k=0.11	10 10-11 38			k=0.113	41-44	k=0.0154 k=0.040 k=0.155 k=0.09 k=0.25	15 10-16 17 24 50	k=0.072 k=0.05	2-12 13
t_o for female in years							t_0=-10.79 t_0=-5.27 t_0=-1.97	15 10-16 17	t_0=-3.75 t_0=-4.7	2-12 13
L∞ for male in cm	L∞=253 FL L∞=302 FL L∞=247.75	10 10-11 38			L∞=285.4	41-44	L∞=302.16 FL L∞=321.8 FL L∞=267 FL L∞=231 FL L∞=274.4 PCL	15 10-16 17 24 50	L∞=321 T L∞=411 TL	2-12 13
K for male /year	k=0.125 k=0.266 k=0.11	10 10-11 38			k=0.113	41-44	k=0.0524 k=0.049 k=0.312 k=0.16 k=0.19	15 10-16 17 24 50	k=0.072 k=0.05	2-12 13
t_o for male in years	t_0=-1	11					t_0=-9.04 t_0=-6.07 t_0=-0.95	15 10-16 17	t_0=-3.75 t_0=-4.7	2-12 13
Longevity in years	45 estimated 32 (females) 29 (males) 31.5 15 (217 cm)	1-2 10 10 38 39	45 estimated	1-2	45 estimated	1-2	45 estimated 28 (females) 29 (males)	1-2 15 15	45 estimated 38 22	1-2 12 46
Maximum size TL in cm	396 396.2 408 estimated	2 25 1	396 408 estimated	2 1	396 408 estimated	2 1	396 408 estimated	2 1	396 408 estimated 350.7	2 1 26
Common size (FL) in cm	207	8	207	8	207	8	207	8	207	8
Maximum weight in kg	505.8	9	505.8	9	505.8	9	505.8	9	505.8 600 (fem. 373 Cm)	9 46

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA

Reproduction

	Atlantic Ocean	Ref.	Mediterranean Sea	Ref.	Indian Ocean	Ref.	West Pacific	Ref.	East Pacific	Ref.
Female maturity size in cm	275-293 298 273 275 FL 270-300	1 7 10 22	275-293 270-300	1 22	275-293 270-300 273 250 FL 266 TL (50%)	1 22 7 41-44 43	275-293 280 273 275-285 278 270-300	1 3 7 18 20 22	275-293 273 270-300	1 7-13 22
Female maturity age in years	18 7 9.8	10 10-11 38			15	41	19.1-21 18-19 16	15 10-17 24	7-8 15	12 13
Male maturity size in cm	203-215 185 FL 180 FL 200-220	1 10 21 22	203-215 200-220	1 22	203-215 200-220 190 FL 189 TL (50%)	1 2 41-44 43	203-215 200-220 195 180-185 FL 210	1 22 3 18 20	203-215 200-220 180 180-195 190.3 TL (50%)	1 22 13-14 20 48
Male maturity age in years	8 3 9.8	10 10-11 38			7	41	6.9-9 13-14 6	15 10-17 24	7-8 7	12 13
Birth size TL in cm	60-70 70-90 70 60-110 60-70	1 2 7 23 32	60-70 70-90 70 60-110	1 2 7 23	60-70 70-90 70 60-110 60-70 74 #70	1 2 7 23 32 20 3	60-70 70-90 70 60-110 60-70	1 2 7 23 32	60-70 70-90 70 60-110 60.5	1 2 7 23 12
Sex ratio	1:1	21	1:1	21	1:1	21	1:1	21	1:1	21
Mode of development	ovoviviparous	21	ovoviviparous	21	ovoviviparous	21	ovoviviparous	21	ovoviviparous	21
Gestation period in months	15-18	1-7	15-18	1-7	15-18	1-7-41	15-18 23-25	1-7 20	15-18	1-7
Spawning & mating periods	late Winter to mid-Summer	1	late Winter to mid-Summer	1	late Winter to mid-Summer	1	late Winter to mid-Summer January to June	1 20	late Winter to mid-Summer	1
Fecundity: number of embryos per litter	4-30 (most. 10-18) 4-25 9-14	1 7 5-7	4-30 (most. 10-18) 4-25 25-30	1 7 7-27	4-30 (most. 10-18) 4-25 9-14 <25	1 7 5-7-44 41	4-30 (most. 10-18) 4-25 9-15 4-16	1 7 20 3	4-30 (most. 10-18) 4-25 2-16	1 7 12
Nursery ground					juveniles use outer continental shelf, slope, canyons and oceanic waters	42			coastal waters	48

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA

Conversion factors

	Atlantic Ocean	Ref.	Mediterranean Sea	Ref.	Indian Ocean	Ref.	West Pacific	Ref.	East Pacific	Ref.
Length / Weight relationships	$W=1.193*10^{-6}*TL^{3.46}$ $W= 1.47*10^{-5}*PCL^{2.95}$ $W=5.2432*10^{-6}*FL^{3.1407}$ $W=7.299*TL(m)^{3.224}$	1-4 1-5 6 7			$W= 1.47*10^{-5}*PCL^{2.95}$ $W=0.349*10^{-4}*FL^{2.7544}$	1-5 41	$W=4.832*10^{-6}*TL^{3.10}$ $W= 5.755*10^{-6}*TL^{3.06}$	1-3 3-31		
Wet weight / dressed weight ratio										
TL / FL	FL= 0.9286*TL -1.7101 FL=0.972TL - 9.36 TL= 1.02FL + 11.75 TL=0.0 + 1.127*FL	6 20 20 40					FL=0.918TL - 2.078 FL=0.952 + 0.890TL	15 20		
TL/PCL	FL=5.292 + 1.069*PCL	40					PCL= 0.784+0.816TL PCL=0.84TL - 2.13	20 24		
Fins / carcass ratios	FW/BW=3.14	33	FW/BW=3.14	33	FW/BW=3.14	33	FW/BW=3.14	33	FW/BW=3.14	33
Stables isotopes N^{15} & C^{14}	iso. Ratio 5.2	36								

