Specific Contract No 2

FRAMEWORK CONTRACT

EASME/EMFF/2016/008

Selecting ecosystem indicators for fisheries targeting highly migratory species

FINAL REPORT

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EXECUTIVE SUMMARY

The ecosystem approach to fisheries management (EAFM) has been advocated for in several international legal agreements and guidelines such as the Convention on Biological Diversity, the UN Stock Agreement and the FAO Code of Conduct for Responsible Fisheries. These instruments have also set minimum standards and key principles to guide the implementation of an EAFM. However, implementation of an EAFM in tuna Regional Fisheries Management Organizations (RFMOs) has been patchy and lacks a long-term plan, vision and guidance on how to operationalize it. There are some practical impediments to the operationalization of an ecosystem approach for highly migratory tuna-and tuna like species, including:

(1) scarcity of ecosystem indicators (and associated reference points) to track the impacts of relevant fisheries on ecosystems, as most ecosystem indicators have been developed for coastal and demersal fisheries;

(2) lack of defined ecoregions in marine pelagic ecosystems to guide ecosystem research, ecosystem planning, and the operationalization of an EAFM in general; and

(3) lack of pre-agreed vision, operational objectives, and ecosystem plans to ensure ecological and socio-economic considerations are accounted for in fishery management advice and decision making.

The Specific Contract N^0 2 under the Framework Contract - EASME/EMFF/2016/008 *provisions of Scientific Advice for Fisheries Beyond EU Waters*- addresses several scientific challenges and provides solutions to support the implementation of an EAFM through collaboration and consultation with the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Indian Ocean Tuna Commission (IOTC).

The main purpose of Specific Contract N^0 2 is to provide the Directorate-General for Maritime Affairs and Fisheries (DG MARE) with:

- A list of ecosystem indicators (and guidance for associated reference points) to monitor impacts of fisheries targeting highly migratory tuna-and tuna like species. These indicators cover all ecological components of an EAFM, including target species, bycatch and threatened species, food-web and trophic relationships, and habitats of ecological significance.
- Candidate ecoregions with meaningful ecological boundaries for highly migratory tuna-and tuna like species and its fisheries in order to facilitate the operationalization of EAFM in marine pelagic ecosystems in ICCAT and IOTC.
- Two ecosystems plans, using two ecoregions as case studies, one within the ICCAT convention area and one within the IOTC convention area. These

ecosystems plans have the main purpose of facilitating the linkage between ecosystem science and fisheries management.

- Recommendations to better link ecosystem science and fisheries management to foster the implementation of an EAFM.

The following tasks were developed under the project:

- Task 1 Review how an EAFM is being implemented in different areas of the world and establishment of best practices and lessons.
- Task 2 Propose candidate ecosystem indicators and their data requirements for monitoring the impacts of ICCAT and IOTC fisheries on Highly Migratory Species (HMS) and the broader pelagic ecosystems.
- Task 3 Propose candidate ecoregions in the Atlantic and Indian Ocean to guide the operationalization of an EAFM.
- Task 4 Propose guidance for choosing reference points and a framework to facilitate the link between ecosystem indicators and fisheries management.
- Task 5 Mid-term workshop between DG MARE, EASME and scientists of the consortium to evaluate progress and select two case study regions (one in the Atlantic and one in the Indian Ocean).
- Task 6 Develop pilot ecosystems plans for the two case study regions, one in ICCAT and one in IOTC.
- Task 7 Identify issues and gaps in information and provide recommendations to facilitate the implementation of the ecosystem plans and the EAFM in ICCAT and IOTC.

Task 1 - Properties of success, best practices and lessons in implementing an EAFM extracted from case studies around the world

This task reviewed how different areas of the world are implementing an EAFM with the objective of identifying elements of success, best practices and lessons that potentially could be transferred to tuna RFMOs. The following case studies were chosen to demonstrate how ecosystem science and advice is currently used to influence fisheries management decisions: (1) North Pacific Fishery Management Council (NPFMC) in the Alaska region in the United States, (2) the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) in the Southern Ocean, and (3) the Northwest Atlantic Fisheries Management Organization (NAFO). Each of the chosen case studies is at a different state of implementing an EAFM, and that allows us to highlight best practices and effective approaches from different stages of the EAFM implementation process. We also reviewed several projects and programs that have worked extensively on the development and use of ecosystem indicators to monitor the impact of fisheries and climate on the status of marine ecosystems around the world. These include: (1) EU project DEVOTES, (2) the EU project EcApRHA, (3) the IndiSeas Programme, and (4) the EU Marine Strategy Framework Directive (MSFD).

Important properties of success in implementing an EAFM include having:

(1) a clear implementation framework,

(2) a transparent and trusted participatory and consultative process,

(3) well-articulated needs and vision,

(4) mechanisms for setting ecosystem objectives and priorities and

(5) fluid and strategic communication.

Best scientific practices observed in the reviewed case studies include:

(1) having well established ecoregions to guide ecosystem assessments and plans,

(2) monitoring of selected ecosystem indicators to track the impacts of pressures (fishing and climate),

(3) assessing trade-offs and cumulative impacts of fishing,

(4) adoption of processes for bycatch reduction and protections of habitats, and

(5) development of tools to visualize indicators and integrate information in support of ecosystem assessments.

The case studies showed that ecosystem-focused fisheries management can be done without full knowledge of the ecosystem, but it was crucial to make use and integrate all available knowledge. They also highlighted the importance of getting the stakeholders involved in the development of ecosystem products from the beginning. Another lesson from the case studies was about having very good knowledge of the annual management cycle since that helped identifying opportunities to incorporate ecosystem science into management decisions. When developing the first ecosystem plan and assessment, it was important to be flexible and adaptive in the process of selecting a small number of key ecosystem indicators to start the process and adapt by doing. The development of regional ecosystem indicators and assessments was also a catalyst for stronger regional collaboration. Finally, effort to develop standardized guidelines for data collections and estimation of indicators (which might also include agreements to override data confidentiality issues) led to stronger outputs, higher participation, and more regional collaborations.

Task 2- A proposal of ecosystem indicators and their data requirements for monitoring the impacts of ICCAT and IOTC fisheries on pelagic ecosystems

This task delivered a list of potential ecosystem indicators of relevance to tuna RFMOs (ICCAT and IOTC) that are suitable to track the impacts of fisheries targeting tuna and tuna-like species on the broader pelagic ecosystem. This task has not developed indicators but conducted a review of those indicators currently in operation in the reviewed case studies under Task 1. The development of a complete indicator suite will take many years and require specific development work to build bespoke indicators for particular issues of concern.

An initial list of more than 200 indicators was extracted from all the reviewed case studies and projects that aimed at monitoring the broader and cumulative impacts of fisheries on the state of the following ecosystem components: (1) target species, (2) bycatch and threatened species, (3) food-web and trophic relationships, and (4) habitats of ecological significance. Initially, all the indicators were catalogued into two broad categories, a category of pressure indicators, and a category for indicators tracking the changes in the state of the ecosystem. After applying filtering criteria, with specific questions in mind on how relevant the indicators were or could be to highly migratory tuna and tuna-like species and their fisheries, a subset of 36 indicators were selected. These 36 indicators were then evaluated in greater detail using an objective framework to test their quality. This resulted in a list of indicators which can guide decisions on where to focus efforts to develop key indicators specific to highly migratory tuna and tuna-like species, their fisheries, and data availability. In order to assist with our evaluation of indicators, this task also reviewed the datasets that are currently held by ICCAT and IOTC as well as other potential external sources of data outside these tuna RFMOs which might also contribute to the indicator development. A large number of the indicators reviewed are not currently calculable in ICCAT and IOTC due to the lack of scientific surveys. If it was considered possible to calculate the indicators using the fisheries dependent data currently held by IOTC and ICCAT, they were evaluated on that basis, while acknowledging that the indicator had not been calculated yet. It is recommended that the list of indicators prioritized should be developed and tested using the available data from the tuna RFMOs and external non-traditional data sources.

Task 3 - A proposal of candidate ecoregions in the Atlantic and Indian Ocean to guide the operationalization of an EAFM in ICCAT and IOTC

The definition of EAFM specifies that it is area-based and its operationalization requires the selection of spatial units that are ecologically and biologically meaningful. This task proposed candidate ecoregions within the Atlantic and Indian Oceans which could be used to guide region-based ecosystem plans, assessments and research to ultimately provide ecosystem management advice on a regional basis. The proposed ecoregions make sense ecologically, and account for spatial patterns and dynamics that characterize the main ICCAT and IOTC species and their fisheries. The ecoregions proposed were based on three pillars of information: (1) the biogeography and oceanographic characteristics of the pelagic waters in the Atlantic and Indian Oceans; (2) the spatial distributions of tuna and tuna-like fish species in these oceans; and (3) the spatial patterns of the main fishing fleets targeting them.

In doing so, first, existing biogeographic classifications for marine pelagic ecosystems were reviewed and their potential relevance for the management and conservation of highly migratory tuna and tuna-like species was discussed. Of the six biogeographic classifications reviewed, the Spalding Pelagic Provinces of the World (PPOW) had the greatest number of qualities to inform the choice of ecologically meaningful spatial units for the management and conservation of highly migratory tuna and tuna-like species.

Secondly, the spatial distribution of catches of tuna and tuna-like species in the Atlantic and Indian Ocean were examined, and their spatial partitioning into communities and degree of overlap with the PPOW biogeographic classification were analyzed. Despite tunas and billfishes having a very broad tolerance for a wide range of environmental conditions, they form unique communities, which are associated with specific pelagic provinces and environmental conditions. The most subtropical and temperate provinces were characterized mostly by a single or double species dominance, and the most tropical provinces were characterized by multispecies dominance. This suggests that the environmental conditions captured by the Spalding provinces might be controlling, to some extent, the spatial distribution and co-occurrence of tuna and billfish communities in these oceans.

Thirdly, the spatial dimensions of the main fleets and fisheries targeting tuna and tuna-like species in these oceans were also examined taking into account their overlap with the PPOW biogeographic classification. Purse seine fleets mainly operate in the tropical provinces targeting tropical tuna species, while longline fisheries operate throughout the entire Atlantic and Indian Oceans targeting a larger number of species.

Based on the three aforementioned pillars of information, seven candidate ecoregions were proposed in the Atlantic Ocean (and adjacent seas) and two candidate ecoregions in the Indian Ocean. This proposal is a response to increased efforts in ICCAT and IOTC towards operationalizing an EAFM. It represents a solid starting point to support ecosystem planning and development of regional ecosystem assessments. The proposed ecoregions will hopefully encourage discussions and debates about the need of a regional classification for the application of the EAFM in ICCAT and IOTC.

Task 4 - Guidance to choose reference points for ecosystem indicators and a framework to facilitate the link between ecosystem indicators and fisheries management.

Determining reference points in ecological indicators to assess ecosystem state is a complex task for a variety of reasons, mainly the lack of data and long-time series, and poor knowledge of the ecosystem response to environmental and human pressures. This difficulty is reflected by the limited work available to address the problem of determining reference points for use in resource management. This task designed a general framework based on a rule-based decision tree to provide guidance on how reference points can be set and used for diverse types of ecosystem indicators, so they can be better used in management decisions. The proposed decision-tree framework was based on several projects and published studies that have developed practical protocols to use the available data and functional relationships in place to define reference points, including the EU project DEVOTES, the Ocean Health Index program, and three relevant methodological studies. The proposed framework describes three broad approaches (based on functional relationship, time series analysis, and spatial comparisons) to define reference points with their respective strengths and weaknesses.

The use of ecosystem indicators to assess the state of marine ecosystems and its communication to policymakers for management purposes also remains a challenging task. This task also examined different existing frameworks and tools used to integrate and visualize multiple ecosystem indicators with the aim of establishing the ecosystem context within which management decisions can take place. Specifically, the frameworks and visualization strategies used by the NPFMC in the United States, CCAMLR, the ocean health index program, and EU DEVOTES project were reviewed to inform potential ecosystem communication strategies to be implemented in tuna RFMOs. Two alternative communication frameworks are presented, each of them includes three elements which aggregate ecosystem information at different levels to fit different purposes and reach different end users. The first element consists of a highly integrated tool that summarizes information from all the ecosystem indicators into a single or few numerical values. The second element consists of an ecosystem report card where top ecosystem indicators are presented in a highly visual manner. The third element consists of an ecosystem assessment which provides detailed information on all the indicators used to monitor pressures and assess the state of different ecosystem components. Due to the novelty of the methodologies and frameworks reviewed and proposed within this task and the complexity of the goals addressed, it is expected that the proposed communication frameworks will need some adjustments when applied to specific case studies.

Task 5- Mid-term workshop

A midterm workshop between DG MARE, EASME and scientists of the consortium was organized in January 2018. During this workshop, two case study regions were selected for the development of pilot ecosystem plans: (1) the tropical ecoregion in the Atlantic Ocean and (2) the temperate ecoregion for the Indian Ocean.

Task 6 - Pilot ecosystems plans for the two case study regions

Effective management needs effective planning. Therefore, operational plans are needed to link higher level policies and objectives to actions. Task 6 developed pilot ecosystem plans for the tropical ecoregion in ICCAT and the temperate ecoregion in IOTC. There are multiple purposes and benefits in developing an ecosystem plan to guide the implementation of an EAFM in a region. It creates a transparent process that may help the tuna RFMO Commissions set ecosystem goals and management purposes. It provides a framework of strategic planning to guide and prioritize fishery and ecosystem research, modelling and monitoring needs. It can help the Commission understand the cumulative effects of fisheries and emergent trade-offs between multiple objectives and, ultimately it can serve as a communication tool to better link ecosystem science to policy.

Each of the pilot ecosystem plans developed here include the following elements:

(1) a strategic long term vision of the Commission on how the ecosystem should look like if management is successful;

(2) an ecosystem overview aiming to integrate and synthesize current knowledge of main pressures and drivers that contribute to the state of the ecosystem;

(3) ecosystem conceptual models aiming to identify and raise a manageable number of issues that need to be monitored or further researched, and also help identify trade-offs for management decision;

(4) a skeleton for indicator-based assessments which aims to list those relevant ecosystem interactions and elements that need to be monitored and assessed, including a list of candidate ecosystem indicators and associated objectives; and

(5) a strategy for communication and provision of ecosystem advice which sets a clear process for sharing the ecosystem plan to different audiences including the Scientific Committees and the Commissions in ICCAT and IOTC.

Each of these elements is seen as the first step towards the development of formalized ecosystem plans in ICCAT and IOTC, and they are not a complete list. Future revisions of these pilot ecosystem plans could also include an ecosystem risk assessment to determine the degree of importance of each of the interactions and issues identified in the pilot ecosystem plans, identify how ecosystem plans interact with other Commission processes and other activities of the Scientific Committee, and identify continuous financial support for the implementation of the plan. Ultimately, the aim of these pilot ecosystem plans is to create awareness about the need for ecosystem planning, start a discussion about the elements that need to be part of a planning process, and initiate future participatory and consultative ecosystem plans in ICCAT and IOTC.

The pilot ecosystem plans are provided in a separate volume of this report (Appendix 5.1 and 5.2).

Task 7 - Recommendations to implement the ecosystem plans and the EAFM in ICCAT and IOTC

This Task includes recommendations to foster development, use, and implementation of ecosystem plans in ICCAT and IOTC that can be operationalized in the short-, medium-, and long-term. In the short-term, these include the presentation of pilot ecosystem plans developed under this project to the Scientific Committees of ICCAT and IOTC to evaluate their usefulness and promote further steps. The regionalization of ecosystem plans, including its potential benefits and drawbacks, is also seen as a critical point that needs to be further discussed and reviewed in ICCAT and IOTC. The on-going ecosystem assessments in ICCAT and IOTC can also benefit from candidate ecosystem indicators included in the pilot ecosystem plans. An EAFM engagement strategy and road map material for widespread use could also be developed to communicate the importance of ecosystem planning and ecosystem assessments to the Commission.

In the medium term, the ICCAT and IOTC Commissions need to agree on an ecosystem vision, goals, and objectives for the pilot Ecosystem Plans (or any other ecosystem plan) if they were to be formalized in future revisions. The creation of an ecosystem plan team in ICCAT and IOTC to oversee the development of future ecosystem plans and provide recommendations and guidance to the Scientific Committees and the Commission is also seen as a good step forward. Future versions of an ecosystem plan could incorporate an ecosystem risk assessment, which determines the degree of importance of each of the interactions and issues identified in the pilot ecosystem plans and identify how the ecosystem plan interacts with other Commission processes and activities of the Scientific Committees. They could also include a section on skills and capabilities to support the implementation of the plan, as well as identify continuous financial support to ensure its implementation.

In the long-term, future versions of the ecosystem plan should also consider socio-economic and governance aspects of the fisheries operating in the region covered by the plan. Until the socio-economic and governance considerations are properly addressed, an ecosystem plan will only be partially guiding the operationalization of EAFM in the covered region. An ecosystem plan coordinator/analyst at the ICCAT and IOTC Secretariat could facilitate the development of many of the activities proposed here.

Furthermore, this task also identified the main issues and information gaps that are jeopardizing the development of comprehensive ecosystem plans, including region-specific ecosystem overviews and indicator-based ecosystem assessments. Development of most ecosystem indicators in ICCAT and IOTC is still thwarted by limited availability and poor quality (e.g. temporal and spatial resolution) of relevant catch, effort and size datasets. Data collected in observer programs are currently underused for the development of ecosystem indicators. These data could support estimation and testing of many of the ecosystem indicators proposed. Limited resources and capacity to conduct end-to-end ecosystem modelling in the ICCAT and IOTC regions is also hindering our understanding of the effects of fishing and climate change on pelagic ecosystems and the development of model-based ecosystem indicators. Finally, this Task also proposed a list of actions, research activities and capacity building activities that could support the implementation of an EAFM in ICCAT and IOTC.

RESUMEN EJECUTIVO

La aproximación ecosistémica a la gestión pesquera (EAFM en sus siglas en inglés) ha sido propuesta en numerosos marcos y directrices como la Convención por la Diversidad Biológica, el Acuerdo de las Naciones Unidas sobre las poblaciones de peces y el Código de Conducta para la Pesca Responsable de la FAO. Estos instrumentos también han establecido normas mínimas y principios clave para guiar la aplicación de una EAFM. Sin embargo, la implementación de una EAFM en las Organizaciones Regionales de Ordenación Pesquera (OROP) ha sido irregular y carece de un plan a largo plazo, visión y orientación sobre cómo materializarla. Existen algunos impedimentos prácticos para la puesta en práctica de un enfoque ecosistémico para las especies altamente migratorias de túnidos y especies afines, entre los que se incluyen:

(1) escasez de indicadores ecosistémicos (y puntos de referencia asociados) para hacer un seguimiento de los efectos de la pesca en aguas lejanas, ya que la mayoría de los indicadores ecosistémicos se han desarrollado para la pesca costera y demersal;

(2) la falta de ecorregiones definidas en los ecosistemas pelágicos marinos para guiar la investigación de los ecosistemas, la planificación de los ecosistemas y la puesta en marcha de una EAFM en general; y

(3) falta de una visión pre-acordada, de objetivos operativos y de planes de ecosistema para garantizar que las consideraciones ecológicas y socioeconómicas se tengan en cuenta en el asesoramiento y la toma de decisiones en materia de ordenación pesquera.

El Contrato Específico N0 2 bajo el Contrato Marco - EASME/EMFF/2016/008 *disposiciones de los dictámenes científicos para la pesca más allá de las aguas de la UE* - aborda varios retos científicos y proporciona soluciones para apoyar la implementación de una EAFM a través de la colaboración y consulta con la Comisión Internacional para la Conservación del Atún Atlántico (ICCAT) y la Comisión del Atún para el Océano Índico (IOTC).

El objetivo principal del Contrato Específico nº 2 es dotar a la Dirección General de Asuntos Marítimos y Pesca (DG MARE) de:

- Una lista de indicadores de ecosistema (y orientación para los puntos de referencia asociados) para dar seguimiento a los impactos de las pesquerías dirigidas a especies altamente migratorias de túnidos y especies afines. Estos indicadores cubren todos los componentes ecológicos de una EAFM, incluyendo las especies objetivo, la captura incidental y las especies amenazadas, las relaciones entre la red alimentaria y las relaciones tróficas, y los hábitats de importancia ecológica.

- Regiones candidatas a ser consideradas ecoregiones con fronteras significativas para atunes (y túnidos) altamente migradores y sus pesquerías con objeto de facilitar la operacionalización del EAFM en ecosistémas pelágicos de ICCAT e IOTC.
- Dos planes de ecosistemas, utilizando dos ecorregiones como casos de estudio, uno dentro de la zona del Convenio de ICCAT y otro dentro de la zona del Convenio de la IOTC. Estos planes de ecosistemas tienen el propósito principal de facilitar el vínculo entre la ciencia de los ecosistemas y la ordenación pesquera.
- Recomendaciones para vincular mejor la ciencia de los ecosistemas y la gestión de la pesca con el fin de fomentar la aplicación de una EAFM.

En el marco del proyecto se desarrollaron las siguientes tareas:

- Tarea 1 Revisar cómo se está implementando una EAFM en diferentes áreas del mundo y establecer buenas prácticas y lecciones aprovechables.
- Tarea 2 Proponer indicadores de ecosistemas candidatos y sus requisitos de datos para el seguimiento de los impactos de las pesquerías de peces altamente migratorios (HMS) de ICCAT y de la IOTC y en los ecosistemas pelágicos más amplios.
- Tarea 3 Proponer unidades de gestión basadas en zonas o ecorregiones candidatas en el Océano Atlántico y el Océano Índico para guiar la puesta en marcha de una EAFM.
- Tarea 4 Proponer orientaciones para la elección de puntos de referencia y un marco para facilitar el vínculo entre los indicadores de los ecosistemas y la gestión de la pesca.
- Tarea 5 Grupo de trabajo entre la DG MARE, EASME y los científicos del consorcio para evaluar el progreso y seleccionar dos regiones de estudio de caso (una en el Atlántico y otra en el océano Índico).
- Tarea 6 Desarrollar planes piloto de ecosistemas para las dos regiones objeto de estudio de caso, una en ICCAT y otra en la IOTC.
- Tarea 7 Identificar temas y lagunas en la información y proporcionar recomendaciones para facilitar la implementación de los planes de ecosistema y de la EAFM en ICCAT y la IOTC.

Tarea 1 - Propiedades del éxito, mejores prácticas y lecciones en la implementación de una EAFM extraídas de estudios de casos en todo el mundo.