Population Dynamics

	Atlantic Ocean	Ref.	Mediterranean Sea	Ref.	Indian Ocean	Ref.	West Pacific	Ref.	East Pacific	Ref.
Stock delineation/range										
Natural mortality	0.150	51					0.155 fishing mortality focus in immature stages catch rate declining 7%/year	51 45 49	fishing mortality focus in immature stages catch rate declining 7%/year	45 49
Stepness										
Intrinsic rate of increase (λ or r) (year[-1])										
Intrinsic rebound potential ($r_{z(MSY)}$)										
Trophic level	4.3 5.0	19 36	4.3	19	4.3	19	4.3	19	4.3	19

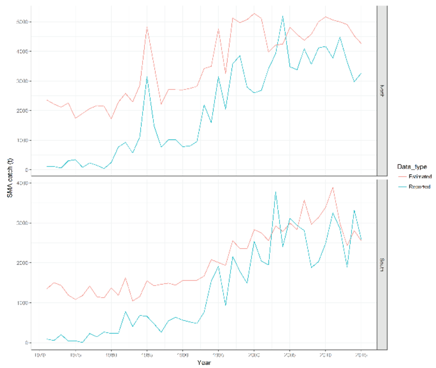
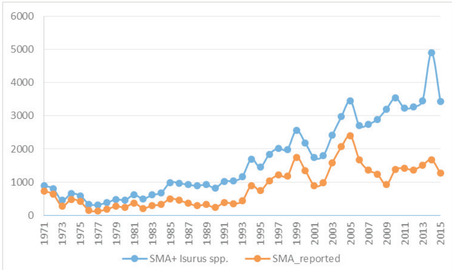
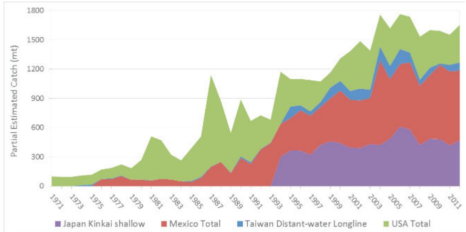
Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean	
			West Pacific Ocean (WCPFC)	East Pacific Ocean (IATTC)
Stock structure	ICCAT assumes that there are three different shortfin mako stocks in the Atlantic: North Atlantic and South Atlantic separated at 5ºN latitude, and the Mediterranean Sea as a separate stock.	IOTC assumes a single stock of shortfin mako shark in the Indian Ocean.	There is evidence for two stocks: North and South.	No information available
Fishery and Catches	The first official catch records for shortfin mako shark in ICCAT dates back to 1971 for Northern and Southern stocks and 1997 for the Mediterranean. For the Northern stock, the official catch statistics increased up to around 3,000 t in 1985, then decreased to around 1,000 t in the period 1986-1992, and since then increased until the highest observed record of around 5,000 in 2004. Since then, official catches fluctuated between 3,000 t. and 4,000 t. In the Southern stock a slightly different trend is observed, showing a continuous increasing trend since the beginning of the time series to reach the highest observed record of around 3,500 in 2003. Since then, official catches fluctuated between 2,000 t. and 3,000 t. The official recorded catches for the Mediterranean have been lower than 10 t with the exception of 17 and 10 tonnes in 2005 and 2006, respectively. The ICCAT official catches have suffered major revision since the last assessment (2012), and were considered to be acceptable for use in the assessment models. As such, the extensive historical calculations (for multiple fleets) carried out for the 2012 assessment based on ratios of shortfin mako to a variety of target species were not repeated for the current assessment (conducted in 2017). This exercise was only performed for the historical catches of some specific fleets where complete series were missing. An alternative hypothesis for the reconstruction of time series of catches for north and south Atlantic stocks of shortfin mako was presented based on a methodology used in an EU project (EASME/EMFF/2016/008-SC01) (Figure 1). These estimations were used in alternative model runs for each of the models.	It appears that significant catches of sharks have gone unrecorded in several countries. Furthermore, many catch records probably under-represent the actual catches of shortfin mako shark because they do not account for discards (*i.e.*, do not record catches of sharks for which only the fins are kept or of sharks usually discarded because of their size or condition), they might reflect dressed weights instead of live weights, and there may be species identification issues. FAO also compiles landings data on elasmobranchs, but the statistics are limited by the lack of species-specific data and data from the major fleets. There is little information on the fisheries prior to the early 1970's, and some countries continue to not collect shark data while others collect but do not report it to IOTC. The catch estimates for shortfin mako shark are highly uncertain and few Members countries have reported detailed data on shortfin mako shark catches. As such, IOTC official catches are considered to represent only a portion of total removals. Officials catch records for shortfin mako shark in IOTC have increased since 1971 up to the highest records in the series of around 2,200 t. in 2005, and since then it slightly decreased to values between 1,000 and 1,500 in the last years. Taking into account the records at the mako genus level (*Isurus* spp.) this increases to around 3,500 t in the most recent years, with the exception of 2014 where catches were close to 5,000 t. (Figure 1).	**Fishery and Catches**: It appears that significant catches of sharks have gone unrecorded in several countries. Furthermore, many catch records probably under-represent the actual catches of shortfin mako because they do not account for species identification, discards (i.e. do not record catches of sharks for which only the fins are kept or of sharks usually discarded because of their size or condition) or they reflect dressed weights instead of live weights. FAO also compiles landings data on elasmobranchs, but the statistics are limited by the lack of species-specific data and data from the major fleets. There is little information on the fisheries prior to the early 1990's, and some countries continue not to collect shark data while others do collect it but do not report it to WCPFC. The catch estimates for shortfin mako are highly uncertain and few Members countries have reported detailed data on shortfin mako catches. For the North stock the estimated time series provide an idea of recent catch history for many of the main fleets, but estimates of total catch for shortfin mako in the North Pacific Ocean are incomplete. Data are lacking for several significant fishing nations (e.g., Korea and China) and specific fleets (e.g., Taiwan small-scale longline, Japan distant-water longline and Japan RTV). Estimates are difficult to derive because discards are often not recorded and retained catch data are available with low quality. Shark species were typically not identified to the species level until recent years. Given that trends in catch cannot be derived from the incomplete catch information provided, the catch time series were not considered for the purposes of providing stock status information.	No information available

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA

Stock Status Executive Summary

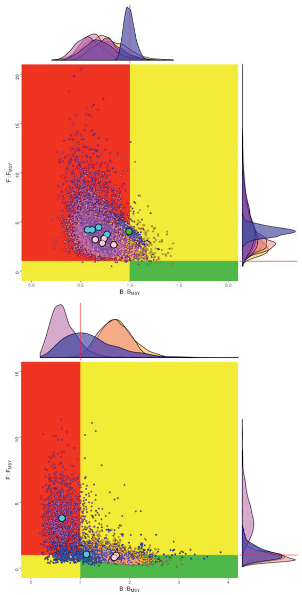
	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean	
			West Pacific Ocean (WCPFC)	East Pacific Ocean (IATTC)
Fishery and Catches	 Figure 1 - Time series of reported (Task I) and estimated shortfin mako shark (SMA) catches, between 1971 and 2015, for the North and South Atlantic stocks.	 Figure 1. Time series of the IOTC official catch statistics for shortfin mako (orange line) and shortfin mako plus sharks reported under the mako genus (blue line).	 Figure 1. Partial catch estimates of shortfin mako shark for several fleets/nations operating in the North Pacific Ocean. Catch estimates are not available for some major fisheries including Taiwan small-scale longline, Japan distant-water longline, and China's and Korea's longline fleets. Trends in shortfin mako catch cannot be derived from the data provided given the data are incomplete and for individual fisheries/nations they may not reflect the entire history of the fishery.	

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean: West Pacific Ocean (WCPFC)	Pacific ocean: East Pacific Ocean (IATTC)
State of the Stock	The last full stock assessment for northern and southern stock of shortfin mako shark were conducted in 2017, applying Bayesian surplus production model, catch-only Monte-Carlo method and length based age structured methods to the available catch data through 2015. Various series of CPUE were available (4 for Northern stock and 5 for Southern stock). Considerable progress was made since the last assessment, especially in the North, with the integration of new data sources (in particular size data and sex-specific information) and modelling approaches (in particular model str ucture). Uncertainty in data inputs and model configuration were explored through sensitivity analysis. The production models in the South had difficulty fitting the increasing trends in the CPUE series combined with increasing catches. The results obtained from these models for this region were implausible as there are conflicts between the data and model assumptions. Management advice was thus based on the CMSY model in the South. The SCRS considers the results for the South Atlantic to be highly uncertain owing to the conflict between catch and CPUE data. *Biomass:* For the Northern stock the biomass in 2015 was estimated to be below or at the biomass at MSY and, thus, most models suggested that the stock is overfished and that biomass is estimated to be below the ICCAT Convention Objective. For the Southern stock the combined probability of the biomass being below biomass at MSY was 32.5% (Figure 2). *Fishing mortality:* For the Northern stock fishing mortality rate in 2015 was estimated to be above the fishing mortality rate at MSY and, thus, it was concluded that overfishing was occurring. For the Southern stock the combined probability of the fishing mortality rate being above the fishing mortality rate at MSY was 41.9% (Figure 2).	Two standardized CPUE series have been provided for some fleets, namely from Japan and Portugal. There remains considerable uncertainty about the relationship between abundance and the standardized CPUE series from the Japanese longline fleet, and about the total catches over the past decade. The standardized Japanese CPUE trend suggest that the longline vulnerable biomass has declined from 1994 to 2003, and has been increasing since then (Kimoto et al., 2011). The standardized Portuguese CPUE index shows some variability for the period studied 1999-2011 with no clear trend (Coelho et al., 2012). No quantitative stock assessment for shortfin mako shark has been carried out by IOTC. However, shark Ecological Risk Assessment for longline and purse seiner was undertaken in 2012 (Murua et al., 2012). Based on that work, shortfin mako shark was ranked as having low productivity among the shark species considered but also showed high susceptibility to the longline gear while the susceptibility was very low for purse seines. Thus, the shortfin mako shark vulnerability to the longline gear was highest (rank 1 out of 16 species) because it is characterized by a combination of low productivity and high susceptibility. Although the shortfin mako shark for the purse seines was ranked as 3rd in the ERA, the vulnerability (due to limited availability to the fishery) was very low.	No quantitative stock assessment for shortfin mako shark has been carried out by WCPFC. In 2015 a stock indicator analysis was conducted, however, stock status could not be determined due to lacking conformation on important fisheries, the untested validity of indicators for determining stock status, and conflicts in the available data.	No information available

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean	
			West Pacific Ocean (WCPFC)	East Pacific Ocean (IATTC)
State of the Stock	 Figure 2 – Top panel: Stock status (2015) of North Atlantic shortfin makos based on Bayesian production models (4 BSP2JAGS and 4 JABBA runs) and 1 length-based age-structured model (SS3). The clouds of points are the bootstrap estimates for all model runs showing uncertainty around the median point estimate for each of nine model formulations (BSP2JAGS: solid pink circles; JABBA: solid cyan circles; SS3: solid green circle). Bottom panel: Stock status (2015) of South Atlantic shortfin makos based on a Bayesian production model (BSP2JAGS) and a catch-only model (CMSY). The clouds of points are the bootstrap estimates for all models combined showing uncertainty around the median point estimate for each of four model formulations (BSP2JAGS: solid pink circles; CMSY: solid cyan circles). The density plots show the marginal frequency distributions of the bootstrap estimates for each model.			