Esta tarea revisó cómo diferentes áreas del mundo están implementando una EAFM con el objetivo de identificar elementos de éxito, buenas prácticas y lecciones que potencialmente podrían ser transferidas a las OROP de túnidos. Se eligieron los siguientes estudios de caso para demostrar cómo se utilizan actualmente la ciencia y el asesoramiento de los ecosistemas para influir en las decisiones de ordenación pesquera: (1) North Pacific Fishery Management Council (NPFMC) en la región de Alaska en los Estados Unidos, (2) la Comisión para la Conservación de los Recursos Vivos Marinos Antárticos (CCAMLR) en el Océano Antártico (CCAMLR) en el Océano Austral, y (3) la Organización de Gestión de Pesquerías del Atlántico Noroeste (NAFO). Cada uno de los estudios de caso seleccionados se encuentra en un estado diferente de implementación de un EAFM, lo que nos permite destacar las buenas prácticas y los enfoques efectivos de las diferentes etapas del proceso de implementación del EAFM. También revisamos varios proyectos y programas que han trabajado extensamente en el desarrollo y uso de indicadores de ecosistemas para monitorear el impacto de las pesquerías y el clima en el estado de los ecosistemas marinos alrededor del mundo. Estos incluyen (1) El proyecto DEVOTES de la UE, (2) el proyecto EcApRHA de la UE, (3) el programa IndiSeas y (4) la Directiva marco sobre la estrategia marina de la UE (MSFD).

Para que la implementación del EAFM sea exitosa se requiere:

(1) un marco claro de aplicación,

(2) un proceso participativo y consultivo transparente y fiable,

(3) necesidades y visión bien articuladas,

(4) mecanismos para establecer los objetivos y prioridades de los ecosistemas y

(5) comunicación fluida y estratégica.

Las buenas prácticas científicas observadas en los estudios de caso revisados incluyen:

(1) contar con ecorregiones bien establecidas para guiar las evaluaciones y planes de los ecosistemas,

(2) Seguimiento de determinados indicadores de los ecosistemas para hacer un seguimiento de los efectos de las presiones (pesca y clima),

(3) evaluar las compensaciones y los impactos acumulativos de la pesca,

(4) adopción de procesos para la reducción de la captura incidental y la protección de los hábitats, y

(5) desarrollo de herramientas para visualizar los indicadores e integrar la información en apoyo de las evaluaciones de los ecosistemas.

Los estudios de caso demostraron que la ordenación de la pesca centrada en los ecosistemas puede llevarse a cabo sin un conocimiento pleno del ecosistema, pero que es fundamental utilizar e integrar todos los conocimientos disponibles. También destacaron la importancia de involucrar a las partes interesadas en el desarrollo de los productos de los ecosistemas desde el principio. Otra lección de los estudios de caso fue que se tenía un muy buen conocimiento del ciclo de manejo anual, ya que esto ayudaba a identificar oportunidades para incorporar la ciencia de los ecosistemas en las decisiones de manejo. Al elaborar el primer plan y evaluación del ecosistema, era importante ser flexible y adaptable en el proceso de selección de un pequeño número de indicadores clave del ecosistema para iniciar el proceso y adaptarse mediante la acción. La elaboración de indicadores y evaluaciones de los ecosistemas regionales también fue un catalizador para una colaboración regional más estrecha. Por último, los esfuerzos por elaborar directrices normalizadas para la recopilación de datos y la estimación de indicadores (que también podrían incluir acuerdos para anular las cuestiones de confidencialidad de los datos) dieron lugar a resultados más sólidos, una mayor participación y un mayor número de colaboraciones regionales.

Tarea 2- Una propuesta de indicadores de ecosistemas y sus requisitos de datos para el seguimiento de los impactos de las pesquerías de ICCAT y de la IOTC en los ecosistemas pelágicos.

Esta tarea proporcionó una lista de posibles indicadores de ecosistema de relevancia para las OROP de túnidos (ICCAT y IOTC) que son adecuados para hacer un seguimiento de los impactos de las pesquerías dirigidas a los túnidos y especies afines en el ecosistema pelágico más amplio. Esta tarea no ha desarrollado indicadores, sino que ha llevado a cabo un examen de los indicadores actualmente en funcionamiento en los estudios de casos examinados en el marco de la Tarea 1. El desarrollo de un conjunto completo de indicadores llevará muchos años y requerirá un trabajo de desarrollo específico para crear indicadores a medida para cuestiones concretas de interés.

Se extrajo una lista inicial de más de 200 indicadores de todos los estudios de caso y proyectos revisados que tenían por objeto hacer un seguimiento de los efectos más amplios y acumulativos de la pesca en el estado de los siguientes componentes del ecosistema: (1) especies objetivo, (2) captura incidental y especies amenazadas, (3) relaciones tróficas y de la red alimenticia y (4) hábitats de importancia ecológica. Inicialmente, todos los indicadores fueron catalogados en dos categorías amplias, una categoría de indicadores de presión y una categoría de indicadores de seguimiento de los cambios en el estado del ecosistema. Tras aplicar criterios de filtrado, con preguntas específicas sobre la pertinencia de los indicadores para los túnidos y especies afines altamente migratorios y sus pesquerías, se seleccionó un subconjunto de 36 indicadores. Estos 36 indicadores fueron luego evaluados en mayor detalle utilizando un marco objetivo para probar su calidad. Esto dio lugar a una lista de indicadores que pueden guiar las decisiones sobre dónde centrar los esfuerzos para desarrollar indicadores clave específicos para los túnidos y especies afines altamente migratorias, sus pesquerías, y la disponibilidad de datos. Con el fin de ayudarnos a evaluar los indicadores, esta tarea también revisaron los datos que mantienen actualmente ICCAT y la IOTC, así como otras posibles fuentes externas de datos ajenas a estas OROP de túnidos que también podrían contribuir al desarrollo de los indicadores. Un gran número de los indicadores examinados no son actualmente calculables en la ICCAT y la IOTC debido a la falta de estudios científicos. Si se consideraba posible calcular los indicadores utilizando los datos dependientes de la pesca que actualmente obran en poder de la IOTC y la ICCAT, éstos se evaluaban sobre esa base, al tiempo que se reconocía que el indicador aún no se había calculado. Se recomienda que la lista de indicadores priorizados sea desarrollada y probada usando los datos disponibles de las OROP de túnidos y fuentes de datos externas no tradicionales.

Tarea 3 - Una propuesta de ecorregiones candidatas en el Atlántico y el Océano Índico para guiar la puesta en marcha de una EAFM en ICCAT e IOTC.

La definición de la EAFM especifica que se ha de aplicar sobre un área geográfica y que su puesta en práctica requiere la selección de unidades espaciales que sean ecológica y biológicamente significativas. Esta tarea proponía ecorregiones candidatas dentro de los océanos Atlántico e Índico que podrían utilizarse para guiar los planes, evaluaciones e investigaciones de los ecosistemas basados en la región a fin de proporcionar asesoramiento sobre la gestión de los ecosistemas a nivel regional. Las ecorregiones propuestas tienen sentido desde el punto de vista ecológico y tienen en cuenta los patrones y la dinámica espacial que caracterizan a las principales especies de ICCAT y de la IOTC y sus pesquerías. Las ecorregiones propuestas se basaban en tres pilares de información: (1) la biogeografía y las características oceanográficas de las aguas pelágicas de los océanos Atlántico e Índico; (2) las distribuciones espaciales de los túnidos y especies afines en estos océanos; y (3) los patrones espaciales de las principales flotas pesqueras que los capturan.

Al hacerlo, en primer lugar, se revisaron las clasificaciones biogeográficas existentes para los ecosistemas pelágicos marinos y se discutió su posible relevancia para la ordenación y conservación de los túnidos y especies afines altamente migratorios. De las seis clasificaciones biogeográficas revisadas, las Provincias Pelágicas del Mundo (PPOW) definidas por Spalding tuvieron el mayor número de cualidades para informar la elección de unidades espaciales ecológicamente significativas para la ordenación y conservación de los túnidos y especies afines altamente migratorios.

En segundo lugar, se examinó la distribución espacial de las capturas de túnidos y especies afines en el Atlántico y el Océano Índico, y se analizó su división espacial en comunidades y el grado de solapamiento con la clasificación biogeográfica del PPOW. A pesar de que los túnidos y peces picudos tienen una gran tolerancia a una amplia gama de condiciones ambientales, forman comunidades únicas, que están asociadas con provincias pelágicas y condiciones ambientales específicas. Las provincias más subtropicales y templadas se caracterizan principalmente por el predominio de una o dos especies, y las provincias más tropicales por el predominio de varias especies. Esto sugiere que las condiciones ambientales capturadas por las provincias de Spalding podrían estar controlando, hasta cierto punto, la distribución espacial y la co-ocurrencia de comunidades de atunes y peces picudos en estos océanos.

En tercer lugar, se examinaron también las dimensiones espaciales de las principales flotas y pesquerías que pescan túnidos y especies afines en estos océanos, teniendo en cuenta su coincidencia con la clasificación biogeográfica del PPOW. Las flotas de cerco operan principalmente en las provincias tropicales y tienen como objetivo las especies de atunes tropicales, mientras que las pesquerías de palangre operan en ambos océanos Atlántico e Índico y tienen como objetivo un mayor número de especies.

Sobre la base de los tres pilares de información antes mencionados, se propusieron siete ecorregiones candidatas en el Océano Atlántico (y mares adyacentes) y dos ecorregiones candidatas en el Océano Índico. Esta propuesta es una respuesta a los mayores esfuerzos de la ICCAT y la IOTC para poner en marcha una EAFM. Representa un punto de partida sólido para apoyar la planificación de los ecosistemas y el desarrollo de evaluaciones de ecosistemas regionales. Se espera que las ecorregiones propuestas fomenten las discusiones y debates sobre la necesidad de una clasificación regional para la aplicación de la EAFM en la ICCAT y la IOTC.

Tarea 4 - Orientación para elegir puntos de referencia para los indicadores de los ecosistemas y un marco para facilitar el vínculo entre los indicadores de los ecosistemas y la gestión de la pesca.

La determinación de puntos de referencia en los indicadores ecológicos para evaluar el estado de los ecosistemas es una tarea compleja por una variedad de razones, principalmente la falta de datos y series a largo plazo, y el escaso conocimiento de la respuesta de los ecosistemas a las presiones ambientales y humanas. Esta dificultad se refleja en el limitado trabajo disponible para abordar el problema de la determinación de puntos de referencia para su uso en la gestión de recursos túnidos. Esta tarea diseñó un marco general basado en un árbol de decisiones basado en reglas para proporcionar orientación sobre cómo se pueden establecer y utilizar los puntos de referencia para diversos tipos de indicadores de ecosistemas, de modo que se puedan utilizar mejor en las decisiones de ordenación. El marco de decisiones propuesto se basaba en varios proyectos y estudios publicados que han elaborado protocolos prácticos para utilizar los datos disponibles y las relaciones funcionales existentes a fin de definir puntos de referencia, entre ellos el proyecto de la UE DEVOTES, el programa del Índice de Salud Oceánica y tres estudios metodológicos pertinentes. El marco propuesto describe tres enfoques amplios (basados en la relación funcional, el análisis de series temporales y las comparaciones espaciales) para definir los puntos de referencia con sus respectivos puntos fuertes y débiles.

La utilización de indicadores de los ecosistemas para evaluar el estado de los ecosistemas marinos y su comunicación a los encargados de la formulación de políticas con fines de ordenación también sigue siendo una tarea difícil. Esta tarea también examinó diferentes marcos y herramientas existentes que se utilizan para integrar y visualizar múltiples indicadores de los ecosistemas con el objetivo de establecer el contexto del ecosistema dentro del cual se pueden tomar decisiones de manejo. Específicamente, se revisaron los marcos y estrategias de visualización utilizados por la North Pacific Management Council (NPFMC) en los Estados Unidos, La Comisión para la Conservación de los Recursos Vivos Marinos Antárticos (CCRVMA), el programa de índice de salud oceánica y el proyecto EU DEVOTES para informar sobre las posibles estrategias de comunicación con el ecosistema que se implementarán en las OROP de túnidos. Se presentan dos marcos de comunicación alternativos, cada uno de los cuales incluye tres elementos que agregan información del ecosistema a diferentes niveles para ajustarse a diferentes propósitos y llegar a diferentes usuarios finales. El primer elemento consiste en una herramienta altamente integrada que resume la información de todos los indicadores del ecosistema en uno o varios valores numéricos. El segundo elemento consiste en un informe sobre el ecosistema en el que se presentan los principales indicadores del ecosistema de una manera muy visual. El tercer elemento consiste en una evaluación del ecosistema que proporciona información detallada sobre todos los indicadores utilizados para monitorear las presiones y evaluar el estado de los diferentes componentes del ecosistema. Debido a la novedad de las metodologías y marcos revisados y propuestos en el marco de esta tarea y a la complejidad de los objetivos abordados, se espera que los marcos de comunicación propuestos necesiten algunos ajustes cuando se apliquen a estudios de casos específicos.

Tarea 5 - Taller de mitad de período

En enero de 2018 se organizó un taller o grupo de trabajo entre la DG MARE, EASME y científicos del consorcio. Durante este taller se seleccionaron dos regiones de estudio de caso para el desarrollo de planes piloto de ecosistemas: (1) la ecorregión tropical del Océano Atlántico y (2) la ecorregión templada del Océano Índico.

Tarea 6 - Planes de ecosistemas piloto para las dos regiones del estudio de caso

Una gestión eficaz requiere una planificación eficaz. Por lo tanto, se necesitan planes operativos para vincular las políticas y los objetivos de nivel superior a las acciones. La Tarea 6 desarrolló planes piloto de ecosistemas para la ecorregión tropical en ICCAT y para la ecorregión templada en la IOTC. El desarrollo de un plan de ecosistema para guiar la implementación de un EAFM en una región tiene múltiples propósitos y beneficios. Crea un proceso transparente que puede ayudar a las Comisiones de las OROP de túnidos a establecer metas de ecosistema y propósitos de ordenación. Proporciona un marco de planificación estratégica para guiar y priorizar la investigación pesquera y de ecosistemas, la modelización y el seguimiento de las necesidades. Puede ayudar a la Comisión a comprender los efectos acumulativos de la pesca y las nuevas compensaciones entre los múltiples objetivos y, en última instancia, puede servir como herramienta de comunicación para vincular mejor la ciencia de los ecosistemas con la gestión.

Cada uno de los planes piloto de ecosistemas desarrollados aquí incluye los siguientes elementos:

(1) una visión estratégica a largo plazo de la Comisión correspondiente sobre el aspecto que debería tener el ecosistema si la gestión tiene éxito;

(2) una visión general del ecosistema con el fin de integrar y sintetizar los conocimientos actuales sobre las principales presiones y factores que contribuyen al estado del ecosistema;

(3) modelos conceptuales de ecosistema destinados a identificar y plantear un número manejable de cuestiones que necesitan ser monitoreadas o investigadas más a fondo, y también ayudar a identificar las compensaciones para las decisiones de gestión;

(4) un esqueleto para las evaluaciones basadas en indicadores que tiene por objeto enumerar las interacciones pertinentes con los ecosistemas y los elementos que deben ser objeto de seguimiento y evaluación, incluida una lista de indicadores de los ecosistemas candidatos y los objetivos conexos; y

(5) una estrategia de comunicación y asesoramiento sobre los ecosistemas que establezca un proceso claro para compartir el plan de ecosistema con diferentes audiencias, incluidos los comités científicos y las Comisiones de ICCAT y la IOTC.

Cada uno de estos elementos se considera como el primer paso hacia el desarrollo de planes de ecosistema formalizados en ICCAT y la IOTC, y no son una lista completa. Las revisiones futuras de estos planes piloto de ecosistemas podrían incluir también una evaluación del riesgo para determinar el grado de importancia de cada una de las interacciones y cuestiones identificadas en los planes piloto de ecosistemas, determinar cómo interactúan los planes de ecosistemas con otros procesos de la Comisión y otras actividades del Comité Científico, y determinar el apoyo financiero continuo para la aplicación del plan. En última instancia, el objetivo de estos planes piloto de ecosistemas es crear conciencia sobre la necesidad de planificar los ecosistemas, iniciar un debate sobre los elementos que deben formar parte de un proceso de planificación e iniciar futuros planes de ecosistemas participativos y consultivos en ICCAT y la IOTC.

Los planes piloto de ecosistemas se presentan en un volumen separado de este informe.

Tarea 7 - Recomendaciones para implementar los planes ecosistémicos y el EAFM en ICCAT y la IOTC.

Esta tarea incluye recomendaciones para fomentar el desarrollo, uso e implementación de planes de ecosistema en ICCAT y la IOTC que puedan ser operativos a corto, medio y largo plazo. A corto plazo, esto incluye la presentación de planes piloto de ecosistemas desarrollados en el marco de este proyecto a los Comités Científicos de la ICCAT y de la IOTC para evaluar su utilidad y promover nuevas medidas. La regionalización de los planes de ecosistemas, incluidos sus posibles beneficios e inconvenientes, también se considera un punto crítico que debe ser discutido y revisado en la ICCAT y la IOTC. Las evaluaciones de ecosistemas en curso en la ICCAT y la IOTC también pueden beneficiarse de los indicadores de ecosistemas candidatos incluidos en los planes piloto de ecosistemas. También podría elaborarse una estrategia de participación de la EAFM y material de hoja de ruta para su uso generalizado, a fin de comunicar a la Comisión la importancia de la planificación y las evaluaciones de los ecosistemas.

A medio plazo, las Comisiones de la ICCAT y de la IOTC deben acordar una visión, metas y objetivos de ecosistema para los Planes de Ecosistemas piloto (o cualquier otro plan de ecosistema) si se formalizaran en futuras revisiones. La creación de un equipo del plan de ecosistema en la ICCAT y la IOTC para supervisar el desarrollo de futuros planes de ecosistema y proporcionar recomendaciones y orientaciones a los comités científicos y a la Comisión también se considera un buen paso adelante. Las versiones futuras de un plan ecosistémico podrían incorporar una evaluación del riesgo para el ecosistema, que determine el grado de importancia de cada una de las interacciones y cuestiones identificadas en los planes ecosistémicos piloto, así como la forma en que el plan ecosistémico interactúa con otros procesos de la Comisión y con las actividades de los Comités Científicos. También podrían incluir una sección sobre habilidades y capacidades para apoyar la implementación del plan, así como identificar el apoyo financiero continuo para asegurar su implementación.

A largo plazo, las futuras versiones del plan de ecosistema también deberían tener en cuenta los aspectos socioeconómicos y de gobernanza de las pesquerías que operan en la región cubierta por el plan. Hasta que se aborden adecuadamente las consideraciones socioeconómicas y de gobernanza, un plan de ecosistema sólo guiará parcialmente la puesta en marcha del EAFM en la región cubierta. Un coordinador/analista del plan de ecosistema en la Secretaría de ICCAT y de la IOTC podría facilitar el desarrollo de muchas de las actividades aquí propuestas.

Además, en esta tarea también se identificaron las principales cuestiones y lagunas de información que están poniendo en peligro la elaboración de planes integrales de los ecosistemas, incluidas las reseñas de los ecosistemas específicas de cada región y las evaluaciones de los ecosistemas basadas en indicadores. El desarrollo de la mayoría de los indicadores de los ecosistemas en ICCAT y la IOTC sigue viéndose frustrado por la limitada disponibilidad y la mala calidad (por ejemplo, resolución temporal y espacial) de los conjuntos de datos de captura, esfuerzo y talla pertinentes. Los datos tomados en los programas de observadores están actualmente infrautilizados para el desarrollo de indicadores de ecosistemas. Estos datos podrían apoyar la estimación y prueba de muchos de los indicadores de los ecosistemas propuestos. Los recursos y la capacidad limitados para llevar a cabo la modelización de ecosistemas de extremo a extremo en las regiones de ICCAT y de la IOTC también están dificultando nuestra comprensión de los efectos de la pesca y el cambio climático en los ecosistemas pelágicos y el desarrollo de indicadores de ecosistemas basados en modelos. Por último, esta tarea también propuso una lista de acciones, actividades de investigación y actividades de creación de capacidad que podrían apoyar la implementación de una EAFM en ICCAT y en la IOTC.

SOMMAIRE EXÉCUTIF

L'approche écosystémique de la gestion des pêches (ci-après désignée par le sigle en anglais EAFM) a été préconisée dans plusieurs accords et directives juridiques internationaux tels que la Convention sur la diversité biologique, l'Accord des Nations Unies sur les stocks et le Code de conduite de la FAO pour une pêche responsable. Ces instruments ont également fixé des normes minimales et des principes clés pour guider la mise en œuvre d'une EAFM. Toutefois, la mise en œuvre d'une EAFM dans les organisations régionales de gestion des pêches (ORGP) thonières a été inégale et manque d'un plan à long terme, d'une vision et de directives sur la façon de le mettre en œuvre. Il existe certains obstacles pratiques à l'opérationnalisation d'une approche écosystémique pour les thonidés grands migrateurs et les espèces apparentées, notamment:

(1) la rareté des indicateurs écosystémiques (et des points de référence associés) pour suivre les impacts de la pêche sur les écosystèmes, étant donné que la plupart des indicateurs écosystémiques ont été élaborés pour les pêches côtières et démersales ;

(2) l'absence d'écorégions définies dans les écosystèmes pélagiques marins pour guider la recherche écosystémique, la planification écosystémique et l'opérationnalisation d'un modèle d'EAFM en général ; et

(3) l'absence d'une vision, d'objectifs opérationnels et de plans écosystémiques préétablis pour s'assurer que les considérations écologiques et socio-économiques sont prises en compte dans les conseils et la prise de décisions sur la gestion des pêches.

Le contrat spécifique N0 2 du contrat-cadre - EASME/EMFF/2016/008 - dispositions relatives aux avis scientifiques pour la pêche au-delà des eaux de l'UE - aborde plusieurs défis scientifiques et fournit des solutions pour soutenir la mise en œuvre d'une EAFM en collaboration et en consultation avec la Commission internationale pour la conservation des thonidés de l'Atlantique (CICTA) et la Commission des thons de l'océan Indien (CTOI).

L'objectif principal du contrat spécifique N0 2 est de fournir à la direction générale des affaires maritimes et de la pêche (DG MARE) :

- Une liste d'indicateurs écosystémiques (et des orientations pour les points de référence associés) pour surveiller les impacts de la pêche ciblant les thonidés grands migrateurs et les espèces apparentées. Ces indicateurs couvrent toutes les composantes écologiques d'une EAFM, y compris les espèces cibles, les prises accessoires et les espèces menacées, les relations trophiques et alimentaires, et les habitats d'importance écologique.

- Écorégions candidates présentant des limites écologiques significatives pour les thonidés grands migrateurs et les espèces voisines et leurs pêcheries afin de faciliter l'opérationnalisation de l'EAFM dans les écosystèmes pélagiques marins de la CICTA et de la CTOI.
- Deux plans écosystémiques, utilisant deux écorégions comme études de cas, l'une dans la zone de la convention CICTA et l'autre dans la zone de la convention CTOI. Ces plans écosystémiques ont pour principal objectif de faciliter l'établissement de liens entre la science écosystémique et la gestion des pêches.
- Recommandations visant à mieux relier la science écosystémique et la gestion des pêches afin de favoriser la mise en œuvre d'une EAFM.

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

- Tâche 1 : Examiner la manière dont une EAFM est mise en œuvre dans différentes régions du monde et définir les meilleures pratiques et les enseignements à en tirer.
- Tâche 2 Proposer des indicateurs d'écosystèmes candidats et leurs besoins en données pour le suivi des impacts des pêcheries de la CICTA et de la CTOI sur le HMS et les écosystèmes pélagiques en général.
- Tâche 3 Proposer des unités ou écorégions candidates de gestion par zone dans l'océan Atlantique et l'océan Indien pour guider l'opérationnalisation d'une EAFM.
- Tâche 4 Proposer des orientations pour le choix des points de référence et un cadre pour faciliter le lien entre les indicateurs écosystémiques et la gestion des pêches.
- Tâche 5 Atelier à mi-parcours entre la DG MARE, l'EASME et les scientifiques du consortium pour évaluer les progrès et sélectionner deux régions (une dans l'Atlantique et une dans l'océan Indien).
- Tâche 6 Élaborer des plans pilotes d'écosystèmes pour les deux régions étudiées, l'une à la CICTA et l'autre à la CTOI.
- Tâche 7 Identifier les problèmes et les lacunes en matière d'information et formuler des recommandations pour faciliter la mise en œuvre des plans écosystémiques et de l'EAFM à l'CICTA et à la CTOI.

Tâche 1 - Propriétés de réussite, meilleures pratiques et leçons tirées d'études de cas dans le monde entier pour la mise en œuvre d'une EAFM

Cette tâche a permis d'examiner comment différentes régions du monde mettent en œuvre une EAFM dans le but d'identifier les éléments de réussite, les meilleures pratiques et les leçons qui pourraient potentiellement être transférés aux ORGP thonières. Les études de cas suivantes ont été choisies pour démontrer comment la science et les conseils écosystémiques sont actuellement utilisés pour influencer les décisions de gestion des pêches : (1) North Pacific Fishery Management Council (NPFMC) dans la région de l'Alaska aux États-Unis, (2) la Commission pour la conservation de la faune et de la flore marines de l'Antarctique (CCAMLR) dans l'océan Austral, et (3) la Northwest Atlantic Fisheries Management Organization (NAFO). Chacune des études de cas choisies en est à un stade différent de mise en œuvre d'une EAFM, ce qui nous permet de mettre en évidence les pratiques exemplaires et les approches efficaces à différentes étapes du processus de mise en œuvre de l'EAFM. Nous avons également examiné plusieurs projets et programmes qui ont beaucoup travaillé à l'élaboration et à l'utilisation d'indicateurs écosystémiques pour surveiller l'impact des pêches et du climat sur l'état des écosystèmes marins dans le monde. Il s'agit notamment des : (1) Projet européen DEVOTES, (2) projet européen EcApRHA, (3) programme IndiSeas et (4) directive-cadre européen sur la stratégie marine (DCSM).

Les propriétés importantes de la réussite de la mise en œuvre d'une EAFM sont les suivantes :

(1) un cadre clair de mise en œuvre,

(2) un processus participatif et consultatif transparent et digne de confiance,

(3) des besoins et une vision bien articulés,

(4) des mécanismes d'établissement des objectifs et des priorités écosystémiques et

(5) une communication fluide et stratégique.

Les meilleures pratiques scientifiques observées dans les études de cas examinées sont les suivantes :

(1) avoir des écorégions bien établies pour guider les évaluations et les plans des écosystèmes,

(2) le suivi d'indicateurs écosystémiques sélectionnés pour suivre les impacts des pressions (pêche et climat),

(3) évaluer les compromis et les effets cumulatifs de la pêche,

(4) l'adoption de processus de réduction des prises accessoires et de protection des habitats, et

(5) l'élaboration d'outils permettant de visualiser les indicateurs et d'intégrer l'information à l'appui des évaluations des écosystèmes.

Les études de cas ont montré que la gestion des pêches axée sur les écosystèmes peut se faire sans une connaissance complète de l'écosystème, mais qu'il est crucial d'utiliser et d'intégrer toutes les connaissances disponibles. Ils ont également souligné l'importance d'impliquer dès le début les parties prenantes dans le développement des produits des écosystèmes. Une autre leçon tirée des études de cas portait sur une très bonne connaissance du cycle annuel de gestion, ce qui a permis de cerner les possibilités d'intégrer la science des écosystèmes dans les décisions de gestion. Lors de l'élaboration du premier plan et de la première évaluation des écosystèmes, il était important de faire preuve de souplesse et d'adaptabilité dans le processus de sélection d'un petit nombre d'indicateurs écosystémiques clés pour démarrer le processus et s'adapter en agissant. L'élaboration d'indicateurs et d'évaluations des écosystèmes régionaux a également servi de catalyseur pour renforcer la collaboration régionale. Enfin, les efforts visant à élaborer des lignes directrices normalisées pour la collecte de données et l'estimation d'indicateurs (qui pourraient également comprendre des ententes visant à outrepasser les questions de confidentialité des données) ont donné lieu à des extrants plus importants, une participation accrue et davantage de collaborations régionales.

Tâche 2- Une proposition d'indicateurs écosystémiques et leurs besoins en données pour le suivi des impacts des pêcheries de la CICTA et de la CTOI sur les écosystèmes pélagiques

Cette tâche a permis d'établir une liste d'indicateurs écosystémiques potentiels pertinents pour les ORGP thonières (CICTA et CTOI) qui permettent de suivre les impacts des pêches ciblant le thon et les espèces apparentées sur l'écosystème pélagique plus large. Cette tâche n'a pas permis d'élaborer des indicateurs, mais plutôt d'examiner les indicateurs actuellement utilisés dans les études de cas examinées dans le cadre de la tâche 1. L'élaboration d'une série complète d'indicateurs prendra de nombreuses années et nécessitera des travaux de développement spécifiques pour élaborer des indicateurs sur mesure pour des questions particulières.

Une liste initiale de plus de 200 indicateurs a été extraite de toutes les études de cas et de tous les projets examinés qui visaient à surveiller les effets généraux et cumulatifs des pêches sur l'état des composantes suivantes de l'écosystème : (1) espèces cibles, (2) prises accessoires et espèces menacées, (3) relations alimentaires et trophiques et (4) habitats d'importance écologique. Au départ, tous les indicateurs ont été catalogués en deux grandes catégories, une catégorie d'indicateurs de pression et une catégorie d'indicateurs de suivi des changements de l'état de l'écosystème. Après avoir appliqué des critères de filtrage, en se posant des questions spécifiques sur la pertinence des indicateurs pour les thonidés et espèces voisines grands migrateurs et leurs pêcheries, un sous-ensemble de 36 indicateurs a été sélectionné. Ces 36 indicateurs ont ensuite été évalués plus en détail à l'aide d'un cadre objectif pour tester leur qualité. Il en est résulté une liste d'indicateurs qui peuvent guider les décisions sur les points sur lesquels concentrer les efforts pour développer des indicateurs clés spécifiques au thon et aux espèces voisines hautement migratoires, à leurs pêcheries et à la disponibilité des données. Afin de nous aider dans notre évaluation des indicateurs, cette tâche a également passé en revue les ensembles de données actuellement détenus par la CICTA et la CTOI ainsi que d'autres sources externes potentielles de données en dehors de ces ORGP thonières qui pourraient également contribuer à l'élaboration des indicateurs. Un grand nombre des indicateurs examinés ne sont pas actuellement calculables à la CICTA et à la CTOI en raison de l'absence d'études scientifiques. S'il a été jugé possible de calculer les indicateurs en utilisant les données actuellement détenues par la CTOI et la CICTA qui dépendent de la pêche, ils ont été évalués sur cette base, tout en reconnaissant que l'indicateur n'avait pas encore été calculé. Il est recommandé que la liste des indicateurs prioritaires soit élaborée et testée en utilisant les données disponibles des ORGP thonières et des sources de données externes non traditionnelles.

Tâche 3 - Proposition d'écorégions candidates dans l'océan Atlantique et l'océan Indien pour guider l'opérationnalisation d'une EAFM à la CICTA et à la CTOI

La définition de l'EAFM précise qu'il s'agit d'un modèle fondé sur la superficie et que son opérationnalisation nécessite la sélection d'unités spatiales qui sont significatives sur les plans écologique et biologique. Cette tâche proposait des écorégions candidates dans les océans Atlantique et Indien qui pourraient servir à orienter les plans, les évaluations et la recherche écosystémiques à l'échelle régionale pour finalement fournir des conseils sur la gestion des écosystèmes à l'échelle régionale. Les écorégions proposées ont un sens écologique et tiennent compte des configurations et dynamiques spatiales qui caractérisent les principales espèces de la CICTA et de la CTOI et leurs pêcheries. Les écorégions proposées reposaient sur trois piliers de l'information : (1) la biogéographie et les caractéristiques océanographiques des eaux pélagiques de l'océan Atlantique et de l'océan Indien ; (2) la répartition spatiale des thonidés et des espèces apparentées dans ces océans ; et (3) les caractéristiques spatiales des principales flottes de pêche qui les ciblent.

Ce faisant, tout d'abord, les classifications biogéographiques existantes pour les écosystèmes pélagiques marins ont été examinées et leur pertinence potentielle pour la gestion et la conservation des thonidés et espèces voisines grands migrateurs a été discutée. Des six classifications biogéographiques examinées, les provinces pélagiques du monde selon Spalding (PPOW) présentaient le plus grand nombre de qualités pour guider le choix d'unités spatiales écologiquement significatives pour la gestion et la conservation des thonidés et espèces apparentées grands migrateurs.

Deuxièmement, la répartition spatiale des prises de thonidés et d'espèces apparentées dans l'océan Atlantique et l'océan Indien a été examinée, ainsi que leur répartition spatiale en communautés et leur degré de chevauchement avec la classification biogéographique du PPOW. Bien que les thons et les istiophoridés aient une très large tolérance pour une large gamme de conditions environnementales, ils forment des communautés uniques, qui sont associées à des provinces pélagiques et des conditions environnementales spécifiques. Les provinces les plus subtropicales et tempérées se caractérisaient surtout par une dominance d'espèces simples ou doubles, et les provinces les plus tropicales par une dominance multispécifique. Cela suggère que les conditions environnementales capturées par les provinces de Spalding pourraient contrôler, dans une certaine mesure, la distribution spatiale et la co-occurrence des communautés de thons et d'istiophoridés dans ces océans.

Troisièmement, les dimensions spatiales des principales flottilles et pêcheries ciblant le thon et les espèces apparentées dans ces océans ont également été examinées en tenant compte de leur chevauchement avec la classification biogéographique du PPOW. Les flottilles de senneurs à senne coulissante opèrent principalement dans les provinces tropicales ciblant les thonidés tropicaux, tandis que les palangriers opèrent dans tout l'Atlantique et dans l'océan Indien ciblant un plus grand nombre d'espèces.

Sur la base des trois piliers d'information susmentionnés, sept écorégions candidates ont été proposées dans l'océan Atlantique (et les mers adjacentes) et deux écorégions candidates dans l'océan Indien. Cette proposition est une réponse aux efforts accrus déployés par la CICTA et la CTOI en vue de rendre opérationnelle la mise en place d'une EAFM. Il représente un point de départ solide pour appuyer la planification écosystémique et l'élaboration d'évaluations régionales des écosystèmes. Il est à espérer que les écorégions proposées encourageront les discussions et les débats sur la nécessité d'une classification régionale pour l'application de l'EAFM à la CICTA et à la CTOI.

Tâche 4 - Orientation pour choisir des points de référence pour les indicateurs écosystémiques et un cadre pour faciliter le lien entre les indicateurs écosystémiques et la gestion des pêches.

La détermination de points de référence dans les indicateurs écologiques pour évaluer l'état de l'écosystème est une tâche complexe pour diverses raisons, principalement le manque de données et de séries à long terme, et une mauvaise connaissance de la réaction de l'écosystème aux pressions environnementales et humaines. Cette difficulté est reflétée par le peu de travaux disponibles pour résoudre le problème de la détermination des points de référence à utiliser dans la gestion des ressources. Cette tâche a permis de concevoir un cadre général fondé sur un arbre décisionnel basé sur des règles afin de fournir des conseils sur la façon dont les points de référence peuvent être établis et utilisés pour divers types d'indicateurs écosystémiques, de sorte qu'ils puissent être mieux utilisés dans les décisions de gestion. Le cadre proposé pour l'arbre de décision était fondé sur plusieurs projets et études publiées qui ont élaboré des protocoles pratiques pour utiliser les données disponibles et les relations fonctionnelles en place afin de définir des points de référence, en particulier le projet DEVOTES de l'UE, le programme Ocean Health Index, et trois études méthodologiques pertinentes. Le cadre proposé décrit trois grandes approches (fondées sur les relations fonctionnelles, l'analyse des séries chronologiques et les comparaisons spatiales) pour définir les points de référence avec leurs forces et faiblesses respectives.

L'utilisation d'indicateurs écosystémiques pour évaluer l'état des écosystèmes marins et leur communication aux décideurs à des fins de gestion reste également une tâche difficile. Cette tâche a également examiné différents cadres et outils existants utilisés pour intégrer et visualiser de multiples indicateurs écosystémiques dans le but d'établir le contexte écosystémique dans lequel les décisions de gestion peuvent prendre place. Plus précisément, les cadres et les stratégies de visualisation utilisés par le NPFMC aux États-Unis, la CCAMLR, le programme de l'indice de santé des océans et le projet DEVOTES de l'UE ont été examinés afin d'éclairer les stratégies potentielles de communication sur les écosystèmes à mettre en œuvre par les ORGP du thon. Deux cadres de communication alternatifs sont présentés, chacun d'eux comprenant trois éléments qui regroupent l'information écosystémique à différents niveaux pour répondre à différents objectifs et atteindre différents utilisateurs finaux. Le premier élément consiste en un outil hautement intégré qui résume l'information provenant de tous les indicateurs écosystémiques en une seule ou quelques valeurs numériques. Le deuxième élément consiste en un bulletin écosystémique où les principaux indicateurs écosystémiques sont présentés d'une manière très visuelle. Le troisième élément consiste en une évaluation écosystémique qui fournit des informations détaillées sur tous les indicateurs utilisés pour surveiller les pressions et évaluer l'état des différentes composantes des écosystèmes. En raison de la nouveauté des méthodologies et des cadres examinés et proposés dans le cadre de cette tâche et de la complexité des objectifs visés, on s'attend à ce que les cadres de communication proposés nécessitent certains ajustements lorsqu'ils seront appliqués à des études de cas spécifiques.

Tâche 5- Atelier de mi-parcours

Un atelier à mi-parcours entre la DG MARE, l'EASME et les scientifiques du consortium a été organisé en janvier 2018. Au cours de cet atelier, deux régions d'étude de cas ont été sélectionnées pour l'élaboration de plans pilotes des écosystèmes : (1) l'écorégion tropicale de l'océan Atlantique et (2) l'écorégion tempérée de l'océan Indien.

Tâche 6 - Plans pilotes d'écosystèmes pour les deux régions étudiées

Une gestion efficace nécessite une planification efficace. Par conséquent, des plans opérationnels sont nécessaires pour lier les politiques et les objectifs de plus haut niveau aux actions. La Tâche 6 a élaboré des plans pilotes d'écosystèmes pour l'écorégion tropicale de la CICTA et l'écorégion tempérée de la CTOI. L'élaboration d'un plan écosystémique visant à guider la mise en œuvre d'une EAFM dans une région comporte de multiples buts et avantages. Il crée un processus transparent qui peut aider les commissions des ORGP thonières à fixer des objectifs écosystémiques et des objectifs de gestion. Il fournit un cadre de planification stratégique pour guider et prioriser les besoins en matière de recherche, de modélisation et de surveillance des pêches et des écosystèmes. Il peut aider la Commission à comprendre les effets cumulatifs de la pêche et les compromis émergents entre de multiples objectifs et, en fin de compte, il peut servir d'outil de communication pour mieux relier la science des écosystèmes aux politiques.

Chacun des plans écosystémiques pilotes élaborés ici comprend les éléments suivants:

(1) une vision stratégique à long terme de la Commission sur la manière dont l'écosystème devrait se présenter si la gestion est réussie ;

(2) une vue d'ensemble de l'écosystème visant à intégrer et à synthétiser les connaissances actuelles sur les principales pressions et les principaux facteurs qui contribuent à l'état de l'écosystème ;

(3) des modèles conceptuels d'écosystèmes visant à identifier et à soulever un nombre gérable de questions qui doivent être surveillées ou faire l'objet de recherches plus poussées, et à aider à identifier les compromis à prendre des décisions de gestion ;

(4) un squelette pour les évaluations fondées sur des indicateurs qui vise à dresser la liste des interactions et des éléments pertinents de l'écosystème qui doivent être

surveillés et évalués, y compris une liste d'indicateurs d'écosystèmes candidats et d'objectifs connexes;

(5) une stratégie de communication et de fourniture d'avis écosystémiques qui établit un processus clair pour partager le plan écosystémique avec différents publics, notamment les comités scientifiques et les commissions de la CICTA et de la CTOI.

Chacun de ces éléments est considéré comme la première étape vers l'élaboration de plans écosystémiques formalisés à la CICTA et à la CTOI, et ils ne constituent pas une liste exhaustive. Les révisions futures de ces plans écosystémiques pilotes pourraient également inclure une évaluation des risques écosystémiques pour déterminer le degré d'importance de chacune des interactions et des questions identifiées dans les plans écosystémiques pilotes, déterminer comment les plans écosystémiques interagissent avec les autres processus de la Commission et les autres activités du comité scientifique, et identifier un soutien financier continu pour la mise en œuvre du plan. En fin de compte, le but de ces plans écosystémiques pilotes est de sensibiliser à la nécessité d'une planification écosystémique, d'entamer une discussion sur les éléments qui doivent faire partie d'un processus de planification et de lancer de futurs plans écosystémiques participatifs et consultatifs à la CICTA et la CTOI.

Les plans pilotes des écosystèmes sont présentés dans un volume distinct du présent rapport.

Tâche 7 - Recommandations pour la mise en œuvre des plans écosystémiques et de l'EAFM à la CICTA et à la CTOI

Cette tâche comprend des recommandations visant à encourager l'élaboration, l'utilisation et la mise en œuvre de plans écosystémiques à la CICTA et à la CTOI qui peuvent être mis en œuvre à court, à moyen et à long terme. A court terme, il s'agira notamment de présenter aux comités scientifiques de la CICTA et de la CTOI les plans pilotes des écosystèmes élaborés dans le cadre de ce projet afin d'évaluer leur utilité et de promouvoir de nouvelles mesures. La régionalisation des plans écosystémiques, y compris ses avantages et inconvénients potentiels, est également considérée comme un point critique qui doit faire l'objet d'un examen plus approfondi à la CICTA et à la CTOI. Les évaluations écosystémiques en cours à la CICTA et à la CTOI peuvent également bénéficier d'indicateurs d'écosystèmes candidats inclus dans les plans pilotes des écosystèmes. Une stratégie d'engagement de l'EAFM et une feuille de route pour une utilisation généralisée pourraient également être élaborées afin de communiquer à la Commission l'importance de la planification et des évaluations écosystémiques.

A moyen terme, les Commissions de la CICTA et de la CTOI doivent se mettre d'accord sur une vision, des buts et des objectifs écosystémiques pour les Plans Écosystémiques pilotes (ou tout autre plan écosystémique) s'ils doivent être formalisés dans les futures révisions. La création d'une équipe de planification des écosystèmes au sein de la CICTA et de la CTOI pour superviser l'élaboration des futurs plans écosystémiques et fournir des recommandations et des orientations aux comités scientifiques et à la Commission est également considérée comme un bon pas en avant. Les versions futures d'un plan écosystémique pourraient comprendre une évaluation des risques pour l'écosystème, qui déterminerait le degré d'importance de chacune des interactions et des questions identifiées dans les plans écosystémiques pilotes et déterminerait comment le plan écosystémique interagit avec les autres processus et activités des comités scientifiques de la Commission. Ils pourraient également inclure une section sur les compétences et les capacités nécessaires pour appuyer la mise en œuvre du plan, ainsi qu'identifier un soutien financier continu pour assurer sa mise en œuvre.

À long terme, les futures versions du plan écosystémique devraient également tenir compte des aspects socio-économiques et de gouvernance des pêches exploitées dans la région visée par le plan. Tant que les considérations socio-économiques et de gouvernance n'auront pas été correctement prises en compte, un plan écosystémique ne guidera que partiellement l'opérationnalisation de l'EAFM dans la région couverte. Un coordinateur/analyste du plan écosystémique au Secrétariat de la CICTA et de la CTOI pourrait faciliter l'élaboration d'un grand nombre des activités proposées ici.

En outre, cette tâche a également permis de recenser les principaux problèmes et lacunes en matière d'information qui compromettent l'élaboration de plans écosystémiques globaux, y compris des aperçus des écosystèmes propres à chaque région et des évaluations des écosystèmes fondées sur des indicateurs. L'élaboration de la plupart des indicateurs écosystémiques de la CICTA et de la CTOI est encore entravée par la disponibilité limitée et la mauvaise qualité (par exemple, résolution temporelle et spatiale) des ensembles de données pertinents sur les prises, l'effort et la taille. Les données recueillies dans le cadre des programmes d'observation sont actuellement sous-utilisées pour l'élaboration d'indicateurs écosystémiques. Ces données pourraient servir à l'estimation et à la mise à l'essai d'un grand nombre des indicateurs écosystémiques proposés. Les ressources limitées et la capacité limitée pour mener une modélisation de bout en bout des écosystèmes dans les régions de la CICTA et de la CTOI entravent également notre compréhension des effets de la pêche et du changement climatique sur les écosystèmes pélagiques et l'élaboration d'indicateurs écosystémiques fondés sur des modèles. Enfin, cette Tâche a également proposé une liste d'actions, d'activités de recherche et d'activités de renforcement des capacités qui pourraient soutenir la mise en œuvre d'une EAFM au sein de la CICTA et de la CTOI.

CONTENTS

1. INTRODUCTION

1.1. General introduction to the specific contract

Several international legal agreements and guidelines such as the Convention on Biological Diversity (CBD, 2004), the UN Stock Agreement (United Nations, 1995) and FAO Code of Conduct for Responsible Fisheries (FAO, 1995) have set the minimum standards and key principles to guide the implementation of an ecosystem approach to fisheries management (EAFM) (Meltzer, 2009). The implementation of an EAFM in tuna Regional Fisheries Management Organizations (RFMOs) has been patchy and with the absence of a long-term plan, vision and guidance of how to operationalize it (Juan-Jordá *et al.*, 2017). There are some practical impediments to the operationalization of an ecosystem approach to manage highly migratory and oceanic tuna-and tuna like species, including (1) the scarcity of ecosystem indicators (and associated reference points and selection criteria) to track the impacts of fisheries on tuna and tuna-like species and the broader oceanic ecosystems, as most ecosystem indicators globally have been developed within the context of coastal and demersal fisheries, (2) the lack of defined ecoregions in marine pelagic ecosystems to guide ecosystem research, ecosystem planning and the operationalization of an EAFM in general, and (3) the lack of a pre-agreed vision and operational objectives as well as a ecosystem plan to ensure ecosystem and socio-economic considerations are accounted in fishery management advice and decision making.