Isurus oxyrinchus (Rafinesque, 1810) Shortfin mako – FAO code: SMA

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean: West Pacific Ocean (WCPFC)	Pacific ocean: East Pacific Ocean (IATTC)
Recommendation	For the North Atlantic stock if the Commission wishes to stop overfishing immediately and achieve rebuilding by 2040 with over a 50% probability, the most effective immediate measure would be a complete prohibition of retention. Additional recommended measures that can potentially further reduce incidental mortality include time/area closures, gear restrictions, and safe handling and best practices for the release of live specimens (since post release survival can reach 70%). The SCRS emphasized that there will be a need for CPCs to strengthen their monitoring and data collection efforts to monitor the future status of this stock, including but not limited to total estimated dead discards and the estimation of CPUE using observer data. For the South Atlantic stock, given the uncertainty in stock status, the large fluctuations in catch, the high intrinsic vulnerability of this species, and the depleted status for the North Atlantic stock, the SCRS recommended that until this uncertainty is reduced, catch levels should not exceed the minimum catch in the last five years of the assessment (2011-2015; 2,001 t with catch scenario C1).	Maintaining or increasing effort will probably result in further declines in biomass, productivity and CPUE. The impact of piracy in the western Indian Ocean has resulted in the displacement and subsequent concentration of a substantial portion of longline fishing effort into certain areas in the southern and eastern Indian Ocean. It is therefore unlikely that catch and effort on shortfin mako shark will decline in these areas in the near future, and may result in localised depletion. The following should also be noted: - The available evidence indicates risk to the stock status at current effort levels. - The two primary sources of data that drive the assessment, total catches and CPUE are highly uncertain and should be investigated further as a priority. - Mechanisms need to be developed by the Commission to encourage CPCs to comply with their reporting requirement on sharks.	Managers should consider the undetermined stock status of shortfin mako shark in the North Pacific when developing and implementing management measures. It is recommended that data for missing fleets be developed for use in the next stock assessment scheduled for 2018 and that available catch and CPUE data be monitored for changes in trends. It is further recommended that data collection programs be implemented or improved to provide species-specific shark catch data for fisheries in the North Pacific.	

	Northen stock	Southen stock
Assessment Year	2017	
Data available	2015	
MSY		
B_{2015}/B_{MSY}	0.57-0.95	0.65-1.75
F_{2015}/F_{MSY}	1.93-4.38	0.86-3.67

	Indian Ocean
Assessment Year	-
Data available	-
Yield 2013	1,510
Yield 2014	1,672
Yield 2005	1,268
Stock status	Not assessed
MSY	-
B/B_{MSY}	-
F/F_{MSY}	-

Stock Status Executive Summary

	Atlantic Ocean and Mediterrenean Sea (ICCAT)	Indian Ocean (IOTC)	Pacific ocean: West Pacific Ocean (WCPFC)	Pacific ocean: East Pacific Ocean (IATTC)
Sources of Information	Anon. 2017a. Report of the 2017 ICCAT shortfin mako data preparatory meeting. 28-31 March 2017. Madrid, Spain. 52 pp. Anon. 2017b. Report of the 2017 ICCAT shortfin mako stock assessment meeting. 12-16 Junho 2017. Madrid, Spain. 64 pp. Anon. 2017c. Report of the Standing Committee on Research and Statistics (SCRS). 2-6 October, Madrid, Spain. 465 pp.	Coelho R., M.N. Santos and P.G. Lino. 2012. Update of the standardized CPUE series for major shark species caught by the Portuguese pelagic longline fishery in the Indian Ocean. IOTC–2012–WPEB08–29. IOTC–SC15 2012. Report of the Fifteenth Session of the IOTC Scientific Committee. Mahé, Seychelles, 10–15 December 2012. IOTC–2012–SC15–R[E]: 288 pp. Kimoto A., Y. Hiraoka, T. Ando and K. Yokawa. 2011. Standardized CPUE of shortfin mako shark (Isurus oxyrinchus) caught by Japanese longliners in the Indian Ocean in the period between 1994 and 2010. IOTC-2011-WPEB07-34. Murua H., R. Coelho, M.N. Neves, H. Arrizabalaga, K. Yokawa, E. Romanov, J.F. Zhu, Z.G. Kim, P. Bach, P. Chavance, A. Delgado de Molina and J. Ruiz. 2012. Preliminary Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC). IOTC–2012–WPEB08–31.	Arrizabalaga, H., de Bruyn, P., Diaz, G.A., Murua, P., Chavance, P., Delgado de Molina, A., Gaertner, D., Ariz, J. and Ruiz, J. 2011. Productivity and susceptibility analysis for species caught in Atlantic tuna fisheries. Aquatic Living Resources 24: 1-12. Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Neves, M., Ribera, M. and Simpfendorfer, C. 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. Aquatic Living Resources 23: 25-34. ISC. 2015. Indicator-based analysis of the status of shortfin mako shark in the North Pacific Ocean. 15th Meeting of the ISC, 15–20 July 2017, Kona, Hawaii, U.S.A. ISC15/SHARKWG Annex 12. 33 pp. Kirby, D.S. and Hobday, A. 2007. Ecological Risk Assessment for the Effects of Fishing in the Western and Central Pacific Ocean: Productivity-Susceptibility Analysis. Third Regular Session of the Scientific Committee. WCPFC-SC3-EB SWG/WP-1. Murua H., R. Coelho, M.N. Neves, H. Arrizabalaga, K. Yokawa, E. Romanov, J.F. Zhu, Z.G. Kim, P. Bach, P. Chavance, A. Delgado de Molina and J. Ruiz. 2012. Preliminary Ecological Risk Assessment (ERA) for shark species caught in fisheries managed by the Indian Ocean Tuna Commission (IOTC). IOTC–2012–WPEB08–31.	

General Recommendations

Data collection

In general, there is a scarcity of data and limited data availability for major fleets and countries in tuna-RFMOs. Attending to historical data, several countries were not collecting fishery statistics, especially in years prior to the development of tuna and tuna-like fisheries in early 1970s. It is thought that important catches of sharks might have gone unrecorded in many countries and fleets. This problem worsens in the case of developing states and, especially, for historical data. Furthermore, many catch records probably under-represent the actual catches of shortfin mako because they do not account for discards (i.e., do not record catches of sharks for which only the fins are kept or of sharks usually discarded because of their size, condition or low value) or they may reflect dressed weights instead of live weights.

Typically, catches of sharks were not recorded by gear and/or species, and often are not disaggregated at the required level for each species by area and fleet. Major shark species such as blue shark and shortfin mako shark have been better reported that other species but still there are inconsistencies and data gaps. Misidentification of shark species is also a common problem. The identification of sharks in port is usually compromised by the way in which the different species of sharks are processed before being landed. Generally, no indication is given on the type of processing that the different specimens underwent. Then, the identification of sharks unloaded as shark carcasses, shark fins or other shark products is difficult. The fins-attached policy adopted for some countries and fleets is improving this situation.