EASME has commissioned the AZTI led Consortium (AZTI, AGROCAMPUS, CEFAS, IEO, IPMA, WMR, IRD, MRAG) for the Framework Contract EASME/EMFF/2016/008 for the "*Provision of scientific advice for fisheries beyond EU waters*"[1]. The present interim report refers to the Specific Contract (SC) Nº 2 EASME/EMFF/2015/1.3.2.3/02/SI2.744915 under this framework.

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

- A list of ecosystem indicators (and guidance for associated reference points) to monitor impacts of fisheries targeting Highly Migratory Species (HMS). These indicators cover all ecological components of an EAFM,

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

including target species, bycatch and threatened species, trophic relationships and habitats.

- Candidate ecological regions with meaningful ecological boundaries for HMS and its fisheries in order to facilitate the operationalisation of EAFM in marine pelagic ecosystems in the International Commission for the Conservation of Atlantic Tunas (ICCAT) and Indian Ocean Tuna Commission (IOTC).
- An ecosystem plan using two ecoregions as case studies, one within the ICCAT convention area and one within the IOTC convention area. This ecosystem or EAFM plan has the main purpose of facilitating the linkage between ecosystem science and fisheries management.
- Recommendations to better link ecosystem indicators and management to foster the implementation of an EAFM.

1.2. Main objectives

To this end the objective of this Final Report is to provide the main results and outcomes achieved under each of the 7 Tasks of this project which were (Figure 1.1):

- Task 1 Review how an EAFM is being implemented in different areas of the world and establishment of best practices and lessons.
- Task 2 Propose candidate ecosystem indicators and their data requirements for monitoring the impacts of ICCAT and IOTC fisheries on HMS and the broader pelagic ecosystems.
- Task 3 Propose candidate ecoregions in the Atlantic and Indian Ocean to guide the operationalisation of an EAFM.
- Task 4 Propose guidance for choosing reference points and a framework to facilitate the link between ecosystem indicators and fisheries management.
- Task 5 Mid-term workshop between DG MARE, EASME and scientists of the consortium to evaluate progress and select two case study regions (one in the Atlantic and one in the Indian ocean).
- Task 6 Develop pilot ecosystems plans for the two case study regions, one in the ICCAT and one in IOTC.
- Task 7 Identify issues and gaps in information and provide recommendations to facilitate the implementation of the ecosystem plans and the EAFM in ICCAT and IOTC.

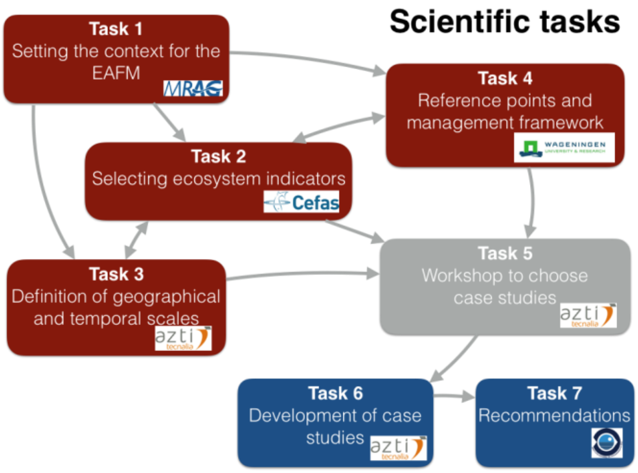

Figure 1.1 SC02 main tasks, their linkages and leading institution.

1.3. Geographic, ecological and taxonomical scope of the study

The geographical scope of this study varies according to the tasks being performed. Task 1 has a global scope as it considers regions across the world to identify and review those in which an EAFM is currently being implemented and ecosystem indicators and ecosystem science is being used to inform fisheries management decisions. Task 1 also reviewed international programs that have been specifically designed to identify and work with ecosystem indicators to track the impact of fisheries on marine ecosystem (e.g. the EU MSFD process, IndiSeas Scientific Programme, EU DEVOTES project, EU EcApRHA project). Tasks 2 and 4 also have a global scope as they deliver a list of ecosystem indicators (and guidelines to set reference points when relevant) within the context of HMS and its fisheries in epipelagic marine ecosystems. Task 2 and 4 have built on lessons and best practices from the case regions selected in Task 1.

Furthermore, Task 3 also has a regional scope as it aims to define meaningful geographic scales to inform the development of ecosystem indicators (and reference points) within the context of HMS and its fisheries in the Atlantic and Indian Oceans. Specifically, it considers three pillars of information to propose candidate ecoregions to guide indicator-based ecosystem assessments: the biogeography of the region, fish communities of tuna and tuna-like species, and the fisheries operating in these regions. Task 3 will inform the selection of ecological regions in Task 5 and the development of EAFM plans in Task 6 relevant to the assessment and conservation of HMS in epipelagic marine ecosystems and relevant to tuna RFMOs. The geographical scope of Task 5 and 6 is the Atlantic and Indian Oceans since these two regions are the areas of competence of ICCAT and IOTC convention areas. The two ecoregions within the Atlantic and Indian Oceans have been chosen such that they can facilitate the integration of all relevant results from Task 1-4. Finally, the focus of Task 7 is on providing recommendations for the implementation of EAFM for HMS fisheries in tuna RFMOs.

The ecological scope of this study covers the impacts of fisheries targeting HMS on the following ecological components of an EAFM: target species, bycatch and threatened species, habitats, and trophic relationships in the context of tuna RFMOs.

The taxonomic scope of this study covers the main pelagic oceanic fish species targeted by large pelagic fisheries under the purview of tuna RFMOs including longline and purse seiners, as well as other major fisheries depending on the areas. Specifically, this study considers the following "Target Species": Skipjack tuna (*Katsuwonus pelamis*), Yellowfin tuna (*Thunnus albacares*), Bigeye tuna (*T. obesus*), Albacore tuna (*T. alalunga*), Atlantic bluefin tuna (*T. thynnus*), and Swordfish (*Xiphias gladius*). This study also coves species impacted and interacting with the main tuna and billfish fisheries (bycatch species). "Bycatch Species" considered important by this study include all billfish species (except Swordfish since is a target species), oceanic sharks, seabirds, sea turtles, marine mammals, and finfishes other than principal market tunas and billfishes (hereafter named "other finfishes") impacted by targeted tuna and swordfish fisheries. However, it is recognized that several species of shark, billfish and finfishes can also be considered target species in some tuna and tuna-like fisheries. Therefore, the indicators that cover species potentially considered as both target and bycatch species will need to be accompanied with additional information to facilitate their interpretation and use.

This study also examines "Trophic Relationships" and identifies ecosystem indicators (through empirical and model-based approaches) depicting trophic interactions and interdependencies involving relevant exploited species, and that are relevant to maintain ecosystem structure and functioning.

"Habitats" support the functioning and structure of marine ecosystems, and this study examines indicators to characterize habitats of special concern (e.g. supporting reproduction, migration, feeding, biodiversity) and/or habitat utilization for key relevant species. This information and understanding will be used to advance the implementation of an EAFM.

This study does not cover indicators of contaminants in fish and other seafood, seafloor integrity, or the effects of underwater noise on HMS.

2. TASK 1 – SET THE CONTEXT AND SCOPE OF THIS STUDY BY EXAMINING AND ANALYSING HOW THE EAFM IS BEING IMPLEMENTED AROUND THE WORLD

Key message

- This section provides an overview of developments in implementing an EAFM covering the general framework, research, and application at regional level. It then uses latest knowledge to identify candidate ecosystem indicators for HMS.
- Implementation of the EAFM is more advanced in the USA but other regions and organisations have also developed approaches and initiatives to make progress in this area. This includes the MSFD in Europe, ESD concept in Australia, and empirical multi-species harvest control rules in CCAMLR. Fisheries organisations such as NAFO have also taken steps to incorporate the EAFM into their processes but this work is at an early stage.
- Important components of an EAFM include a clear vision and commitment to EAFM, agreed principles for taking it forward, a transparent mechanism for setting objectives, adaptable and participatory processes, and strategic communication.
- The selection of the indicators for HMS was done using 8 quality criteria including scientific bias, ecosystem relevance, responsiveness to pressure, and costs effectiveness.

2.1. Objectives

The objective of this task is to set the context and scope of this study by examining and analysing how different areas of the world are implementing an EAFM and establishing a list of best practices and a list of ecosystem indicators.

To accomplish this, Task 1 is divided in the following sub-tasks:

- Subtask 1.1 - Revision and description of how EAFM is being implemented in different areas of the world and establishment of good practices.
- Subtask 1.2 - Establishment of a preliminary list of ecosystem indicators including their strengths and weaknesses.
- Subtask 1.3 - A revision of state of the art in defining the impacts of exogenous, unmanageable, pressures on target and by-catch HMS species.

2.2. Sub-task 1.1 – Revision and description of how EAFM is being implemented in different areas of the world and establishment of good practices

A review of developments in defining the different ecosystem approaches, starting with the simple question of what EAFM is, was the focus of the first part under this Task (Appendix 1.1). Terms commonly used such as Ecosystem-Based Fisheries Management (EBFM), Ecosystem Approach to Fisheries (Management) (EAF or EAFM), and Ecosystem-Based Approach to Fisheries Management (EBAFM) were reviewed and described within the broader context of ecosystem-based management. These terms are underlying the same broad concept; they all recognise that fisheries management must deal with a full set of ecological consequences and needs to understand the social and economic implications of all fisheries activities.

Therefore, the adoption of the EAFM represents a transition from a management system that aims to achieve sustainability for target species to one that also considers the major components of an ecosystem and the social and economic benefits they can provide (Garcia *et al.*, 2003). Such transition requires developing a more holistic view on the impact of fisheries and their interdependencies with other species and services (see Table 1 in Appendix 1.1). Key impacts that fishing can have on marine ecosystems include:

- catching unwanted species (bycatch);
- causing physical damage to benthic habitats;
- changing species composition and communities;
- disrupting food chains.

These impacts are not usually considered in single-species assessments; therefore, data to support risk assessment of such impacts will be required when transitioning from conventional fisheries management to an ecosystem-focused one. Conversely, an EAFM management can complement existing approaches to both fisheries and other marine resource management such as integrated coastal zone management and marine spatial planning (Figure 2.1).

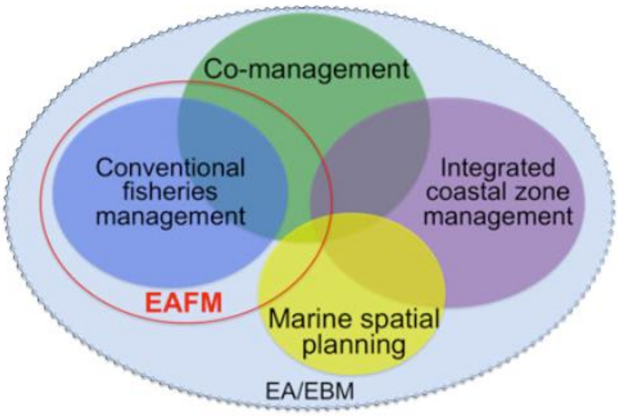

Figure 2.1 EAFM in relation to other marine management systems (Staples *et al.*, 2014).

For the purpose of this study, the internationally adopted FAO definition is used:

- *"the purpose of an **ecosystem approach to fisheries** is to plan, develop and manage fisheries in a manner that addresses the multiplicity of societal needs and desires, without jeopardizing the options for future generations to benefit from a full range of goods and services provided by marine ecosystems".*
- "*an ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries".*

This definition is also very similar to the one adopted by the European Union (see Table 2 in Appendix 1.1). The value of efforts by National Oceanic and Atmospheric Administration (NOAA) of the United States and other entities to define and differentiate among the different levels of applications for EBM for the fisheries sector are also acknowledged (as portrayed in Table 3 in Appendix 1.1).

For the second part of this subtask, an extensive literature review was conducted to identify areas of the world where an EAFM is being implemented and where ecosystem indicators and ecosystem science is notably being used to inform fisheries management. The EAFM has been at different stages of development around the world both in terms of the level of sophistication but also the length of time during which such an approach has been in place.

In the European Union, the Marine Strategy Framework Directive (MSFD) has been the flagship initiative to promote the ecosystem approach in the region. The MSFD aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020[2], which includes application of the ecosystem principles to fisheries. The MSFD is relatively new (adopted in 2008) and currently being implemented by each of the CPCs (Contracting Party or Cooperating non-Contracting Party, Entity or Fishing Entity). In the US, the EAFM has been implemented in several parts of the country and the work to operationalise it has been going on for more than 10 years. The concept was also incorporated into legislation for fisheries management in 2006 in the Magnuson-Stevens Fishery Conservation and Management Act. Its implementation is supported by regular ecosystem assessments or updates and production of fishery ecosystem plans and EAFM risk assessment reports. In Antarctica, the Convention that created the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) explicitly set ecosystem-focused principles for exploitation of resources[3]. This means that EAFM has been part of their work for more than 30 years (the convention was adopted in 1980). Their approach includes empirical multi-species harvest control rules and an ecosystem monitoring programme that is in operation since the early 90s[4].

In Australia, ecologically sustainable development (ESD) is the overarching concept guiding management of their resources[5]. As part of ESD, Australia undertakes ecosystem-focused fisheries work such as the Ecological Risk Assessment for Effect of Fishing. This is a comprehensive assessment of the ecological risks arising from fishing[6] and it has been applied to Australian fisheries for more than 10 years. In the Atlantic region, the Northwest Atlantic Fisheries Organization (NAFO) incorporated the concept of EAFM into their Convention in 2007 but ratification is still underway. Despite that, some work has already been done, mainly at the scientific level, to integrate aspects of EAFM into NAFO procedures, such as work to develop a roadmap for EAFM in NAFO (NAFO, 2016).

This study reviewed areas of the world that have proven experience of using ecosystem science and advice to influence fisheries management decisions (Figure 2.2). Specifically, the following case studies were reviewed: (1) North Pacific

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2 http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm
3 http://archive.ccamlr.org/pu/e/sc/eco-app-intro.htm
4 https://www.ccamlr.org/en/science/ccamlr-ecosystem-monitoring-program-cemp
5 http://www.environment.gov.au/about-us/esd
6 https://www.environment.gov.au/system/files/pages/0c373548-1124-4e99-bda8-5f2bb7e99362/files/sbt-attachmentb-fishery-report.doc

Fishery Management Council (NPFMC) in the United States, (2) CCAMLR, and (3) NAFO. The chosen areas are at different stages of implementing an EAFM and that allows for best practices and effective approaches from different states of the EAFM implementation process to be highlighted (Appendix 1.2).

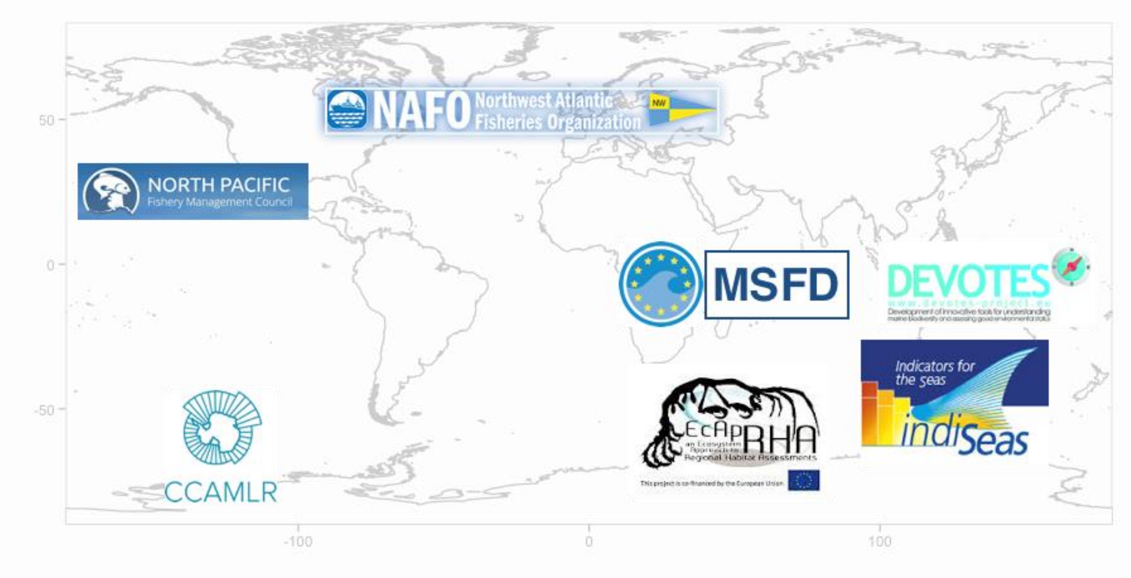


Figure 2.2 Institutions and regions of the world with proven experience of using ecosystem science and advice to influence fisheries management decisions. Relevant projects and programs that have worked extensively on the development and use of ecosystem indicators to monitor the impact of fisheries and climate on marine ecosystems are also shown.

This study also reviewed relevant projects and programs (Appendix 1.2) that have worked extensively on the development and use of ecosystem indicators to monitor the impact of fisheries and climate on marine ecosystems (Heiskanen *et al.*, 2016; Patrício *et al.*, 2016; Teixeira *et al.*, 2016). These were (1) EU projects DEVOTES[7], and EcApRHA[8] and (2) the IndiSeas Programme[9] supported by UNESCO-IOC. The DEVOTool catalogue from the DEVOTES project was also examined to identify possible indicators relevant for this study. Finally, indicators developed to support the EU Marine Strategy Framework Directive (MSFD) were also examined.

Through this review, key components that underpin implementation of EAFM and good practices that have fostered the implementation of an EAFM in the regions

[7] www.devotes-project.eu/
[8] www.ospar.org/work-areas/bdc/ecaprha
[9] www.indiseas.org

considered were identified. These are summarized below and also discussed in detail in Appendix 1.2.:

Key components underpinning EAFM

- ***Well-articulated needs and vision* –** The adoption of EAFM both in NPFMC and CCAMLR has been supported by an explicit commitment to EAFM. This provides clarity and sets the basis for developing a path to achieving the vision.

- ***Clear framework of implementation* –** Agreed principles underpinned the EAFM vision in NPFMC, CCAMLR, and MSFD. Those principles cover both management and science and, in the case of NPFMC and CCAMRL, included rules for how to implement the EAFM, e.g. a roadmap in NPFMC, and how to use ecosystem considerations in management decisions.

- ***Transparent and trusted participatory and consultative process*** – All the case studies considered have stressed the importance of transparent and open processes. Access to information, processes, and science used to develop the EAFM strengthens transparency and supports participation from a broader spectrum of stakeholders. An open and inclusive consultation process at each key stage can help build trust among interested parties, improve consensus, and increase support.

- ***Mechanisms for setting ecosystem objectives and priorities* –** Broad consultations using workshops, formal meetings, or by developing ecosystem risk assessments are an effective mechanism for discussing and setting ecosystem objectives as well as priorities. This was the process followed in the NPFMC.

- ***Flexible and adaptive process*** – The process of developing ecosystem indicators needs to be flexible and adaptive to adjust to new knowledge and management needs. This was characteristic of the NPFMC and MSFD processes.

- ***Fluid and strategic communication*** – This, for example, requires good knowledge of management processes so, ecosystem information can be prepared and adapted to fit management cycles and needs. Communication tools including visual tools can also facilitate more tailored communication with decision makers and stakeholders.

Good scientific practices fostering the implementation of EAFM

1. ***Setting area-based assessment units or ecoregions to guide ecosystem planning, assessments, research and management advice* –** This defines areas based on ecological criteria to better capture ecosystem processes. They serve as the basis for ecosystem productivity estimates and can also set the spatial level at which management approaches are evaluated.

2. ***Monitor selected ecosystem indicators to track the impacts of pressures (fishing and climate) on the state of the ecosystems* –** As the case studies have highlighted, there is a need to focus effort on a manageable number of indicators to achieve efficiency both in analysis and communication but also because of resource constraints.

4. ***Data collection and assessment processes that allow for estimation of cumulative impacts of fishing* –** This is a fundamental transition in data collection and analysis that is needed to facilitate evaluation of impacts from different processes on single species and ecosystems. Examples of this include collection of data to map the range of species affected by fishing and calculate rates of incidental mortality.

6. ***Quantification of ecosystem production and thresholds* –** This approach is being used to provide the broader context within which management decisions for the exploitation of single species or groups of species are taken. Production estimates could be the outcome of multispecies /ecosystem models, empirical studies, or both.

7. ***Development of ecosystem risk assessments* –** This process examines the ecological and economic impacts of the different commercial activities. It can identify priority areas and issues for management attention but also highlight research needs. This approach is used extensively around the world; for example, CCAMLR requires that an ecosystem risk assessment be undertaken before any new fishing activities can be authorised while ICCAT and IOTC have used Ecological Risk Assessments (ERAs) to support management considerations about incidentally caught species, such as sharks and birds. The NPFMC has also conducted Ecosystem Risk Assessments for each of its regions to identify the most pressing ecosystem issues and prioritize actions.

8. ***Processes to support by-catch reduction and protection of food webs and habitats –*** Data collection and other processes that have been employed in this field include mandatory observers on board all vessels and detailed logbooks for recording by-catch and other impacts of fishing (e.g. litter). Methods for identifying Vulnerable Marine Ecosystems (VMEs) and protocols that govern vessels actions once they encounter VMEs are also well developed and it is an area of ecosystem-related work that has progressed in all 3 regions considered.

9. ***Digital tools to visualize indicators and integrate information in support of ecosystem assessments –*** As the work of IndiSeas project highlighted, visualisation and other digital tools can increase outreach and help inform fisheries scientists, policy makers, and the public about the status of marine ecosystems and their response to fishing.

Useful lessons to guide the development of EAFM

Based on the application of EAFM and good practices reviewed, there are considerations that have been consistently highlighted as useful lessons to guide future development of EAFM. They are summarized below and also discussed in detail in Appendix 1.2.

- ***Ecosystem-focused fisheries management can be done without full knowledge of the ecosystem, but making use of all knowledge available is crucial.*** This lends support to iterative, adaptive processes and recognises that not all ecosystem components or challenges could be addressed at the same time.
- ***Good knowledge of the annual management cycle will help identify opportunities for incorporating ecosystem information into management decisions.*** Strengthening engagement between scientists and managers is another area that has been highlighted as important for progressing EAFM; making timely and tailored scientific contributions could support that.
- ***The process of selecting ecosystem indicators needs to be flexible and adaptive to identify a small number of key indicators.*** Characteristics of such key indicators that have been highlighted include comparability across different systems and making use of data currently available. An adaptable process could help deal with challenges relating to data gaps and resources

and recognises that not all ecosystem issues could be identified at the start of the EAFM process.

- ***Stakeholders need to be involved in the development of ecosystem products from the beginning through transparent processes and tailored communication.***
- ***Development of ecosystem indicators and assessments can provide an opportunity for stronger regional collaboration.*** Sharing data and knowledge is emerging as a key action for making best use of resources and provides a further incentive for collaboration. Adoption of standardised guidelines for data collection and estimation of indicators (and to override data confidentiality issues) will support stronger outputs and can increase participation and regional collaborations.

2.3. Sub-task 1.2 – Establishment of a preliminary list of ecosystem indicators with its strengths and weaknesses

The list of ecosystem indicators identified for each of the reference cases and projects covered in sub-task 1.1 consists of more than 200 indicators. Following the development of the preliminary list of ecosystem indicators, a general framework was created to compile and group the indicators into main types and support the work of subsequent tasks. Strengths and weaknesses of the main types of indicators were also summarized using knowledge built through their application to fisheries management in the reference regions and elsewhere. This process is described in more detail below and the results (standardized list of indicators) can be found in Appendix 1.3. A first level of screening of the standardised list of indicators was also done under this task using simple criteria such as excluding indicators that still require considerable development.

Several published criteria were examined to select and rank indicators (Rice & Rochet, 2005; Shin *et al.*, 2010; Queirós *et al.*, 2016) and identify those that were more relevant for the purposes of this project. The chosen (and adapted) criteria were used for the second level of screening to select indicators under Task 2.

2.3.1. Framework to organize and catalogue the indicators

A set of 8 attributes was chosen to describe each of the indicators identified in the case studies and programs to provide a standardised format. The attributes are shown in Table 2.1.

Table 2.1 Attributes used to describe the indicators organized in Appendix 1.3.

Attributes
Origin or program of indicators
Indicator name (original name)
Indicator name (short name)
Description
Data sources
Indicator classification
Ecosystem components monitored
Type of indicator

For some of the attributes, a set of pre-determined options were used to maintain consistency in the description and process of cataloguing the indicators (see "Read me" file in Appendix 1.3). For example, the attribute "indicator classification" had 3 possible options: Pressure indicator (monitoring impacts from human activities, e.g. fishing pressure), state indicator (monitoring changes in the ecosystem, e.g. abundance), and response indicator (relating to societal response and management measures, e.g. proportion of sea within marine protected areas).

The ecosystem indicators identified provided wide coverage across all attributes considered. There was also high degree of overlap in the type of indicators extracted from the case studies and programs reviewed. Given that high degree of overlap and the large number of indicators identified, all the indicators from each case study were catalogued into 4 main categories to reflect the main ecosystem components (target species, by-catch species, habitats, and trophic links). This helped identify duplicate indicators and reduce the number of indicators in the list[10]. As expected, indicators that described changes in population size or spawning stock for target or non-target species were the most common across the case studies.

[10] The new clustering and reduced list of indicators are not presented here due to space limitations but are presented in Task 2.

Indicators that were focusing on changes in mean length in single populations or across different species (e.g. top predators) were also found in more than one of the case studies reviewed. Interestingly, there was a great number of indicators that have already been developed for trophic relations, and this probably reflects the intense interest in monitoring the broader impacts of fisheries on marine food webs. A first level of screening was also done at this stage and excluded mainly indicators that were still at the early stage of development and were expected to require further testing before becoming operational.

The four categories of indicators together with the criteria described in the following section were used in Task 2 to further narrow down the list of indicators for monitoring the impact of fisheries targeting HMS on marine ecosystems. A summary of strengths and weaknesses for the type of indicators considered was also developed to support the next phase of screening and provide an overview of relevant considerations (Table 2.2).

2.3.2. Criteria for the selection of indicators

Previous European projects and other international initiatives have proposed and developed numerous ecological indicators to support EAFM. Often many more indicators have been considered than what can be implemented in practice, and a selection of the most suitable indicators from the more extensive list had to be taken. To ensure objectivity in the final selection, a set of criteria are typically applied to rank indicators given their strengths and weaknesses relative to key attributes that define an indicator, its use, and applicability. Rice and Rochet (2005) outlined the necessary steps to select from diverse potential indicators:

Step 1 - determine user needs

Step 2 - develop a list of candidate indicators

Step 3 - determine screening criteria

Step 4 - score indicators against criteria

Step 5 - summarize scoring results

Step 7 - make final selection

Step 8 - report on the suite of indicators

Table 2.2 Summary of strengths and weaknesses of different indicator types

Type/family of indicators	Category it applies	Strengths	Weaknesses
Relative reproductive capacity of stocks and associated parameters (e.g. size at first maturity)	Target, by-catch	Simple to derive, information on spawning biomass, % of fish above mature size, etc. are often collected or calculated as standard. Can provide a single summary metric at ecosystem level.	Difficult to calculate sustainable targets for biomass, rather than precautionary lower limits, since multi-species reference points are required (e.g. biomass targets associated with fishing at multi-species maximum sustainable yield).
Population structure indicators (sex ratio, age/length/maturity structure of catches/ population, ratio of bigger fish, min/max length of species, etc.)	Target, by-catch, trophic relations	Simple statistics. Already used in single species to detect changes due to fishing pressure. Could capture ecosystem-level impact and functioning (e.g. combine data across species) using data some of which might be collected already (e.g. length distribution).	Surveys will be needed to collect some of the data, reduce bias that fishery-based data introduce, and cover species for which no data from fisheries statistics or standard sampling exist.
Fish condition (e.g. length-weight residuals, disease indicators)	Target by-catch	Can be used as a proxy for survival/resilience and link to ecosystem impacts/health.	Tailored surveys and additional resources for analysis will probably be needed.
Fishing pressure indicators (e.g. combined fishing mortality)	Target, by-catch, trophic relations	A direct index of impact – provides a combined view of the effect, could be calculated through standard stock assessment for some species.	Data intensive, often relies on modelling, tailored surveys are required.
Spatial distribution indicators (e.g. distributional range of pelagic fish, species evenness)	Target, by-catch, Trophic relations	Could pick up loss of subpopulations or diversity. Would be useful to measure any change due to management of marine protected areas	Mainly relies on detailed surveys and data that are not collected routinely.
Overall by-catch impacts (e.g. mammals, birds, elasmobranch, cetacean) using numbers, mortality rates, reproductive success,	By-catch, trophic relations	Reflect impacts on the whole ecosystem using simple statistics (i.e. numbers of individuals). It can also provide information about trophic relations and used to detect changes/impacts in them.	Observer programs are required, possibly with specialised training and cumulative analysis of data (i.e. data collected from several countries, operations) is needed to provide representative figures. Numbers of by-catch require

etc.			abundance estimates to interpret level of impact.
Absolute or relative (CPUE, etc.) abundance of a set of selected species	Trophic relations	Simple statistics, data for some of the species might be collected for stock assessments (for target species) or through observers.	Only available for some species so additional data will be required. Could mask real impacts; as numbers of one selected species decrease another might increase to replace the former.
Primary production indicators (e.g. plankton biomass, structure, production, distribution)	Trophic relations	Data can be collected through passive monitoring, so cost efficient, easy to understand metric and can be linked to fish condition.	Requires additional resources for data analysis, not clear how to link responses observed to management measures.
Top predators indicators (ratio of combined biomass, average trophic level they occupy, predation mortality)	Trophic relations	Provides information about ability of the group to control and regulate abundance at lower trophic levels and changes in the diversity of the ecosystem (e.g. changes in their average trophic level).	Data for some species might be available through conventional data collection but more surveys will probably be needed to cover a representative set of species and collect specialised data such as stomach content.
Diversity indicators (species richness, community composition move from big fish to many small fish)	Trophic level	Easy to communicate and some data are already collected.	Rely on survey data mainly and could be characterised by high variability.
Habitat spatial structure indicators (distribution range, pattern, volume, areas no accessible to fishing, etc.)	Habitats	Generally easy to communicate and some data are already collected. Could pick up losses of habitat/communities.	Rely on survey data mainly and requires considerable resources for data analysis and habitat mapping.
Habitat conditions (physical damage, relative abundance of typical species and communities, etc.)	Habitats	Some data are available, could link to condition of species in higher trophic levels or pick up losses in diversity.	Rely on survey data mainly and requires considerable resources for data analysis and habitat mapping.

Rice and Rochet (2005) evaluated existing screening criteria and suggested that there were 9 criteria that should always be considered, namely: Concreteness; Theoretical basis; Public awareness; Cost; Measurement; Historical data; Sensitivity; Responsiveness; Specificity (see Appendix 1.4 for details). In recent years there have been multiple attempts to improve on and/or adapt these criteria. A set of relevant studies were reviewed, and we considered whether any adaptations were required in the context of HMS and fisheries under the purview of tuna RFMOs.

Study 1: Indicators of the Seas (IndiSeas) – Shin et al. 2010

Shin *et al.* (2010) report on an IndiSeas working group that adapted the screening criteria of Rice and Rochet (2005) (Appendix 1.4) for the application on multiple ecosystem assessments in a comparative exercise. They argued that meeting the criterion for "General public awareness" would require that indicators also meet the "Concreteness" criterion. The three criteria of "Cost, Measurement, and Historical data" were combined to a single criterion "Measurability". The "Responsiveness" and "Specificity" criteria were not used since the evidence base was not considered strong enough. Indicators were subsequently screened against four criteria only (ecological significance, sensitivity, measurability, and general public awareness), and were considered to either meet the criteria satisfactorily or not in a binary fashion. However, in order to create a suite of indicators that included the key components for their ecosystem assessments an additional constraint was required. This constraint was that, at least, one indicator should be retained for each category in the assessment (size-based, species based, trophodynamic, pressure, biomass-related) and one indicator for each management objective considered (i.e. conservation of biodiversity, maintaining ecosystem stability and resistance to perturbation, maintaining ecosystem structure and functioning, maintaining resource potential). As a result, the four criteria led to the acceptance of 8 key indicators. Later the working group adopted a fifth criterion, 'Tractability', to reflect the following aim: the set of indicators must remain tractable, i.e. small. It must permit synthesis of the states and trends of exploited ecosystems and it must be possible to estimate the set of indicators (i) for an extended range of ecosystems, and (ii) with annual updates. Redundancy of indicators should be avoided as much as possible.

Their analysis showed that application of the criteria alone does not necessarily lead to a suite of indicators that cover all focal components of the ecosystem nor all management objectives. Therefore, additional constraints might be required (such as the one described above) to achieve that.

Study 2: Indicators for Puget Sound –Kershner et al. 2011

In contrast to the reduction of criteria by IndiSeas, a specific study on food web indicators for Puget Sound, USA, expanded the screening criteria to 19 but aggregated them into three categories: primary considerations, data considerations, and other considerations (Kershner *et al.*, 2011) (see more details in Appendix 1.4). To address the need to steer the screening of indicators towards a suite that includes all focal components of the ecosystem and management objectives, the screening procedure was embedded within a hierarchical framework. A scoring procedure was implemented and numerical weights were applied to each criterion based on their perceived importance to stakeholders. For each indicator a single value was determined based on the summation of the score multiplied by the corresponding weight.

The application of a hierarchical framework showed that an extensive list of criteria can be reduced to a single score for comparative purposes, which can aid selection.

Study 3: Indicators from multiple studies – Queirós *et al.* (2016)

Lynam *et al.* (2016) reviewed the selection criteria published prior to their study and selected a set of 8 quality criteria (Table 2.3). The authors developed a hypothesis-based protocol under which indicators could be evaluated. Indicators were assessed using a simple ranking system that quantifies the strengths or weaknesses of indicators. In line with Kershner *et al.* (2011) and Andrews *et al.* (2015) a single score is determined per indicator and this can be used to give an overall comparable ranking. However, tabular output showing the scores for each Indicator Quality (IQ) should be retained to demonstrate where shortcomings and needs for development remain. The authors also suggest that all indicators should attain an overall minimum score (i.e. a value of 4) to be considered useful for ecosystem assessment. Furthermore, the thresholds for IQ1, ”Scientific basis”, and IQ3, ”Responsiveness to pressure”, must both be passed for the indicator to be considered to meet essential quality standards. Thus, if either IQ1 or IQ3 scored zero the indicator would fail even if the overall score from all IQs would be greater than 4. They also argued that all operational indicators need to have both a strong scientific basis and are shown to be responsive to pressures in order to be used in ecosystem assessments. Therefore, criteria related to IQ1 and IQ3 are more important than other criteria.

Table 2.3 Indicator quality criteria from Queirós *et al.* (2016).

List of IQ
IQ1. Scientific basis: Based on sound scientific concept as documented by peer reviewed publications and general acceptance within the scientific community. There is a conceptual understanding between pressure and indicator response with some degree of consistency in that response.
IQ2. Ecosystem relevance: Needs to be indicative of changes within a biological component that reflect the status of the ecosystem in terms of structure and function/process. It should also be linked to ecosystem services where possible (based on documented evidence/published, peer-reviewed literature).
IQ3. Responsiveness to pressure: Reflects changes in ecosystem component that are caused by variation in any specified manageable pressure. Must have a high signal to noise ratio. The indicator should respond sensitively to particular changes in pressure. The response should be unambiguous and in a predictable direction, based on theoretical or empirical knowledge, thus reflecting the effect of the pressure on the ecosystem component in question. Ideally the pressure-state relationship should be defined under both the disturbance and recovery phases.
IQ4. Possibility to set targets: The indicators should provide a basis for setting targets against which environmental status can be objectively assessed. Clear targets that meet appropriate target criteria (absolute values or trend directions) for the indicator can be specified that reflect management objectives.
IQ5. Precautionary capacity/early warning/anticipatory: Indicators that signal potential future change in an ecosystem attribute, before actual harm, are advantageous. This could facilitate preventive management, which could be less costly than restorative management.
IQ6. Concrete, measurable, accurate, precise and repeatable: Indicators should ideally be (easily and) accurately determined using technically feasible and quality assured methods. Quantitative measurements are preferred over qualitative, categorical measurements, which are, in turn, preferred over expert opinions and professional judgment.
IQ7. Cost-effective: Sampling, measuring, processing, analysing indicator data, and reporting assessment outcomes, should make effective use of limited financial resources. The cost of achieving a certain level of accuracy and precision and spatial cover should be considered.
IQ8. Existing/ongoing (monitoring) data: Indicators must be supported by current or planned monitoring programmes that provide the data necessary to derive the indicator. Ideal monitoring programmes should have a time- series capable of supporting baselines and reference point setting. Data should be collected on multiple sequential occasions using consistent protocols, which account for spatial and temporal heterogeneity.

Additional approaches to further refine suite of indicators

Lynam *et al.* (2016) reviewed a range of modelling approaches and their uses within an assessment cycle for the MSFD. The authors suggest that analytical approaches should be fundamental to the selection of indicators in addition to their evaluation. Many examples of empirical modelling of indicators can be found in the scientific literature. In particular, a statistical approach (Principal Components Analysis) was used by Methratta and Link (2006) to group, rank, and ultimately select between multiple indicators, where time-series data were available. The approach ranked indicators relative to one another in terms of their explanatory power and also provided a means to examine indicator redundancies. The authors argued that this approach should be used to extend the evaluation procedure to determine an appropriate indicator suite after the screening criteria have been applied to cull those indicators that have only minimal utility. For indicators that represent change in food web functioning, Torres *et al.* (2017) suggest that statistical modelling studies should be undertaken to investigate linkages between indicators and demonstrate their relationships to multiple pressures. Such an approach can also help identify where redundancies lie and allow for a further shortening of the indicator list.

A summary

After reviewing the published selection criteria, the consortium agreed to apply the Queirós et al. (2016) approach for our evaluation of indicators in Task 2. There was great commonality between the criteria developed suggesting a consensus on the key criteria. The Queirós et al. (2016) approach integrated much of the developments that had been made before it and created a clear framework for assessing the indicators strengths and weaknesses, providing a statistical summary for each indicator while retaining a comprehensible level of detail.

2.4. Sub-task 1.3 – A revision of state of the art concerning the impacts of exogenous unmanageable pressures, on target and bycatch highly migratory species

The Consortium investigated and reviewed existing knowledge on impacts of exogenous pressures in the context of HMS. This review focused on climate change, as another potential major pressure on the state of HMS and associated ecosystems (Bell *et al.*, 2013), and summarised current evidence on its impact on target and bycatch HMS under the purview of tuna RFMOs. The review included ecosystem modelling approaches such as that presented in the Western Central Pacific Fisheries Council (WCPFC) and Inter-American Tropical Tuna Commission (IATTC) (e.g. Ecopath with Ecosim and SEAPODYM) to consider the impacts of climate change and environmental variability on key target tuna species (Lehodey *et al.*, 2014; IATTC, 2015). A summary of the major outcomes identified for different types of species was prepared to highlight their relevance and applicability to the current work undertaken in ICCAT and IOTC.

2.4.1. Indirect and direct effects of climate change on HMS

While commercial fishing has been identified as the primary pressure affecting HMS, many of which are under the purview of tuna RFMOs (Collette *et al.*, 2011), climate change is now arising as another potential major pressure on the state of HMS and associated ecosystems (Bell *et al.*, 2013). Many studies forecast an increase in sea surface temperature of 3 ° C, a drop in pH of 0.3 units, oxygen concentrations below the mixing layer of less than 30 µmol / kg, and a decline in the salinity of the oceans (Nye, 2010) in the next hundred years. The reduction of the oxygen dissolved in the water is expected to produce an expansion of midwater Oxygen Minimum Zones (OMZ), which imply a reduction of the useful habitat for the pelagic species, mainly for the non-hypoxia tolerant species (Gilly *et al.*, 2012; Stramma *et al.*, 2012). This could have implications in terms of food availability but also in fisheries catchability as explained in the next section. Moreover, the combined effect of temperature and salinity changes due to climate warming are expected to reduce the density of the surface ocean, increase vertical stratification, and change surface mixing (Barange & Perry, 2009). These changes will probably have an immediate effect on the primary production, with potential cascading effects on the different trophic levels. In addition, tuna larvae in particular and fish larvae in general are physiologically sensitive to acidification which increases mortality (Bromhead *et al.*, 2015). Consequently, climate change can affect HMS populations indirectly, through changes in the ecosystem properties and trophic relationships. Moreover, it can have direct impacts on these populations due, for example, to changes in their habitats, which in turn may affect species distribution, metabolic balances, and spawning success. The following sections look at those impacts in more detail.

Indirect effects of climate change on HMS

Studies on the impact of climate change on non-marine species are numerous and take into account several sources of uncertainty such as the different atmosphere–

ocean general circulation models and Intergovernmental Panel on Climate Change (IPCC) emission scenarios. The IPCC developed a Special Report on Emissions Scenarios (SRES) and the scenarios considered in it have been used in the analysis of possible climate change, its impacts, and options to mitigate climate change (Nakicenovic *et al.*, 2000). The SRES included 40 different scenarios grouped into four different families (A1, A2, B1, B2) according to their expected storyline and future greenhouse gases. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. They cover a wide range of key "future" characteristics such as demographic change, economic development, and technological change. In this context, in the Western Pacific, the IPSL-CM4 model shows that there is likely to be a 9% decrease in primary production in the Warm Pool by 2011 under certain scenarios (Marti *et al.*, 2010), and a 20-33% decrease in the adjacent Archipelagic Deep Basins province. Similar reductions in the biomass of zooplankton are expected (Le Borgne *et al.*, 2011). Ultimately, these reductions in primary and secondary production could cascade up the food web, and affect the abundance and spatial distribution of zooplankton, larvae, HMS, etc. IATTC and WCPFC have been pioneers among the tuna RFMOs in developing ecosystem models (e.g. Ecopath with Ecosim and SEAPODYM models). A reason for that is possibly the strong influence of El Niño Southern Oscillation (ENSO) over the distribution and abundance of several species, including apex predators, in the Pacific Ocean. These ecosystem models can serve, among other things, to quantify the impacts of environmental variability and climate change over these species (Olson & Watters, 2003; Lehodey *et al.*, 2014). In the Western and Central Pacific, projected changes under climate change scenarios point to lower larval survival in the most western areas, hence increasing the proportion of individuals that are spawned in more favourable areas in the east, and shifts in the HMS feeding grounds due to changes in the mid-trophic levels of the pelagic food web (Lehodey *et al.*, 2011). More recently, *Dueri et al. (2014)* predicted global changes in skipjack abundance and distribution, partly due to changes in the availability of food resources.

Direct effects of climate change on HMS

Climate change is expected to have significant effects over the oceanic environment. In addition to their impact on lower components of the food web, changes on ocean temperature, dissolved oxygen, ocean currents and ocean acidification have also been predicted to result in direct effects on HMS populations. Some of these direct effects include changes in spawning location and spawning success, as well as changes in the distribution of fish in response to spatio-temporal changes in the distribution/abundance of their preferred habitats (Lehodey *et al.*, 2011). Additionally, the increase in ocean temperature and mixed layer stratification leads to the expansion of areas with hypoxic waters and oxygen-depleted dead zones (Altieri & Gedan, 2015).

Oxygen concentration can therefore be a limiting factor in the species distribution in some areas. It has been shown to compress the habitat of HMS in some areas into a narrow surface layer. This can potentially limit the vertical distribution of HMS to shallow waters, where they are more vulnerable to surface gears (Prince & Goodyear 2006). HMS such as tunas can also be sensitive to changes in oceanic circulation as they determine (i) the location of spawning grounds; (ii) the dispersal of larvae and juveniles; and (iii) the distribution of prey for adults (Lehodey *et al.*, 2011).

Lastly, ocean acidification can directly affect HMS such as tuna populations in several ways. It may affect their physiological costs in dealing with acidosis and have an effect on their growth performance and formation of otoliths. Ocean acidification can also affect the distribution of calcifying phytoplankton and zooplankton and impact sound propagation (sound absorption is expected to be reduced by 20-60 % in the upper few hundred meters of the Pacific Ocean by 2100) (Lehodey *et al.*, 2011).

2.4.2. Predicted effects of climate change on HMS

Effects of climate change on tunas

The natural inter-annual variability of large-scale climate phenomena, known as climatic oscillations are measured through different climatic indexes such as North Atlantic Oscillation (NAO), South Oscillation Index (SOI) or Arctic Oscillation (AO) between others. The effect of climatic oscillations on tropical tunas are well described in the literature, in such a way that these oscillations are known to have an effect on abundance (Lima & Naya, 2011; Kumar *et al.*, 2014; Rubio *et al.*, 2016), physical condition (Báez *et al.*, 2011; Kanaji *et al.*, 2012; Muñoz-Expósito *et al.*, 2017), and maturation (Kim, 2015). Furthermore, a recent study has also concluded that climatic oscillations could affect the physical condition of albacore tuna, and suggest they have a cumulative effect on its life history affecting the number of spawning events that can be carried out throughout its life (Báez *et al.*, 2011).