In order to improve the stock assessments of shortfin mako harvested in tuna-RFMO fisheries, the tuna-RFMOs also recommended that member countries submit the corresponding statistics of all fisheries capturing shortfin makos, including recreational and artisanal fisheries. Countries are required to report all catches of shortfin mako, including available historical data according to data reporting procedures of the specific RMFOs. Particular reporting requirements apply to shark species in each region. Countries are also urged to report steps taken to improve data collection. It is considered that for a correct assessment of the status of the stocks and management of those species a solid basis to estimate total removals (total catches including discards) is necessary.

The data available by flag in the public domain is scarce in RFMO countries. In some cases due to confidentiality issues it is difficult to get the basic fishery information regarding the fleet activity catching shortfin mako, especially for historical data. It is difficult to extract disaggregated and aggregated data for some fleets, especially for coastal fisheries. Attempts should be made to allow the Scientific Committees of the tuna-RFMOs to access the available data for improving stock assessments.

Observer programmes

In tuna-RFMOs, data is mostly reported as the nominal catch data (landings and discards by species, stock, gear, fleets and year) which is the basic information used in most stock assessments, but also data on catch/effort and size data are provided, which are more detailed in terms of time and geographic area information. Although the objectives of Observer Programs can vary widely, in general in the case of sharks their objective is to collect basic fishery statistics such as catch and effort data as well as to conduct biological sampling. Fishery observers therefore offer one of the few methods appropriate to obtain accurate location, catch and effort information for sharks caught in tuna fisheries.

Although the objectives of the observer programmes can be diverse, observer programs will generally require high or moderate levels of precision if the purpose of the observer program is to provide adequate information to improve fisheries stock assessments, endangered species protections, and ecosystem management. In tuna-RFMOs, when the goal is to monitor the total tuna catch and/or bycatch/discards, the coverage agreed range between 5 % and 20 %. As such, in relation to the estimation of shark catches, the different coverage agreed have a clear effect on the ability to obtain accurate data of both shark catch estimates and status (alive or dead) of sharks discarded.

Although the level of observer coverage for the estimation of shark mortality depends on species and fleets specific cases, it is important that the observer programme has the following characteristics:

- Sufficient coverage to provide statistically accurate estimates of catch, bycatch and discards. A preliminary aim is to have observer coverage of 20% or above, noting, however, that currently even the 5% coverage is not achieved by the majority of the countries and fleets that operate under the various tuna-RFMOs.
- Sufficient spatial/temporal coverage of the main fleets.
- Sufficiently trained observers: to develop an observer training programme in order for observers to be sufficiently competent to record the data required by the tuna-RFMOs for management purposes.
- Species identification guides: species identification is a major problem with regard to shark bycatch data collection and, thus, species identification guides need to be available.
- Data forms: harmonized data forms to collect the shark bycatch and discard information (sex, size, additional biological information as reproductive stage, and condition status: alive or dead upon retrieval of the gear and at time of discarding).
- Database: database for recording of all observer data as well as well-designed protocols for accessing the data, taking into account data confidentiality and ownership.

Alternative ways to improve the collection of fishery statistics could be the use of "self-sampling" and Electronic Monitoring (EM).

Self-sampling methodology uses fisheries scientists and/or technicians to collect information on commercial catches

General Recommendations

which is a cost effective method. Therefore, currently there is ongoing effort worldwide to develop programmes to use fishers to self-sample their catches. Such programmes have generally two major objectives: i) reduce costs and increase efficiency on the collection of commercial fishery data; and, ii) to involve fishing industry in the assessment process by having them work closely with the scientists. Thus, the overall purpose of the programmes is to improve data collection and consequently reduce stock assessments uncertainty.

One of the major recognized problems with self-sampling is that some scientists do not see the data as fully scientific or valid. In order to shift this attitude it is necessary to properly verify the usability, high quality of data and cross-validated the data collected by self-sampling with data compiled by traditional observer programs. Moreover, for a successful program of self-sampling the willingness and collaboration from industry is necessary. Therefore, they should rely on the development of guidelines of best practice and general recommendations to assist in the initiation and execution of self-sampling and self-reporting programmes. Moreover, such schemes should rely on good collaboration between scientists and fishers, aiming to define clear aims and generate high quality data.

Confidentiality is another important issue that should be assured on these programmes, namely by ensuring that when used the data is presented in an anonymous and aggregated way. This is particularly important as some data sets might be used for enforcement purposes, and therefore might endanger trust between scientists and fishers.

Electronic monitoring (EM) systems are being used in some fisheries as an alternative, or a complement to human observers. The EM systems consist of a centralized computer combined with several sensors and cameras, which can be deployed on fishing vessels to monitor a range of fisheries issues, including: fishing location, catch, catch handling, fishing methods, protected species interactions, and mitigation measures. The efficacy of EM for monitoring issues varies according to fishing methods and other factors. Over the past decade, pilot studies have been carried out in more than 25 fisheries to test the efficacy of this technology, being involved different countries, gears and target species.

During 2012, the first trial with EM on a tropical tuna purse seine was performed in the Atlantic Ocean and this study suggested that EM is a viable tool for monitoring effort, set-type and tuna catch within the tropical tuna purse seine fishery. However, some limitations exist for the monitoring of the bycatch and especially for reliably estimation and identification of some shark species. Furthermore, observers constantly identified sharks to a higher taxonomic level, as 100 % of the shark species were identified by the observer, EM system provided limited identification (e.g. often only to family level). However, the problems observed with this first trial on the tuna purse seine fleet can be easily solved with some adjustments on the system such as the use of digital cameras and some modification on the crew catch handling behaviour.

Similar to the self-sampling programmes, the success of an EM program would depend on the good collaboration between fishers and scientist as it requires that the vessel owners and crew understand the importance of standardized catch handling protocols. EM systems are designed to be flexible enough to accommodate a variety of catch handling methods, but handling must be consistent and standardized in order to collect reliable data. For example, if a camera is installed above the discard handling area, and discarding handling is moved to another area of the vessel, the camera will no longer capture discarding events. This example illustrates the importance of having strong support from the vessel owners, officers and crew to achieve monitoring objectives.

It is also possible to apply such EM systems to gillnet and longline fleets. For example, a study on a gillnet fishery shows that EM offers opportunities for monitoring shark gillnet fishing activity. Overall, the high quality of imagery, the ability to identify most catch items, and no missing imagery in the data set, indicated that EM equipment was reliable and suitable for shark gillnet vessels. In the particular case of gillnet tuna fisheries, due to size of the fleet and the artisanal nature of the fisheries, it could be quite difficult a full-implementation of the EM sampling program. However, taking into account the complete lack of data and non existence of observers programs in gillnets tuna fisheries, the application of EM in a pilot observer vessels (100 % EM coverage of few vessels of the gillnet fishery) can be considered a suitable approach for collecting shark bycatch statistics on artisanal and coastal gillnet fisheries. In the case of longliners, it might be worthy and easier to implement such system.

Management measures

Management measures are essential when a given stock is seriously affected by the fishing activity and are aimed at limiting the impact of this activity. The election of a measure will depend on the stock status, on the behavior of the species, on the species being target or not, etc.

The main problem for pelagic shark's management is that there are few targeted fisheries. In the case of shortfin mako it can be considered that some of the longline fisheries catching sharks are targeting them, at least in some areas and seasons of the year.

In general for sharks, all tuna-RFMOs recommend that precautionary management measures are needed for stocks where there is the greatest biological vulnerability and conservation concern, and for which there are very few data. Taking into consideration the results of the modeling approaches used in the assessment, the associated uncertainty, and that maintaining or increasing effort will probably result in further declines in biomass and productivity, it can be recommended that the fishing mortality of shortfin mako should not be increased.

And for the application of these recommendations several management measures can be recommended, such as:

General Recommendations

TACs

Total allowable catches (TACs) are catch limits that are set for most significant commercial fish stocks, and is widely used as the main management measure for several exploited stocks. Although shortfin mako sharks are also caught as bycatch, there are fisheries directly targeting those sharks. In the case where the productivity of the stocks and the impact of the fisheries can be adequately assessed, the establishment of TACs can ensure these populations are kept at levels that do not significantly affect their productivity. This could be the case of shortfin mako shark stocks for which an assessment and management advice is provided (e. g. ICCAT case).

Spatial/temporal closures

Time and/or area closures have been widely used as management measures to prevent overfishing and to protect certain marine habitats. Although there are very few examples on the use of this kind of measures to reduce shark bycatch, the development of protected areas or time closures, focused on shark "hot spots" or in critical habitats (e.g. nursery grounds) might have great conservation potential. A measure of this kind must take into account the effect of effort reallocation to adjacent areas, as well as the possible reduction in target species catch.

However, for applying those measures it is first necessary to investigate possible spawning/nursery areas of great conservation potential. Until those studies are available the application of these types of management measures will not be possible and/or might result in choosing inappropriate areas. Moreover, while the monitoring, surveillance and control of this kind of regulations can be easily enforced in industrial fisheries (e.g., by using VMS systems), it is much more difficult for the artisanal fleets, typically smaller vessels without VMS systems implemented.

No retention polices

Shortfin mako shark is in most cases taken as a bycatch and, thus, the "no retention policies" described in the mitigation measures and post-release tables of the report would be applicable for this species. If a reduction of catch rates is advisable by the assessment and cannot be reached with TAC measures, it might be possible to do so with a reduction of the use of wire leaders/traces and/or shark lines as the use of those may imply targeting of sharks. Circle hooks might also mitigate post-release mortality of discards, even thought it has been shown that the catch/retention of sharks with circle hooks is higher. The trade-off between lower mortality versus higher retention for sharks when using circle hooks is not clear.

Finning

Finning is the practice of slicing off fins and dumping carcasses at sea. Although shark finning has been banned in the four main tuna-RFMOs, discussion is now focused on the enforcement of this regulation. Most of the current measures allow for a 5% shark fin to body weight ratio, but this ratio is highly dependent on the fin usage (primary fin sets vs all fins), on the species, on the type of processing of the fins (dried or fresh fins) and on the way the body weight is computed (whole, dressed, etc) and can therefore lead to finning going undetected. Because of those concerns, several nations have established the fins-attached policy, that besides the previously mentioned issues also addresses other issues such as difficulties in species identification for processed carcasses. This policy is now established for some particular fleets (e.g., EU fleets), as well as in one particular case within the tuna-RFMOs, specifically in IOTC for fleets that land fresh sharks. It would be highly advisable to promote and expand this measure within all tuna-RFMOs and for all fleets.

References

1 – Compagno, L.J.V. 2001. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Vol. 2. Bullhead, mackerel and carpet sharks (Heterodontiformes, Lamniformes and Orectolobiformes). *FAO Spec. Cat. Fish. Purp.*, 1(2): 1-269. Rome, FAO.

2 – Caillet, G., Martin, L., Kusher, D., Wolf, P., Welden, B. 1983. Preliminary studies on the age and growth of the blue, *Prionace glauca*, common thresher, *Alopias vulpinus*, and shortfin mako, *Isurus oxyrinchus*, sharks from California waters. In Prince ED & LM Pulos (eds). Proceedings of the International workshop on age determination of oceanic pelagic fishes: tunas, billfishes, and sharks. *NOAA Tech. Rep. NMFS,* 8: 179-188.

3 – Stevens, J. 1983. Observation on reproduction in the shortfin mako *Isurus oxyrinchus*. *Copeia,* 1983(1): 126-130.

4 - Guitart Manday, D. 1975. Las pesquerias pelagico-oceanicas de corto radio de accíon en la regíon noroccidental de Cuba. *Ser. Oceanol. Acad. Cienc. Cuba*, 31: 1-26.

5 – Cliff, G., Dudley, S., Davis, B. 1990. Sharks caught in the protective gillnets of Natal, South Africa. 3. The shortfin mako shark *Isurus oxyrinchus* (Rafinesque). *Sth Afric. J. Mar. Sci.*, 9: 115-126.

6 – Kohler, N., Casey, J., Turner, P. 1995. Length-weight relationships for 13 species of sharks from the western North Atlantic. *Fish. Bull.,* 93: 412-418.

7 - Mollet, H., Cliff, G., Pratt, H. Jr., Stevens, J. 2000. Reproductive biology of the female shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, with comments on the embryonic development of lamnoids. *Fish. Bull.,* 98: 299-318.