These studies show that tuna biology and its fisheries respond quickly to the climatic variability. In this framework, a growing number of studies are also evaluating the current and future impacts of climate change on the physiology, distribution, abundance, and reproductive and feeding migrations of these species (Dufour *et al.*, 2010; McIlgorm, 2010; Muhling *et al.*, 2011; Bell *et al.*, 2013; Dueri *et al.*, 2014) (Table 2.4). Most of these studies have taken place in the Pacific Ocean. While most studies predict no changes or minor changes in the abundance of several species of tunas in the long term in the Pacific Ocean, it is important to note that many of them foresee significant changes in their distributions and their catches (Lehodey *et al.*, 2010; Lehodey *et al.*, 2013). However, Dueri *et al.* (2014) showed different trends in changes in skipjack tuna biomass among the oceans, with the Indian Ocean showing large increases in biomass in the first half of the 21st century followed by sharp declines in the second half. These changes in tuna biomass may have important implications for the governance of highly migratory fish stocks. Dell *et al.* (2015) projected a poleward and offshore shift in the core fishing areas of yellowfin tuna in the Tasman Sea.

In the Western and Central Pacific, another modelling study found that distribution of skipjack tuna, the major tuna resource in the area, may move further east across the region. This eastward movement of skipjack tuna could benefit some nations by increasing their access to tuna resources and adversely affect other nations which will lose access to optimum tuna fishing grounds (Bell *et al.*, 2013).

In the Atlantic Ocean, it has been documented that North Atlantic albacore tuna and East Atlantic bluefin tuna arrive progressively earlier each year in the Bay of Biscay area, a major feeding ground. The results indicate that these species may be gradually adapting the timing of their feeding migrations and latitudinal distributions in response to climate change (Dufour *et al.*, 2010). Another modelling study has suggested that climate change might alter the temporal and spatial spawning and migratory activity of the West Atlantic bluefin tuna in the Gulf of Mexico with subsequent effects on population sizes and fisheries (Muhling *et al.*, 2011). The impacts of climate change on tuna and billfish species are raising concerns and need to be further understood, in order for governments and tuna RFMOs to respond rapidly to climate change with mitigation and adaptation programs.

In summary, while some studies predict no changes or minor changes in the abundance of several species of tuna from Pacific Ocean in the next 20-30 years, a reduction in the biomass of tuna species as well as changes in their distributions are expected by the end of this century for certain areas (Lehodey *et al.*, 2010 ;

Dueri *et al.*, 2014). Thereby, climate impact on tuna biology and its fisheries could depend on time and region. As previously mentioned, most studies have focused on investigating the impacts of climate change in the Pacific Ocean, therefore the impacts on other oceans remains poorly understood.

Table 2.4 The main foreseen effects from climate change models on tuna species.

Reference	Species	Region	Projection	Indirect Effect	Direct Effect	Foreseen effects
Lehodey *et al*. (2010)	Bigeye tuna	Pacific Ocean	2100	Yes	Yes	Habitat improvement in Eastern tropical Pacific, while in the western tropical Pacific it worsens. Increase in biomass in the eastern Pacific. Biomass stable and then decrease in the western Pacific.
Lehodey *et al*. (2011)	Skipjack and bigeye tunas	Pacific Ocean	2100	Yes	Yes	Skipjack biomass and catch expected to increase in the EPO and decrease in the WCPO. Bigeye biomass and catch decreasing in both regions.
Lehodey *et al*. (2013)	Skipjack tuna	Pacific Ocean	2100	Yes	Yes	Slight increase in biomass in the western tropical Pacific until 2050, then it stabilizes and starts decreasing after 2060. Habitat improvement in Eastern tropical pacific. Lehodey et al., 2013 in figure 1a estimate (in a no fishing scenario) an increase in biomass to 7.5E^6 t by 2050 and a decrease in biomass to 5.5E^6 t after that and by 2100. Nevertheless, IPCC-type models are still coarse in resolution and can produce significant anomalies. These limitations have direct and strong effects when modelling the dynamics of populations.
Dueri *et al*. (2014)	Skipjack	Pantropical	2100	Yes	Yes	Changes in the distribution and increases in global biomass between 2010 and 2050. Biomass decrease towards the end of the century
Dell *et al*. (2015)	Yellowfin tuna	Eastern Australia	2060	No	Yes	The spatial distribution of YFT is expected to change due to the impacts of global climate change (between now and 2060). That is, spatial distribution of catches of YFT in the Tasman Sea will shift poleward and towards open sea waters.
Matear *et al.* (2015)	Skipjack	Western Pacific	2060	No	Yes	No changes expected.

Woodworh-Jefcoasts *et al*. (2015)	HMS	Central Northern Pacific	2100	No	Yes	Reduction in biomass by 15-30%.
Yen *et al*. (2016)	Skipjack	Western and Central Pacific	2050	No	Yes	Increase in catches.
Muhling *et al*. (2017)	Atlantic Bluefin Tuna	Atlantic Ocean	2100	No	Yes	Projections showed reductions in habitat. Climate change will increase metabolic stress on Bluefin tuna.
Lehodey *et al*. (2017)	Yellowfin tuna	Pacific Ocean	2100	No	Yes	The predicted impact of climate change on this yellowfin tuna population is mainly driven by the change in spawning habitats (temperature and productivity), and subsequent larval recruitment with a decrease in the WCPO and increase in the EPO. The temporal trends in larval biomass predicted are relatively stable in the WCPO until 2050 and start to decrease in the second half of the century.

Effects of climate change on non-tunas highly migratory fish species

Highly Migratory Species other than tuna have also been listed in Annex 1 of UNCLOS (United Nations Convention of the Law of the Sea) including billfishes, oceanic sharks, and other migratory fishes (dolphin fishes, pomfrets, and sauries), and cetaceans. The effects of natural climatic oscillation as well as climate change have also been investigated, although to a lesser extent, on billfishes, oceanic sharks and other teleost migratory species. Although there are many studies that provide some indication of the effect of climate change on the biology of these HMS, there are few studies that directly focus on forecasting the effect of climate change on them. Below, we provide a summary of the current situation at species-specific level. A summary of the work in this area is also provided in Table 2.5.

Billfishes

There are no direct studies on the effect of climatic change on billfishes. However, there are some studies that have tried to identify links between climate change and billfishes. For example, it has been documented that the Atlantic blue marlin (*Makaira nigricans*) abundance responds to physical oceanography, temperature, and dissolved oxygen (Goodyear, 2016). Thereby, it is expected that changing climatology could affect the distribution of the entire population.

It has also been documented that the extension of deep hypoxic bodies of water limits the distribution of tunas and billfishes by compressing their preferred habitat into a narrow surface layer making these species more vulnerable to over-exploitation by surface gears (Prince & Goodyear, 2006). Thus, climate change might have an effect on billfish species by changing their physiologies, temporal and spatial, horizontal and vertical distributions and abundance within the water column (Hill *et al.*, 2016; Carlisle *et al.*, 2017).

Oceanic sharks

Studies documenting the effect of climate change on oceanic sharks are also scarce. Oceanic sharks are biologically sensitive to the potential increase of CO_2 level due to climate change (Rosa *et al.*, 2017). Recent studies have highlighted the clear effects of oceanic acidification on the physical condition, growth, aerobic potential and prey detection on tropical oceanic shark *Chiloscyllium punctatum* (Rosa *et al.*, 2014; Rosa *et al.*, 2016; Rosa *et al.*, 2017). Another recent study expects changes in the distribution of silky shark *Carcharhinus falciformis* due to climate change by the end of current century (Lezama-Ochoa *et al.*, 2016). It suggests that oceanic sharks from Western Mediterranean Sea respond to the inter-annual climatic oscillations, and these oscillations contribute to the local Catch Per Unit Effort (CPUE) fluctuations. Thus, climatic oscillations could change migration pattern of oceanic sharks annually, modifying its local abundance. Thereby, it is expected that changing climatology could impact the local abundance of oceanic sharks in this region.

Other migratory teleost fishes (dolphin fishes, pomfrets, and sauries)

Studies on the effect of climate change on highly migratory teleosts fishes other than tunas have also been limited. Pimentel *et al*. (2014) suggests that the ocean acidification, through metabolic and locomotory changes, may potentially influence the recruitment, dispersal success, and the population dynamics of the early larvae of dolphinfish (*Coryphaena hippurus*) (Pimentel *et al.*, 2014). Currently, there are also projects in progress focusing on the effect of climate change on the distribution, physiology and behaviour of dolphin fishes (Ospina-Alvarez *et al.*, 2017).

Another study has also indicated that climate-ocean changes affect the body size, abundance and catch rates of Pacific saury (*Cololabis sira*) from the Tsushima Warm Current region (including Yellow Sea, East China Sea and East/Japan Sea) (Gong & Suh, 2013).

Table 2.5 The main forecast results from climate change models for non-tunas highly migratory fish species.

Reference	Species	Region	Indirect forecast effect	Direct forecast Effect	Foreseen effects.
Gong & Suh (2013)	*Cololabis sira*	North Western Pacific	Yes	No	Climate-ocean changes affect the body size, abundance and catch rates
Pimentel *et al.* (2014)	*Coryphaena hippurus*	Tropical areas	Yes	No	The ocean acidification, through metabolic and locomotory changes, may potentially influence the recruitment, dispersal success, and the population dynamics of the early larvae of dolphinfishes
Baez (2015)	Oceanic Sharks	Mediterranean Sea	Yes	No	The local CPUE fluctuations of Oceanic sharks from Western Mediterranean Sea linked to the NAO and AO. Thereby, it is expected that changing climatology will affect the local abundance of oceanic sharks from this region.
Gooyear (2016)	*Makaira nigricans*	Atlantic Ocean	Yes	No	Atlantic blue marlin (*Makaira nigricans*) abundance responds to physical oceanography, temperature and dissolved oxygen. Thereby, it is expected that changing climatology will affect the distribution of the entire population.
Lezama-Ochoa *et al.* (2016)	*Carcharhinus falciformis*	Tropical areas	No	Yes	Changes in distribution.
Rosa *et al*. (2017)	*Chiloscyllium punctatum*	Tropical areas	Yes	No	Biological responses of sharks to ocean acidification.

Effects of climate change on other marine HMS

Cetaceans

Studies documenting the effect of climate change on Cetaceans are also scarce. However, there is broad agreement that certain species and populations are likely to be especially vulnerable to climate related changes, including those with a limited habitat range, or those for which sea ice provides an important habitat for the cetacean population and/or that of their prey (Simmonds & Eliott, 2009). According to Whitehead *et al.* (2008), the cetacean diversity from Pacific and Indian Ocean will decline across the tropics and will increase at higher latitudes due to climate change.

Sea turtles

Sea turtles are marine migratory species not included in UNCLOS annex listing HMS, but they are also accidentally by-caught in pelagic tuna fisheries (Clarke *et al.*, 2014).

Studies on the effect of climate change on sea turtles have focused on the effect of global warming, specifically the increase of water temperatures on the sex determination of embryos during their development at nesting beaches (Hays *et al.*, 2017). The sex of most turtles is determined by the environment after fertilization. In these reptiles, the temperature of the eggs during a certain period of development is the deciding factor in determining sex, and small changes in temperature can cause dramatic changes in the sex ratio (Bull, 1980). Often, eggs incubated at low temperatures (22-27 °C) produce males, whereas eggs incubated at higher temperatures (30 °C and above) produce females. There is only a small range of temperatures that allow both males and females to hatch from the same brood of eggs (Pieau *et al.*, 1999). In this context, there are growing concerns about the effect of global warming on sex ratios in sea turtles, because they will become increasingly female-skewed (Hays *et al.*, 2017).

Furthermore, other studies predict climate change effects on hatchling viability and dispersal performance (Cavallo *et al.*, 2015), and habitat impacts (Willis-Norton *et al.*, 2015).

Effects of climate change on ecosystems as a whole

While numerous studies have focused on studying the direct impacts of climate change over the distribution of suitable habitats for different HMS species (Dueri *et* *al.*, 2014; Dell *et al.*, 2015; Lezama-Ochoa *et al.*, 2016), few studies have addressed the impacts of climate change from a global perspective, analysing the pelagic ecosystem as a whole (i.e. multiple trophic levels and multiple species and their interactions) (Woodworth-Jefcoats *et al.*, 2015; Woodworth-Jefcoats *et al.*, 2017). Thus, although it is expected that some species will increase their distribution areas in the short-time due to global warming (e.g. YFT models from Hartog *et al.* (2011)), it must be borne in mind that these distributional changes will lead to direct competition with other species. A recent study has also suggested that increasing temperatures due climate change may alter the spatial distribution of tuna and billfish species richness across the North Pacific basin (i.e. modify its current distribution and local extinctions) (Woodworth-Jefcoats *et al.*, 2017). Moreover, declining zooplankton densities may act cumulatively to lower carrying capacity for commercially valuable fish.

To describe foreseeable species distribution changes, Cheung *et al.* (2013)have developed a tropicalization index, denominated Mean Temperature of the Catch (MTC). The index is calculated from the average inferred temperature preference of exploited species weighted by their annual catch. The MTC is formulated as follows:

$$MTC_{yr} = \frac{\sum_i^n T_i C_{i,yr}}{\sum_i^n C_{i,yr}}$$

Here, $C_{i,yr}$ is catch of species *i* in a specific region in year *yr*, T_i is the median temperature preference of species *i* and *n* is the total number of species. With global warming, it is expected that there is an increase in the MTC means. These will imply the major presence of tropical species in temperate and cold areas. Thus, due to climate change there will be changes in distribution patterns of many species, thus the MTC index could be a useful tool for monitoring these changes.

2.4.3. Conclusions and recommendations

As shown above, many studies predict the various effects of climate change on the biology, distribution, and abundance of HMS species individually. However, there are few studies that address the effect of climate change on the pelagic ecosystem as a whole, from a multispecies or multi-trophic level perspective. Looking at the pelagic ecosystem as a single unit, climate change could trigger a cascade effect on the whole ecosystem, with non-foreseeable consequences. Although limited knowledge about the specific links between climate change and ecosystem processes and associated reactions makes it difficult to identify actions to address this challenge, some steps can be taken already. This includes building monitoring systems and indicators to detect potential changes and developing processes to facilitate the uptake of climate-related findings in scientific advice and management considerations.

Improving knowledge about the impact of climate change on tuna and other HMS can help build more robust management. Research could focus on studying the impact of climate change on tunas, including small tunas, and their ecosystems from oceans other than the Pacific Ocean. Improving our ability to forecast the effects of climate change on tunas as well as other HSM groups will also support identification of appropriate actions to mitigate the impacts of those effects.

2.5. Research recommendations for future work

The Consortium proposes a series of recommendations derived from the development of Task 1 to foster the implementation of EAFM in tuna RFMOs:

- The transition to an EAFM will lead to a significant increase in the amount of data and technical expertise required. This includes multidisciplinary monitoring programmes at a more tailored spatial scale and more complex data and simulation analysis. Work to identify the most cost-effective ways, including partnerships, standardisation protocols, and maximum use of existing programmes, to collect and analyse data and ensure access to the skills required will pay dividends in the medium term.
- Research to set reference points (or benchmarks) for ecosystem indicators for HMS will provide a very good starting point for applying the EAFM as it will increase the robustness of the approach.
- Improve knowledge about specific links between climate change and ecosystem processes and associated reactions. This could include building monitoring systems and indicators to detect potential changes.
- Develop processes to facilitate the uptake of climate-related findings into scientific advice and management considerations.

3. TASK 2 – SELECT ECOSYSTEM INDICATORS AND IDENTIFY DATA REQUIREMENTS IN THE CONTEXT OF FISHERIES TARGETING HIGHLY MIGRATORY SPECIES

Key message

- A set of ecosystem indicators are proposed that are considered useful to support the EAFM in the tuna RFMOs.
- The strengths and weaknesses of available datasets that can be used to develop ecosystem indicators are highlighted and the benefits of non-traditional datasets are demonstrated.
- The development of ecosystem indicators will be largely dependent on the fisheries data collected by CPCs as well as the development of ecosystem models.
- The proposed indicators are ranked in order of priority for development given the quality of the indicator (including cost effectiveness and relevance of the indicator to the tuna RFMOs).

3.1. Objectives

The objective of task 2 is to deliver a list of potential ecosystem indicators of relevance to tuna RFMOs (ICCAT and IOTC) that are suitable to track the impacts on marine ecosystems of fisheries targeting HMS. The project is not developing indicators but conducting a review of those indicators currently in operation or being developed for use in ecosystem assessments. To identify useful indicators, Task 2 completed the following sub-tasks:

- Subtask 2.1 **–** Selection of potential list of ecosystem indicators
- Subtask 2.2 – Description of supporting information and complementary programmes
- Subtask 2.3 – Description of data sources for indicators
- Subtask 2.4 – A proposal of ecosystem indicators (summary table)

The development of a complete indicator suite will take many years and require specific development work to build bespoke indicators for particular issues of concern. Instead, we concentrated on identifying potential ecosystem indicators of relevance to tuna RFMOs. We focused on indicators that monitor the broader and cumulative impacts of fisheries on the state of the following ecosystem components: (1) target species, (2) bycatch and vulnerable species, (3) food-web and trophic interactions and (4) habitats. Therefore, we prioritized community level indicators, habitats indicators and/or those that represent trophic interactions and the wider impacts of fisheries. We prefer indicators with a strong evidence base, rather than those indicators that were at a preliminary stage of development. We valued more ecosystem indicators that capture the cumulative impacts of fisheries on the whole community (including targeted and non-targeted species) and capture the indirect impacts of fisheries on food webs. While single-species indicators (such as biomass or age/size structure of stocks), commonly examined through conventional fisheries management, are still required and are an essential element in operationalizing an ecosystem approach, we stress that additional information can be gained by incorporating more integrative indicators into ecosystem assessments and we suggest that HMS fisheries should consider these to be a priority.

3.2. Subtask 2.1 - Selection of potential list of ecosystem indicators

During Task 1 a range of approaches to ecosystem management were reviewed. From the case studies reviewed >200 indicators were collated (including state and pressure metrics) (full list Appendix 1.3). A common problem identified during the implementation of an indicator framework for ecosystem assessments is the myriad of indicators suggested by the scientific community. It is not feasible for any organization to develop and agree 200 indicators at once and the initial step required is therefore to prioritize from the suggested list those indicators that are key to build the structure of the assessment (its “backbone”). In this subtask, those indicators that are essential to initial implementation of the ecosystem approach for HMS fisheries were prioritize based on literature review and expert judgement. Initially the set of >200 indicators was screened by the project team with the specific question in mind of how relevant the indicator was or could be to HMS fisheries. A subset of 36 indicators was created that related directly to the broader impacts of fisheries on target species and communities they form, bycatch and threatened species (marine mammals, seabirds, sharks and turtles), pelagic habitats (plankton indicators), and trophic relationships (primary production, predatory-prey relationships) (Table 3.1). These 36 indicators were then evaluated in great detail using a ranking procedure (see Table 2.3 which describes the ranking procedure) to create an ordered list of indicators which can guide the choice of where to place efforts to develop key indicators specific to HMS fisheries and their data.

Table 3.1 Final list of ecosystem indicators to monitor the impacts of fisheries targeting HMS on marine ecosystems.

Final list of 36 indicators
Group spawning stock biomass relative to a reference level (e.g. B_{MSY} or proxies)
Group fishing mortality relative to a reference level (e.g. F_{MSY} or proxies)
Single species biomass/abundance/catch rate indicators
Mean trophic level indicators (model derived)
Community size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (model based)
Size spectra (total, by guild/community) (model based)
Total catch (total, by guild)
Community size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (catch based)
Mean trophic level indicators (catch)
Frequency of bycatch and total number of interactions
Population level mortality (non-target species)
Distributional range (extent, centre of gravity, pattern within range and along environmental gradients)
Proportion of non-declining exploited species
Recovery in the population abundance of sensitive fish species
Single species spawning stock biomass relative to reference level (e.g. B_{MSY} or proxies)
Single species fishing mortality relative to a reference level (e.g. F_{MSY} or proxies)
Single species size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation)

Zooplankton biomass and/or abundance
Primary production
Biomass indicators (total, guild/community) including fish, marine mammals and seabirds
Mean maximum length of fish and elasmobranchs (catch data)
Predation mortality from multispecies models
Mean maximum length of fish and elasmobranchs (model derived)
Single species catch (length-frequency; catch sex and maturity composition)
Proportion of predatory fish or "large species indicator" (model derived)
Proportion of predatory fish or "large species indicator" (catch data)
Fish condition (length-weight residuals) for main commercial species
Single species age-based indicators
Zooplankton biomass and size structure
Abundance-biomass comparison (ABC) curves
Species diversity indices (Shannon/Simpson/Evenness/Richness) (model derived)
Ichthyoplankton abundance indices
Species size at first sexual maturation
Species diversity indices (Shannon/Simpson/Evenness/Richness) (catch data)
Discard survival
Population genetic structure (single species)

To compare the merits of the short-listed indicators we apply the Indicator Quality (IQ) evaluation method, with the pelagic food web specifically in mind, following Queirós *et al.* (2016) (see Task 1.2). However, in our application only IQ1 "Scientific basis" was considered a one-out-all-out criterion (0 or 1 score). Furthermore, we make a minor adjustment to the methodology: in IQ3 "responsiveness to pressure", we allow a three-level score (0, 0.5 and 1), rather than simply zero or one, since many of these indicators are potentially responsive to pressure in the waters of direct concern to ICCAT and IOTC but with little or no testing specifically in the oceanic region (and this potential was scored as 0.5).

On further evaluation and with the pelagic community in mind, 2 indicators failed IQ1 (i.e. scored 0 for "Scientific basis"): namely, the Population genetic structure indicator and Discard survival for which responsiveness was unclear. The full evaluation of ecosystem indicators is available in Appendix 2.1, which contains many key references consulted during the evaluation. Only 2 indicators, Group Spawning Stock Biomass relative to reference level (e.g. B_{MSY} or proxies) and Group Fishing mortality relative to a reference level (e.g. F_{MSY} or proxies), were both cost-effective and had data readily available for tuna RFMOs to implement since these rely solely on traditional stock assessment outputs. An additional 13 indicators were considered cost-effective since some data are collected currently and the additional information could be collected. For the remaining indicators the data to estimate the indicators are either not currently collected, are collected and not publicly available, and in some cases the data required may need new scientific surveys. To assist with our evaluation of indicators, we thus review not only the datasets that are currently analysed by ICCAT and IOTC (see Task 2.3), but also what supporting information and complementary programmes outside these tuna RFMOs might contribute to indicator development and ecosystem assessment.

3.3. Subtask 2.2 - Supporting information and complementary programmes

In addition to the effects of fishing activity on the ecosystem, there are exogenous pressures that can affect both the estimates and the status of the state indicators. The effect of an exogenous driver on the estimation of an indicator can bias our perception of its state or of the effect of fishing activity (or any other human impact) on the ecosystem component being evaluated. Additionally, and noting the overarching objective of the current project is selecting indicators for fisheries targeting HMS, it is of utmost important to distinguish the impacts derived from the fishing activity from other exogenous pressures. In this context, it becomes essential that monitoring programs consider the wider context within which indicators are measured (such as climate change and ocean acidification) (Lynam *et al.*, 2016). As discussed under task 1.3, environmental changes are expected to have important effects, through numerous mechanisms, on several components of the ecosystem, including the biomass, distribution, physiological condition, and catchability of highly migratory target species.