8 – Carpenter, K., Niem, V. 1998. The living marine resources of western central Pacific. Vol 2. Cephalopods, crustaceans, holothurians and sharks. FAO, Rome. 716 pp.

9 – Fishbase. 2017. *Isurus oxyrinchus.* http://fishbase.mnhn.fr/summary/Isurus-oxyrinchus.html

10 – Natanson, L., Kohler, N., Ardizzone, D., Cailliet, G., Wintner, S., Mollet, H. 2006. Validated age and growth estimates for the shortfin mako, *Isurus oxyrinchus*, in the North Atlantic Ocean. *Environ. Biol. Fish.,* 77: 367-383.

11 – Pratt, H.Jr., Casey, J. 1983. Age and growth of the shortfin mako, *Isurus oxyrinchus*, using four methods. *Can. J. Fisher. Aquat. Sci.,* 40(11): 1944–1957.

12 – Cailliet, G., Bedford, D. 1983. The biology of three pelagic sharks from California waters and their emerging fisheries: a review. *Cal. COFI Rep.* vol. XXIV.

13 - Ribot-Carballal, M., GalvánMagaña, G., Quiñónez-Velázquez, F. 2005. Age and growth of the shortfin mako shark *Isurus oxyrinchus* from the western coast of Baja California Sur, Mexico. *Fisher. Res.,* 76: 14-21.

14 – Conde, M. 2005. Aspectos de la biología reproductiva del tiburón mako *Isurus oxyrinchus* (Rafinesque 1810) en la costa occidental de Baja California Sur, México. B.Sc. dissertation, Universidad Autónoma de Baja California Sur, México. 72 pp.

15 – Bishop, S., Francis, M., Duffy, C., Montgomery, J. 2006. Age, growth, maturity, longevity and natural mortality of the shortfin mako (*Isurus oxyrinchus*) in New Zealand waters. *Mar. Freshw. Res.*, 57:143–154.

16 – Hsu, H. 2003. Age, growth, and reproduction of shortfin mako, *Isurus oxyrinchus* in the northwestern Pacific. MS thesis, National Taiwan Ocean Univ., Keelung, Taiwan. 107 pp. [In Chinese].

17 – Chan, R. 2001. Biological studies on sharks caught off the coast of New South Wales. PhD Thesis, University of New South Wales, Sydney, Australia. 323 pp.

18 – Francis, M., Duvy, C. 2005. Length at maturity in three pelagic sharks (*Lamna nasus, Isurus oxyrinchus and Prionace glauca*) from New Zealand. *Fish. Bull.*, 103: 489-500.

19 – Cortés, E. 1999 Standardized diet compositions and trophic levels of sharks. *ICES J. Mar. Sci.*, 56: 707-717.

20 – Joung, S.J., Hsu, H.H. 2005. Reproduction and embryonic development of the shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, in the northwestern Pacific. *Zool. Stud.*, 44(4): 487-496.

21 – Maia, A., Queiroz, N., Cabral, H., Santos, A., Correia, J. 2007. Reproductive biology and population dynamics of the shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, off the southwest Portuguese coast, eastern North Atlantic. *J. Appl. Ichthyol.*, 23: 246-251.

22 – Campana, S., Marks, L., Joyce, W. 2005. The biology and fishery of shortfin mako sharks (*Isurus oxyrhinchus*) in Atlantic Canadian waters. *Fisher. Res.*, 73: 341-352.

23 – Gilmore, R. 1993. Reproductive biology of lamnoid sharks. *Environ. Biol. Fish.*, 38(1-3): 95-114.

24 – Semba, Y., Nakano, H., Aoki, I. 2009. Age and growth analysis of the shortfin mako, *Isurus oxyrinchus*, in the western and central North Pacific Ocean. *Environ. Biol. Fish.*, 84: 377–391.

25 – Bigelow, H., Schroeder, W. 1948. Sharks. In Fishes of the western North Atlantic. Mem. Sears Found. Mar. Res., Yale Univ., No. I (Part I): 59-546.

26 – Applegate, S. 1977. A new record-size bonito shark, *Isurus oxyrinchus* Rafinesque, from southern California. *Calif. Fish Game,* 63:126-129.

27 – Sanzo, L. 1912. Embrione di Carcharodon Rondeletii M. Hie. (?) con particolare disposizione del sacco vitellino. *Regio Comitate Talassografico Italiano, Memoria*, 11: 1-12.

28 – Suk, S., Smith, S., Raon, D. 2009. Bioaccumulation of mercury in pelagic sharks from the northeast Pacific Ocean. *Calif. COFI Rep.*, 5: 172-177.

References

29 – Walker, T. 1988. Mercury concentrations in edible tissues of elasmobranchs, teleosts, crustaceans and mollusks from south-eastern Australian waters. *Austr. J. Mar. Freshw. Res.*, 39: 39-49.

30 – Bowman, R., Stillwill, C., Michaels, W., Grosslein, M. 2000. Food of Northwest Atlantic Fishes and Two Common Species of Squid. US Dept. Commer., *NOAA Tech. Mem. NMFS NE*, 155: 1-137.

31 – Stevens, J. 1984. Biological observation on sharks caught by sport fishermen off New South Wales. *Aust. J. Mar. Freshw. Res.*, 35: 573–590.

32 – Bass, A., D'Aubrey, J., Kistnasamy, N. 1975: Sharks of the east coast of Southern Africa. IV. The Families Odontaspidae, Scapanorhynchidae, Isuridae, Cetorhinidae, Alopiidae, Orectolobidae and Rhiniodontidae. *Invest. Rep. Oceanog. Res. Inst.*, 39: 1-102.

33 – Biery, L., Pauly, D. 2012. A global review of species-specific shark fin to body mass ratios and relevant legislations. *J. Fish. Biol*., 80: 1643-1677.

34 – Rogers, P.J., Huveneers, C., Page, B., Hamer, D.J., Goldsworthy, S.D., Mitchell, J.G., Seuront, L. 2012. A quantitative comparison of the diets of sympatric pelagic sharks in gulf and shelf ecosystemsn off southern Australia. *ICES J. Mar. Sco. 69 (8*): 1382-1393.

35 – Biton Porsmoguer, S., Banaru, D., Béarez, P., Dekeyser, I., Fornelino, M.M. 2014. Unexpected headless and tailless fish in the stomach contente of shortfin mako *Isurus oxyrinchus. PLOS on*e, 9(2): e88488.

36 - Biton Porsmoguer, S., 2015. Biologie, écologie et conservation du requin peau bleue (Ptionace glauca) et du requin makp *(Isurus oxyrinchus*) en Atlantique nord-est. Thèse doctorat Océanographie, Université de Marseille. 20 Novembre 2015.

37 – Gorni, G., Loibel, S., Goitein, R., Amorim, A.F. 2012. Stomach contents analysis of shortfin mako (*Isurus oxyrinchus*) caught off southeren Brazil: a Baysesina analysis. *Collect. Vol. Sci. Pap. ICCAT,* 68(5): 1933-1937.

38 – Kone, A., N'Da, K., Kouassi, S.K., Agnissan, J.P. 2014. Dynamique de la population exploitée de deux requins: *Sphyrna zygaena* (Linnaeus, 1758) et *Isurus oxyrinchus* (Rafinesque, 1809) des côtes ivoiriennes. *Internat.l J. Biol.l & Chem. Sci*., 8(4).

39 – Doño, F., Montealegre-Quijanao, M., Domingo, A., Kinas, P.G. 2104. Bayesian age and growth analysis of the shortfin mako shark *Isurus oxyrinchus* in the Western South Atlantic Ocean using a flexible model. *Environ. Biol. Fish.*, 98(2): 517-533.

40 – Mas, F., Forselledo, R., Domingo, A. 2014. Length-Length relationships for six pelagic shark species commonly caught in the southwestern Atlantic Ocean. *Collect. Vol. Sci. Pap. ICCAT*, 70(5): 2441-2445.

41 – IOTC. 2014. Proposition: Résumé exécutif: Requin-taupe bleu. 17th Scientific Committee, 8-12 December 2014, Victoria, Seychelles. IOTC document IOTC-2014-SC17-ES20(F): 7 pp.

42 – Rogers, P.J., Huveneers, C., Page, B., Goldsworthy, S.D., Coyne, M., Lowther, A.D., Mitchell, J.G., Seuront, M. 2015. Living on the continental shelf edge: habitat use of juvenile shortfin makos *Isurus oxyrinchus* in the Great Australian Bight, southern Australia. *Fish Oceanogr.* 24(3): 205-218.

43 – Verghese, S.P., Unnikrishnan, N., Deepak, K.G., Ayoob, A.E. 2017. Size, sex and reproductive biology of seven pelagic sharks in the eastern Arabian Sea. *J. Mar. Biol. Assoc. UK*, 97(1): 181-196.

44 – Groeneveld, J.C., Cliff, G., Dudley, S.F., Foulis, A.J., Santos, J., Wintner, S.P. 2014. Population structure and biology of shorfin mako, *Isurus oxyrinchus*, in the south-west Indian Ocean. *Mar. & Freshw. Res.*, 65(12): 1045-1058.

45 - Tsai, W.-P., Sun, C.-L., Punt, A.E., Lui, K.-M. 2014. Demographic analysis of the shortfin mako shark, *Isurus oxyrinchus*, in the Northwest Pacific using a two-sex stage-based matrix model. *ICES J. Mar. Sci.* 71(7): 1604-1618.

46 – Lyons, K., Preti, A., Madigan, D. J., Wells, R. J. D., Blasius, M. E., Snodgrass, O. E., Kacev, D., Harris, J. D., Dewar, H., Kohin, S., MacKenzie, K., Lowe, C. G. 2015. Insights into the life history and ecology of a large shortfin mako shark *Isurus oxyrinchus* captured in southern California. *J. Fish Biol.*, 87(1): 200-221.

47 – Wells, R.J., Smith, D., Kohin, S.E., Freund, S., Spear, E., Ramon, N., Darlen, A. 2013. Age validation of juvenile shortfin mako *(Isurus oxyrinchus)* tagged and marked with oxytetracycline off southern California. *Fish. Bull.* 111(2): 147-160.

48 – Bustamante, C., Bennett, M.B. 2013. Insights into the reproductive biology and fisheries of two commercially exploited species, shortfin mako *(Isurus oxyrinchus*) and blue shark (*Prionace galuca*) in the south-east Pacific Ocean. *Fish. Res.*, 143: 174-183.

49 – Clarke, S.C., Harley, S., Hoyle, S.D., Rice, J.S. 2013. Population trends in Pacific Oceanic sharks and the utility of regulations on shark finning. *Cons. Biol*., 27(1): 197-209.

50 – Kai, M., Shiozaki, K., Ohshimo S., Yokawa, K. 2015. Growth and spatiotemporal distribution of juvenile shortfin mako *(Isurus oxyrinchus*) in the western and central North Pacific. *Mar. & Freshw. Res*, 66(12): 1176-1190.

51 – Au, D.W., Smith, S.E., Show, C. 2015. New abbreviated calculation for measuring intrinsic rebound potential inexploited fish population - example for sharks. *Can. J. Fish. Aquat. Sci*., 72: 767-773.

HOW TO OBTAIN EU PUBLICATIONS

Free publications:

- one copy:
  via EU Bookshop (http://bookshop.europa.eu);

- more than one copy or posters/maps:
  from the European Union's representations (http://ec.europa.eu/represent_en.htm);
  from the delegations in non-EU countries
  (http://eeas.europa.eu/delegations/index_en.htm);
  by contacting the Europe Direct service (http://europa.eu/europedirect/index_en.htm)
  or calling 00 800 6 7 8 9 10 11 (freephone number from anywhere in the EU) (*).

  (*) The information given is free, as are most calls (though some operators, phone boxes or hotels may charge you).

Priced publications:

- via EU Bookshop (http://bookshop.europa.eu).

Priced subscriptions:

- via one of the sales agents of the Publications Office of the European Union
  (http://publications.europa.eu/others/agents/index_en.htm).

EA-02-19-274-EN-N

Publications Office

doi: 10.2826/229340