The effect of exogenous drivers on indicator estimates

Many of the indicators listed under Task 2.1 require an estimate of either the total biomass or biomass trends of ecosystem components. Stock assessments and biomass trends of HMS rely primarily on data from fisheries. However, the vulnerability of the stock to the gears, and its spatio-temporal variability, remains poorly understood, requiring simplifying assumptions to be made. As an example, the main source of information on stock biomass trends in HMS fisheries is the CPUE series of key fisheries (e.g. tunas), i.e. those in which the variables defining the effective amount of effort exerted can be easily captured (typically, longline fisheries). The use of CPUE series as an index of abundance usually requires a standardization process consisting of isolating all those exogenous factors from temporal variations in abundance from the CPUE time-series. These exogenous factors include those generated by modifications in fishing efficiency and strategies and environmental fluctuations. The selection of the latter is considered to be one of the most difficult, arbitrary, and poorly documented stages (Quiroz *et al.*, 2011).

In the context of a changing environment, the catchability of a given species or guild may vary due to environmental drivers that are not usually captured in CPUE standardization models. As an example, several studies that have used habitat-based models for the standardization of catch rates of several large pelagic species have shown that combining habitat preferences information with oceanographic data may change critically our perception of abundance trends (Hinton & Nakano, 1996; Maunder *et al.*, 2006). Hence, it is of utmost importance to account for environmental drivers that can change abundance estimates due to changes in the species distribution or in its catchability.

Additionally, environmentally-driven changes in species growth rates can distort our view on changes in the population size structure and resulting estimates of selectivity of fishing gears. Selectivity patterns are a common tool for measuring the impact of fishing activity on the ecosystem and size structure metrics are commonly used to develop state indicators for fish. Environmental changes can drive the spatial distribution of several species, thus taking potential shifts in species distribution into account is critical when interpreting many of the state indicators already identified.

Exogenous pressures can introduce sources of bias in many other types of indicators. These exogenous pressures can be as variable as the effect of dissolved and suspended matter over phytoplankton estimation or sediment loading on primary production (Lynam *et al.*, 2016), market demand over size distribution of the catch (Reddy *et al.*, 2013), etc.

The impact of drivers, other than fishing pressure, on population status

There are other factors that can indirectly influence the effect of fishing on several of the ecosystem components. As an example, it is well known that economic drivers can result in gear configuration and fishing strategy modifications aimed at maximizing economic yield, which can affect the catchability of different species (Quaas *et al.*, 2016; Tidd *et al.*, 2016). Changes in gear configuration to improve profitability of fisheries have also been reported to result in changes in bycatch frequency (Camiñas *et al.*, 2006) and gear selectivity towards certain size classes of bycatch species (Wallace B.P. *et al.*, 2008). Therefore, economic information (e.g. market prices) can also help understand trends in indicators which cannot be easily accounted for with the information typically available from fisheries (Katara *et al.*, 2016).

There is also a huge variety of human pressures, other than fishing, that can alter HMS populations. As an example, Francis and Lyon (2013) reviewed impacts on cartilaginous fishes and indicated that human activities as variable as pile driving, electromagnetic fields or sonar surveys can lead to displacements, interference with migratory, spawning and feeding behaviour, and, ultimately, animal death.

The evaluation of the impact of HMS fisheries must therefore take into account these additional pressures when monitoring the different ecosystem indicators. These additional pressures should also be noted and incorporated where possible when establishing reference levels.

Recommendations on how to incorporate additional information in the ecosystem indicators estimation and interpretation.

Noting the above, it is recommended that when possible additional sources of information need to be accounted for when interpreting the results of the state indicators described previously and listed under Task 2.1. There are different ways in which this type of non-conventional information, listed under Task 2.3, can be incorporated in the estimation and interpretation of ecosystem indicators:

- Include additional explanatory variables in the calculation of indicators

In many instances, the estimation of an indicator is the result of a standardization process that allows for the inclusion of as many explanatory variables as needed. As discussed under section 2.3, there are several sources of additional data, ranging from remote sensing or oceanographic modelling to economic data, that are currently available and can further improve the estimation of state indicators (Katara *et al.*, 2016). It must be noted, however, that the influence of some variables on indicators can be subject to several issues, like time and/or spatial lags (Hinton & Nakano, 1996), correlation among variables, etc., that require a combination of expert advice and statistical approaches (e.g. use of transfer function models) to describe them (Quiroz *et al.*, 2011).

- Estimation of trends in habitat distributions

The effect of environmental conditions on species distribution (see Task 1.3) has been investigated frequently by analysing spatio-temporal patterns in the catch distribution of certain gears and, more recently, by combining information about its habitat preferences (Arrizabalaga *et al.*, 2015). Examples of indicators relating to distribution and habitats are the use of habitat suitability indices, spatial variations in centre of habitat distribution (Hill *et al.*, 2016), spatial variation in the centre of mass of the catch or of the catch rates (Hyder *et al.*, 2009; Dufour *et al.*, 2010) and habitat suitability area (Lezama-Ochoa *et al.*, 2016).

- Development of models that account for different effects on HMS stocks.

The combination of laboratory or field experiments with oceanographic models can provide a tool to account for the effect of environmental conditions on HMS populations (Lehodey *et al.*, 2013). In a broader context, Lynam *et al.* (2016) have recently discussed in detail the key role of ecological models in the implementation of the MSFD (European Commission, 2008). As these authors indicate, one of the major strengths of these models is that, based on the integration of data collected at limited points in time and space, the models can be used to derive change in indicators over more extensive spatiotemporal scales and to assess the impacts of change on those components that are poorly monitored (e.g. marine mammals). Moreover, these models are readily available to estimate indicators that address several issues at once (such as multiple descriptors for the determination of "good environmental status" laid down under the MSFD). The use of these models has also been advocated *inter alia* as a tool for the selection of indicators and associated reference points, in addition to their role in the estimation of ecosystem state (see Lynam *et al.* (2016) for review).

3.4. Subtask 2.3 - Data sources for indicators

3.4.1. Traditional data sources in ICCAT and IOTC

ICCAT and IOTC species

ICCAT is in charge of managing tuna and tuna-like species in the Atlantic Ocean. The ICCAT Convention defines the term of tuna and tuna-like fish as the Scombriformes, with the exception of the families Trichiuridae and Gempylidae and the genus Scomber within the family Scombridae. Thus, the Convention mandate covers the following species distributed in the ICCAT Convention Area (Table 3.2). In addition, the Commission has instructed the Secretariat to collate data on non-target, associated and dependent species affected by tuna fishing operations, including pelagic sharks and rays, marine turtles, seabirds and marine mammals. The main bycatch shark species of special importance in ICCAT are blue shark, shortfin mako, porbeagle, thresher, bigeye thresher, oceanic whitetip shark, scalloped hammerhead, smooth hammerhead and sphyrna mokarran. Yet, some of these species are also being increasingly targeted by some fleets (e.g. blue shark, shortfin mako).

Table 3.2 List of species under the management of ICCAT

FAO English name	Scientific name	Species code
Atlantic bluefin tuna	*Thunnus thynnus*	*BFT*
Yellowfin tuna	*Thunnus albacares*	*YFT*
Skipjack	*Katsuwonus pelamis*	*SKJ*
Bigeye tuna	*Thunnus obesus*	*BET*
Albacore tuna	*Thunnus alalunga*	*ALB*
Blackfin tuna	*Thunnus atlanticus*	*BLF*
Spotted Spanish mackerel	*Scomberomorus maculatus*	*SSM*

Cero mackerel	*Scomberomorus regalis*	*CER*
King mackerel	*Scomberomorus cavalla*	*KGM*
West African Spanish mackerel	*Scomberomorus tritor*	*MAW*
Serra Spanish mackerel	*Scomberomorus brasiliensis*	*BRS*
Bullet tuna	*Auxis rochei*	*BLT*
Frigate tuna	*Auxis thazard*	*FRI*
Little tunny	*Euthynnus alleteratus*	*LTA*
Atlantic bonito	*Sarda sarda*	*BON*
Plain bonito	*Orcynopsis unicorlor*	*BOP*
Wahoo	*Acanthocybium solandri*	*WAH*
White marlin	*Tetrapturus albidus*	*WHM*
Roundscale georgii	*Tetrapturus georgii*	*RSP*
Mediterranen shortbill spearfish	*Tetrapturus belone*	*MSP*
Blue marlin	*Makaira nigricans*	*BUM*
Sailfish	*Istiophorus albicans*	*SAI*
Spearfish	*Tetrapturus pfluegeri*	*SPF*
Swordfish	*Xiphias gladius*	*SWO*

The IOTC Convention Agreement covers the conservation and optimum utilization of 16 species of tuna and tuna-like species, which include the principal market tunas, neritic tunas, mackerels and billfishes (Table 3.3). In addition, the Commission has instructed the Secretariat to collate data on non-target, associated and dependent species affected by tuna fishing operations, including pelagic sharks and rays, marine turtles, seabirds and marine mammals.

Table 3.3 List of species under the management of IOTC

FAO English name	Scientific name	Species code
Yellowfin tuna	*Thunnus albacares*	*YFT*
Skipjack tuna	*Katsuwonus pelamis*	*SKJ*
Bigeye tuna	*Thunnus obesus*	*BET*
Albacore tuna	*Thunnus alalunga*	*ALB*
Southern Bluefin tuna	*Thunnus maccoyii*	*SBT*
Longtail tuna	*Thunnus tonggol*	*LOT*
Kawakawa	*Euthynnus affinis*	*KAW*
Frigate tuna	*Auxis thazard*	*FRI*
Bullet tuna	*Auxis rochei*	*BLT*
Narrow barred Spanish mackerel	*Scomberomorus commersoni*	*COM*
Indo-Pacific king mackerel	*Scomberomorus guttatus*	*GUT*
Blue marlin	*Makaira nigricans*	*BUM*
Black marlin	*Makaira indica*	*BLM*
Striped marlin	*Tetrapturus audax*	*MLS*
Indo-Pacific sailfish	*Istiophorus platypterus*	*SFA*
Swordfish	*Xiphias gladius*	*SWO*

Main datasets available in ICCAT and IOTC

The ICCAT and IOTC secretariats are in charge of managing and maintaining various fisheries dependent datasets (Table 3.4). The level and quality of fishery statistics information held in ICCAT and IOTC and available in the public domain varies. Overall, the nominal catch as well as catch and effort and size frequency data disaggregated by species, areas, gear, flag and month is quite comprehensive. However, the information on bycatch and observer programs, although some of it is available in the public domain, is scarcer and of poorer quality. Information of tagging programmes carried out in the Atlantic and Indian Ocean are also of good quality for the main commercial tuna species and is available in the public domain of IOTC/ICCAT.

A brief overview of the status of data for each major dataset (Table 3.4) in the ICCAT and IOTC Secretariat is provided below. The overview focuses on describing the statistics of catch, effort, size frequency, observer data and other biological data for the main species of tunas and billfishes, sharks as well as the other species that are caught accidentally by tuna fisheries (some sharks, seabirds, sea turtles, marine mammals). For each dataset, the quality of the data held by the secretariat is briefly summarized by providing examples of a particular data submission for a given year. We also briefly described what species are reported and the spatial and temporal coverage of the dataset (when possible). With these examples, the aim is to provide an overall picture of data availability and quality. The CPCs have the responsibility of reporting these data and therefore, their level of completeness depends on the quality of data reported by each member state. Furthermore, it is noted that the level of implementation for the data collection, data requirements and data submission applicable to the species managed by ICCAT and IOTC has slowly been changing over time, and not until recently, CPCs had the obligation of submitting data on bycatch species (for example see IOTC timeline of implementation of Resolutions of data collection, Table 3.5).

Table 3.4 List of ICCAT and IOTC main traditional datasets maintained by their Secretariat which could be of interest to this project. It presents an overview of the main datasets and reporting obligations.

Name dataset	Brief description
Nominal catch information (Task I)	Provided nominal annual catch data (landings and discards from the 1950s) by species, stock, region, gear, fleet and flag. Species include tuna and tuna-like species and non-target fish species (by-catch).
Catch and effort (Task II)	Catch and fishing effort statistics for each species by small areas (1x1 degree squares for most gears, 5x5 degree squares for longlines), gear, flag and month.
Size information (Task II)	Individual lengths of samples measured for each species by small area (1x1 degree squares for most gears, 5x5 degree squares for longlines), gear, flag and month
CATDIS (Task II)	Task II catch data raised to total landings (5x5 degree squares, quarter, gear)
EFFDIS (Task II)	Spatio-temporal estimates of overall Atlantic fishing effort for longline and purse seine fleets (5x5 degree squares, quarter, gear)
Information of observer programs	Detailed information collected by National Observer Programmes, either aggregated or set-by-set under Rec. 11-10, 16-14
Biological information of the species	These data are collected under National Observer Programmes or National/International Research Programs
Tagging data	The Secretariat maintains an extensive database of conventional tagging data for tuna and tuna-like species for both conventional and electronic tagging data
Record of Vessels	Fleet craft, characteristics and number of authorised active vessels to fish tuna and tuna-like species are available since 2014 in ICCAT
Fish Aggregating Devices (FAD) management plans and FAD activity	The Secretariat maintains FAD management Plans submitted by CPCs. CPCs also need to submit information on the total number of FADs deployed per 1º x1º strata, number of FAD activated and deactivated, FAD losses, etc.

Table 3.5 Timeline of implementation of IOTC Resolutions on data collection and submission as an indication of the period during which they are in force (IOTC, 2017).

Res.	Description	Fisheries applies to:	Species applies to:	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
15/02	Min. data reporting requirements: Nominal catch	All fisheries	IOTC species														■	■	■	■	■	■	■
			Main sharks														■	■	■	■	■	■	■
	Min. data reporting requirements: Catch-and-effort	All fisheries	IOTC species				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
			Main sharks											■	■	■	■	■	■	■	■	■	■
	Min. data reporting requirements: Size data	All fisheries	IOTC species				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
			Main sharks											■	■	■	■	■	■	■	■	■	■
	FADs and Supply vessels requirements	Purse seine	N/A							■	■	■	■	■	■	■	■	■	■	■	■	■	■
15/01	Minimum data requirements: Logbooks	Purse seine	IOTC species and main sharks													■	■	■	■	■	■	■	■
		Longline															■	■	■	■	■	■	■
		Pole-and-line; gillnet																			■	■	■
		Handline; trolling																				■	■
15/08	FAD logbook reporting requirements	Purse seine, pole-and-line	As 15/02																		■	■	■
11/04	Regional Observer Scheme	Coastal fleets	As 10/02															■	■	■	■	■	■
		Industrial fleets >=24m LOA	All species															■	■	■	■	■	■
		Industrial fleets <24m LOA	All species															■	■	■	■	■	■
05/05	Data requirements: Sharks	As per 15/02	Main sharks											■	■	■	■	■	■	■	■	■	■
13/06	Data requirements: Oceanic whitetip shark	Authorised vessels	Oceanic whitetip																			■	■
12/09	Data requirements: Thresher shark		Thresher sharks																	■	■	■	■
13/05	Data requirements: Whale shark		Whale shark																			■	■
12/06	Data requirements: Seabirds		Seabirds												■	■	■	■	■	■	■	■	■
12/04	Data requirements: Marine turtles		Marine turtles																		■	■	■
13/04	Data requirements: Cetaceans		Ceteceans																			■	■

Task I Nominal Catch Information Databases

This database provides declared annual catches (landings and discards from the 1950s) by species, stock, region, gear, fleets and flag. These data are aggregated by calendar year for tuna and tuna-like species and non-target species (by-catch). Responsibility for reporting landings and discards data rests with flag states, as for the rest of the datasets in Table 3.4. The nominal catch data are in the public domain. Nominal catches are available for the ICCAT and IOTC main tuna and billfishes species, as well as other sharks and teleost fishes interacting with ICCAT and IOTC fisheries. Task I nominal catch data is a "key" dataset used in all the stock assessments. Thus, completeness and timely available datasets are essential for the Scientific Committee studies. The Nominal catch database is a key dataset to estimate many of the ecosystem indicators that rely on catch statistics.

To get an overview of data completeness, some summaries of data submissions by Members States, prepared by the ICCAT and IOTC Secretariats, are summarized below.

The ICCAT Report Card of Task I data for 2016 (Table 3.6) shows a summary of data submissions for Task I data. In 2016 these data were received from 63 CPCs (Contracting Party or Cooperating non-Contracting Party, Entity or Fishing Entity) (85%

reporting ratio). Only 11 flag CPCs (15%) did not yet reported this information. In terms of species coverage, the ICCAT Task I data contains catches for 173 species. Yet the temporal coverage of this data varies by major species group (Figure 3.1).

The IOTC Task I Nominal catch data, Task II catch and effort and size data was fully reported or partially reported (depending on the species group) in 2016 from 25 fishing parties (Figure 3.2). Five fishing parties have not reported statistics to IOTC for a period longer than 4 years (16% of the reporting ratio). In general, the nominal catch reporting coverage is the highest followed by catch-and-effort, while size data reporting levels are well below the levels reported for the other two datasets (Figure 3.2). The species coverage also varies substantially between species groups across the three datasets (Figure 3.2).

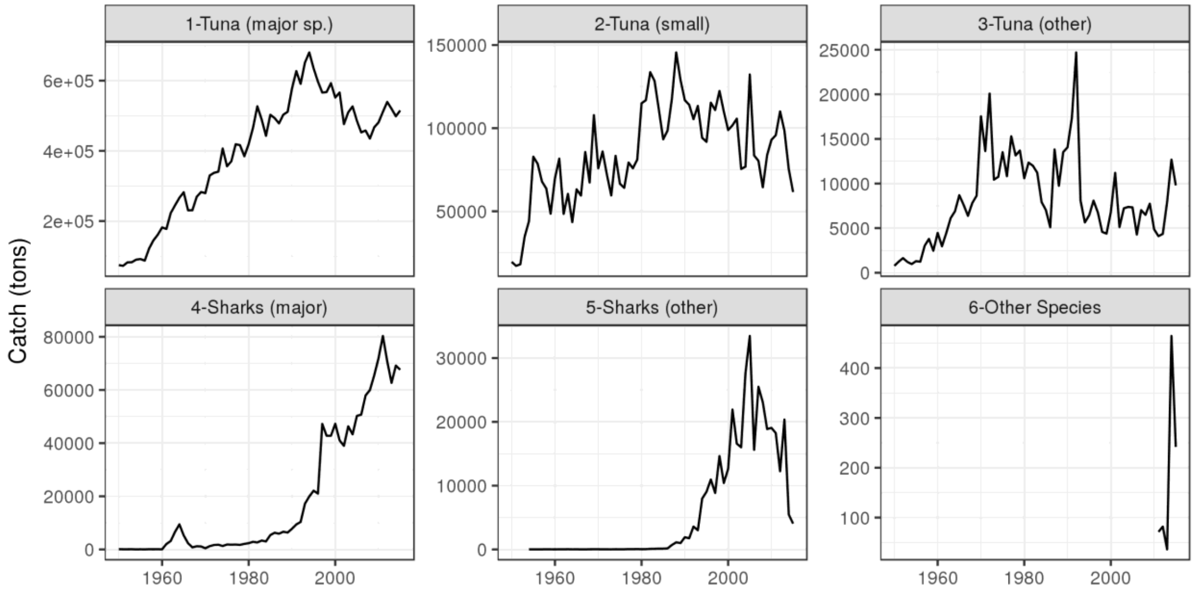


Figure 3.1 ICCAT Task I data, catch in tonnes, for major species groups over time. Major Tuna species include ALB(Albacore tuna), BET (Bigeye tuna), BFT (Bluefin tuna), SAI (Sailfish), SKJ (Skipjack tuna), SPF (Spearfish), SWO (Swordfish), WHM (White marlin) and YFT (Yellowfin tuna).

Table 3.6 ICCAT Task I nominal catch submission status for 2016 ("green": before deadline; "yellow": after deadline; "orange": has not passed the filter) (IOTC, 2017).

			Deadline (+1 day tolerance): 2017-08-01													
			Tuna (major sp.)										Small tuna	Sharks (major sp.)		
Status	Party	Flag	ALB	BET	BFT	BUM	SAI	SKJ	SPF	SWO	WHM	YFT	(any of 14 sp)	BSH	POR	SMA
CP	ALBANIA	Albania														
	ALGÉRIE	Algerie	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	ANGOLA	Angola						-0.2					-0.2			
	BARBADOS	Barbados	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	BELIZE	Belize	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
	BRAZIL	Brazil														
	CANADA	Canada	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	CAP-VERT	Cape Verde														
	CHINA PR.	China PR	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	CÔTE D'IVOIRE	Côte d'Ivoire	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
	CURAÇAO	Curaçao	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	EGYPT	Egypt			1											
	EL SALVADOR	El Salvador	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	EUROPEAN UNION	EU.Bulgaria											-0.2			
		EU.Croatia	1	-0.2	1	-0.2	-0.2	-0.2	-0.2	1	-0.2	-0.2	1	-0.2	-0.2	-0.2
		EU.Cyprus	1	1	1	1	1	1	1	1	1	1	1		1	1
		EU.Denmark														
		EU.España	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		EU.France	1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2		1
		EU.Germany											-0.2			
		EU.Greece	1		1					1			1			
		EU.Ireland	1		1					1						
		EU.Italy	1		1			1		1			1	1	1	
		EU.Latvia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		EU.Lithuania														
		EU.Malta	1		1					1			1	1		
		EU.Netherlands			-0.2			-0.2					-0.2			
		EU.Portugal	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		EU.United Kingdom	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	FRANCE (St-Pierre et Miquelon)	FR.St Pierre et Miquelon														
	GABON	Gabon														
	GHANA	Ghana	1	1	1	1	1	1		1		1		1	1	1
	GUATEMALA	Guatemala	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	GUINEA BISSAU	Guinea Bissau														
	GUINEA ECUATORIAL	Guinea Ecuatorial														
	GUINÉE REP.	Guinée Rep.														
	HONDURAS	Honduras														
	ICELAND	Iceland	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	JAPAN	Japan	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	KOREA REP.	Korea Rep.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	LIBERIA	Liberia	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
	LIBYA	Libya			1											
	MAROC	Maroc	1	-0.2	1	-0.2		-0.2		1		-0.2	-0.2		-0.2	1
	MAURITANIA	Mauritania														
	MEXICO	Mexico	1	1	1	1	1	1	1	1	1	1	1	1		1
	NAMIBIA	Namibia	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	NICARAGUA	Nicaragua														
	NIGERIA	Nigeria														
	NORWAY	Norway			1					1					1	
	PANAMA	Panama	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PHILIPPINES	Philippines														
	RUSSIA	Russian Federation	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	S. TOMÉ E PRINCIPE	S. Tomé e Príncipe	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	SENEGAL	Senegal	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	SIERRA LEONE	Sierra Leone														
	SOUTH AFRICA	South Africa	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	St VINCENT & GRENADINES	St. Vincent and Grenadines	1	1			1	1	1	1		1	1	1		
	SYRIA	Syria			0											
	TRINIDAD & TOBAGO	Trinidad and Tobago	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	TUNISIE	Tunisie											-0.2			
	TURKEY	Turkey	1		1					1			1			
	UNITED KINGDOM (O.Territories)	UK.Bermuda	1													
		UK.British Virgin Islands														
		UK.Sta Helena	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		UK.Turks and Caicos														
	UNITED STATES	U.S.A.	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	URUGUAY	Uruguay														
	VANUATU	Vanuatu														
	VENEZUELA	Venezuela	1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
NCC	Bolivia	Bolivia														
	Chinese Taipei	Chinese Taipei	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Costa Rica	Costa Rica														
	Guyana	Guyana								0			0			
	Suriname	Suriname														
NCO	Non-contracting parties	Dominica	-0.2	-0.2	-0.2		-0.2	-0.2	-0.2	-0.2		-0.2	-0.2			
		Saint Kitts and Nevis	1	1	1	1	1	1	1	1	1	1	1	1	1	1

NOTES:

NO FISHING ACTIVITY (flags in green, 12 flags): Bolivia, Costa Rica, FR.St Pierre et Miquelon, Guinea Ecuatorial, Nicaragua, Nigeria, Philippines, Suriname, UK.British Virgin Islands, UK.Turks
NO TARGETTING ACTIVITIES (some bycatch): Angola (small traps), EU.Germany, EU.Netherlands
ERRORS / INVALID FORMATS: Côte d'Ivoire, EU-France, EU-España, EU.Netherlands, etc.

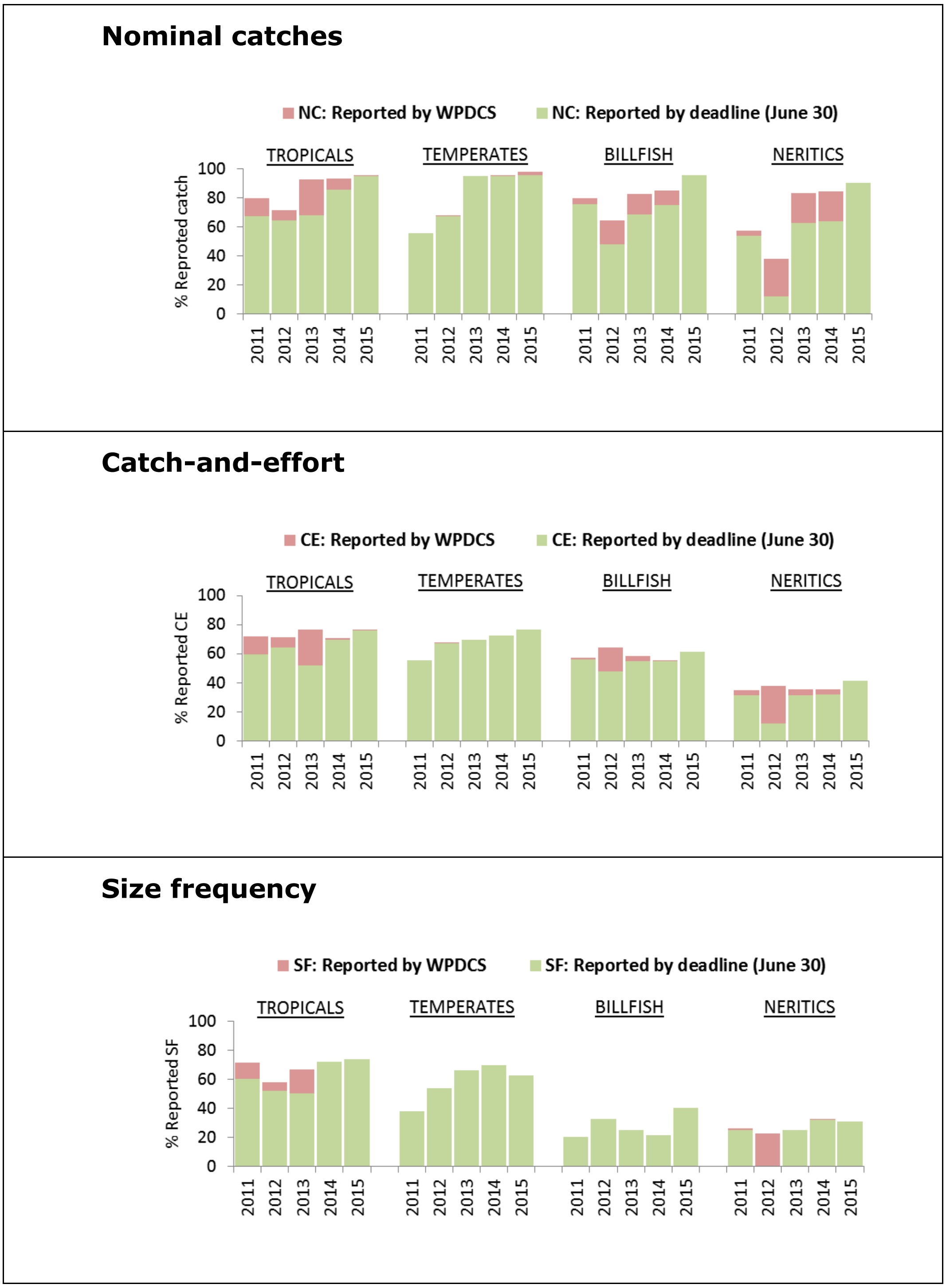


Figure 3.2 IOTC availability of data by the deadline for data submission (30 June 2017) and at the end of the year. NC: Proportion of total catch available; CE: Proportion of total catch for which catch-and-effort are available; SF: Proportion of total catch for which size frequency data are available; WPDCS: Working party on Data Collection and Statistics (IOTC, 2017).

Task II Catch & Effort Databases

Task II database includes catch and effort data, size sampling data and catch-at size data. This database is more detailed in terms of time and geographic information than Task I database, but often it reflects partial coverage (or sampling) compared to Task I statistics. Catch and fishing effort statistics for each species and stock is available by area (with a resolution of 1x1 degree squares for most gears, 5x5 degree squares for longlines), gear, flag and month. Catches and effort are not available for all nominal catches strata. 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. Yet, Task II information is the main source of data used by the Secretariat to estimate important datasets such as CATDIS (Catch distribution in the area), EFFDIS (effort distribution by gear), CAS (Catch at size) and Catch at age (CAA) for the main tuna and billfish species in ICCAT and IOTC for which stock assessments are conducted. The catch and effort database is a key dataset to estimate ecosystem indicators that rely on catch, effort, and size statistics.

To get an overview of data completeness, several report cards provided by the IOTC and ICCAT Secretariats are presented, which illustrate the quality of the data in terms of species coverage as well as gear, spatial, and temporal coverage.

The ICCAT Report Card of the catch and effort data for 2016, which summarizes the data submission by CPCs, illustrates how a total of 56 flags CPCs (76% reporting ratio), including 7 late-reporting flag CPCs, have reported catch effort data (Table 3.7). No information was yet submitted by 20 flag CPCs. Therefore, the Task II catch effort data are less complete than the Task I data. The majority of the Task II catch effort data submitted includes the geographical resolution required by the Scientific Committees (spatial resolution of 1x1 degrees or better for surface fisheries, and, 5x5 degrees or better for longline fisheries). The number of datasets submitted with the exact geographical location (Latitude/Longitude) continues its slow increasing trend.

The number of species reported in the ICCAT Task II catch and effort datasets has also increased lately, in particular for the pelagic shark species. The Task II catch effort dataset provides data for about 31 species, a much smaller number compared to the 173 species covered by Task I data (Table 3.8).

Table 3.7 ICCAT Task II catch and effort submission status for 2016 ("green": before deadline; "yellow": after deadline; "orange": has not passed the filter). Species codes in Table 3.2 (IOTC, 2017).

			Deadline (+1 day tolerance): 2016-08-01													
			Tuna (major sp.)										Small tuna	Sharks (major sp.)		
Status	**Party**	**Flag**	ALB	BET	BFT	BUM	SAI	SKJ	SPF	SWO	WHM	YFT	(any of 14 sp)	BSH	POR	SMA
CP	ALBANIA	Albania														
	ALGÉRIE	Algerie														
	ANGOLA	Angola	1	1				1		1		1				
	BARBADOS	Barbados	1	1		1	1	1		1	1	1	1	1		1
	BELIZE	Belize	1	1		1	1	1		1		1	0	1		1
	BRAZIL	Brazil														
	CANADA	Canada	1	1	1	1		1		1	1	1	1	1	1	1
	CAP-VERT	Cape Verde		0				0				0	0			
	CHINA PR	China PR	1	1	1	1	1		1	1	1	1		1		1
	CÔTE D'IVOIRE	Côte d'Ivoire	1	1		1	1	1		1	1	1	1	1		1
	CURAÇAO	Curaçao	1	1				1				1	1			
	EGYPT	Egypt			1											
	EL SALVADOR	El Salvador		0				0				0	0			
	EUROPEAN UNION	EU.Bulgaria											1			
		EU.Croatia	1		1					1			1			
		EU.Cyprus	1		1					1						
		EU.Denmark														
		EU.España	1	1	1			1		1		1	1	1		
		EU.France	1	1	1			1				1	1			
		EU.Germany														
		EU.Greece			1											
		EU.Ireland	1		1					1						
		EU.Italy	1		1					1			1			
		EU.Latvia														
		EU.Lithuania														
		EU.Malta	1		1					1			1	1		
		EU.Netherlands											1			
		EU.Portugal	1	1	1	1	1	1		1	1	1	1	1		1
		EU.United Kingdom	1		1								1	1		
	FRANCE (St-Pierre et Miquelon)	FR.St Pierre et Miquelon														
	GABON	Gabon														
	GHANA	Ghana		1		1	1	1		1		1		1		
	GUATEMALA	Guatemala	1	1				1				1	1			
	GUINEA BISSAU	Guinea Bissau														
	GUINEA ECUATORIAL	Guinea Ecuatorial														
	GUINÉE REP.	Guinée Rep.														
	HONDURAS	Honduras														
	ICELAND	Iceland			1											
	JAPAN	Japan	1	1	1	1	1	1	1	1	1	1		1	1	1
	KOREA REP.	Korea Rep.	1	1	1	1	1	1		1		1	1	1		1
	LIBERIA	Liberia														
	LIBYA	Libya		1												
	MAROC	Maroc		1	1					1		1				1
	MAURITANIA	Mauritania														
	MEXICO	Mexico	1	1	1	1	1	1	1	1	1	1	1	1		1
	NAMIBIA	Namibia	1	1		1		1		1		1		1	1	1
	NICARAGUA	Nicaragua														
	NIGERIA	Nigeria														
	NORWAY	Norway			1											
	PANAMA	Panama	0	0				0				0	0			
	PHILIPPINES	Philippines														
	RUSSIA	Russian Federation						0					0			
	S. TOMÉ E PRINCIPE	S. Tomé e Príncipe														
	SENEGAL	Senegal	1	1		1		1		1		1	1	1		1
	SIERRA LEONE	Sierra Leone														
	SOUTH AFRICA	South Africa	1	1		1		1	1	1		1		1		1
	St VINCENT & GRENADINES	St. Vincent and Grenadines	1	1			1		1	1		1	1	1		1
	SYRIA	Syria			0											
	TRINIDAD and TOBAGO	Trinidad and Tobago	1	1		1	1			1	1	1	1	1		1
	TUNISIE	Tunisie			1											
	TURKEY	Turkey														
	UNITED KINGDOM (O.Territories)	UK.Bermuda														
		UK.British Virgin Islands														
		UK.Sta Helena		0		0		0				0	0			0
		UK.Turks and Caicos														
	UNITED STATES	U.S.A.	1	1	1	1	1	1		1	1	1	1	1	1	1
	URUGUAY	Uruguay														
	VANUATU	Vanuatu														
	VENEZUELA	Venezuela	1	1		1	1	1	1	1	1	1	1	1		1
NCC	Bolivia	Bolivia														
	Chinese Taipei	Chinese Taipei	1	1		1	1	1	1	1	1	1		1		1
	Costa Rica	Costa Rica														
	Guyana	Guyana														
	Suriname	Suriname														

NOTES:

NO FISHING ACTIVITY (flags in green, 12 flags): Bolivia, Costa Rica, FR.St Pierre et Miquelon, Guinea Ecuatorial, Nicaragua, Nigeria, Philippines, Suriname, UK.British Virgin Islands, UK.Turks

NO TARGETTING ACTIVITIES (some bycatch): Angola (small traps), EU.Germany, EU.Netherlands

ERRORS / INVALID FORMATS: Côte d'Ivoire, EU-France, EU-España, EU.Netherlands, etc.

Table 3.8 Number of species and coverage by species group in ICCAT Task I and Task II catch and effort datasets.

Species Group	# of species in task I – Nominal catch	# of species in task II – Catch & effort	% coverage of species	% of coverage of catches for the covered species	% of coverage of catches for all the species
1-Tuna (major sp.)	10	10	100	68	68
2-Tuna (small)	15	14	93	20	18
3-Tuna (other)	22	4	18	27	4
4-Sharks (major)	3	3	100	19	19
5-Sharks (other)	96	0	0	0	0
6-Other Species	27	0	0	0	0

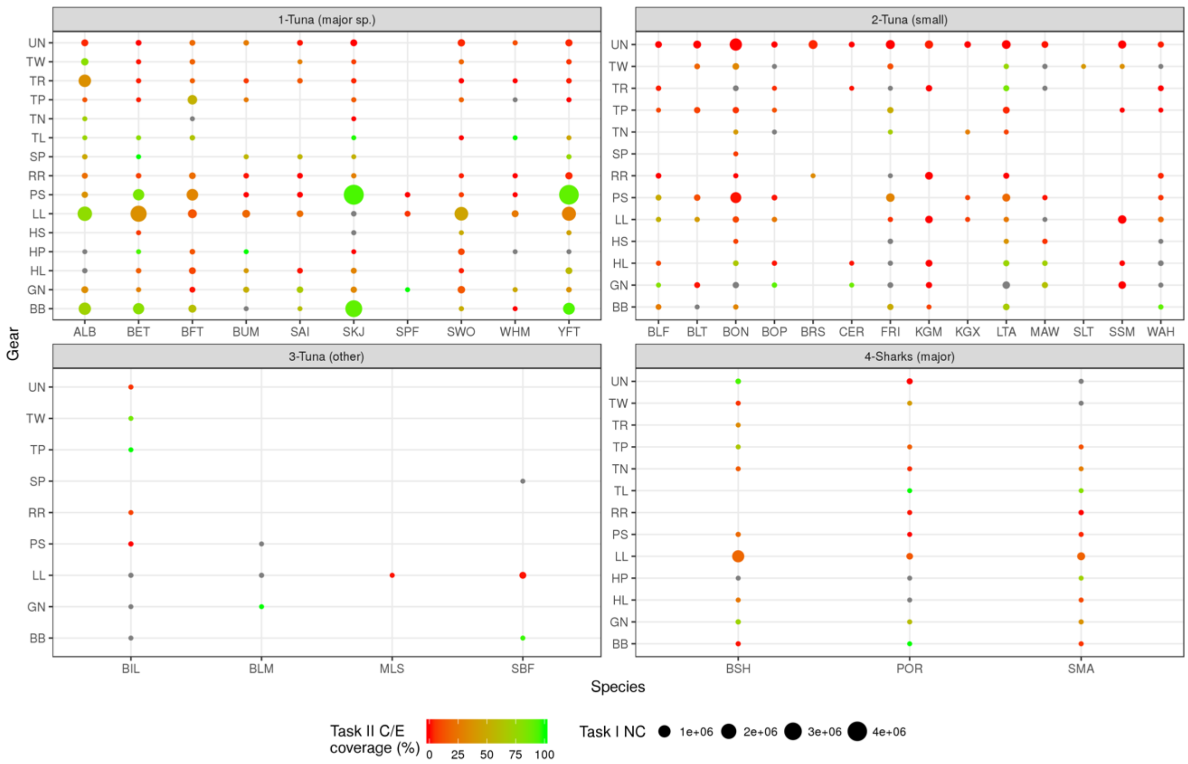


Figure 3.3 Species covered by ICCAT task II catch and effort dataset by gear group. The color indicate the catch coverage of the task II catch and effort related to task I nominal catches (NC), and the size of the circle indicate the total catch for the species /

gear in the task I NC dataset. Major gears: BB (Bait-boat), GN (Gillnet), LL (Longline), PS (Purse Seine), TP (Trap). Species codes in Table 3.2.

The coverage of ICCAT Task II catch and effort for each major gear disaggregated at the species level is relatively quite good for the main tuna species followed by the small tuna species group, although it varies by gear, and it is really poor for the rest of group species, including sharks and the others (Figure 3.3).

In terms of temporal coverage, the ICCAT Task II catch effort data are relatively good for the main tuna species, which increases and gets better over time, particularly for tropical tuna species (Figure 3.4). The temporal coverage for billfishes and sharks is much sparser (Figure 3.5). Note that in Figure 3.4 in some years the % coverage of Task II catch effort data relative to Task I nominal catch data is larger than 100% which indicates the necessity of adjusting the Task II catch and effort sampling to Task I.

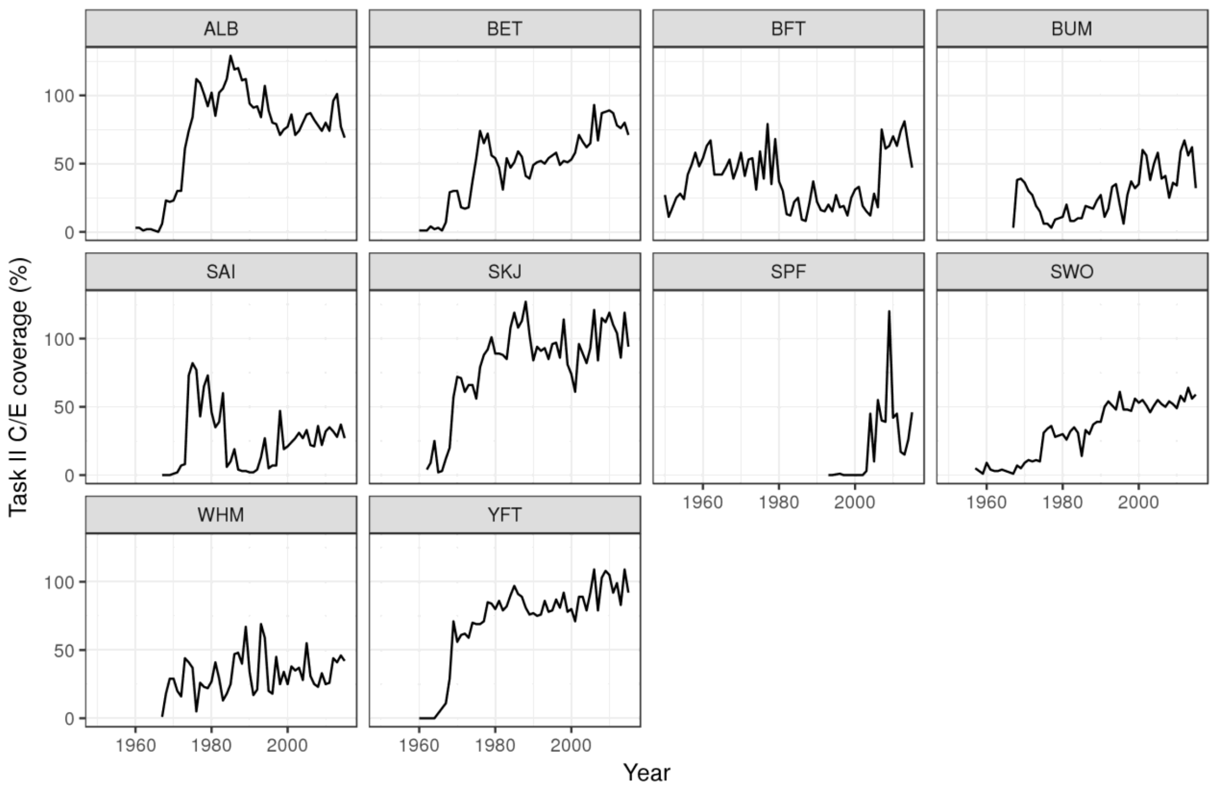


Figure 3.4- Main tuna species coverage by year in ICCAT Task II catch effort (C/E) data. It is calculated as the % of Task II catch effort data relative to Task I nominal catch data. Species codes in Table 3.2.

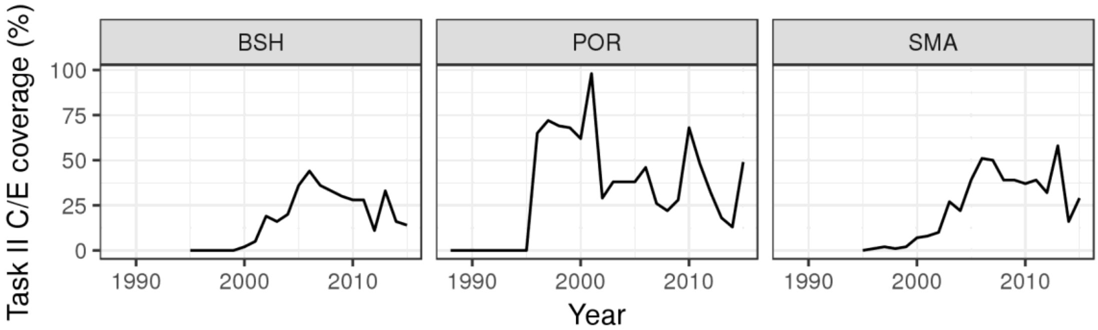


Figure 3.5 Major shark species coverage by year in ICCAT Task II catch effort (C/E) data. It is calculated as the % of Task II catch effort data relative to Task I nominal catch data. Shark species: BSH – Blueshark, POR – Porbeagle, and SMA – Shortfin Mako sharks.

The quality of the IOTC Task II catch and effort, as well as size frequency data, also varies widely across species and across major gear types. The IOTC secretariat prepares every year a Report Card for the catch, catch and effort and size data submitted with a quantitative analysis of its quality. A Report Card of the quality of nominal catch, catch and effort data and size frequency for each major species and year is illustrated in Table 3.9. The scoring system used by IOTC to assess the quality of the statistics available for each species is also presented in Table 3.10. Overall, nominal catch, catch-effort and size data are considered to be of fair good quality for the major tunas and swordfish while for the rest of species the quality remains poor (Table 3.9

Table 3.9 Overall status of IOTC catch, effort, and size frequency statistics, by year and species (1976-2015). Full description of legend can be found in Table 3.10 (IOTC, 2017).

Table 3.10 Scoring system used to assess the quality of statistics of IOTC species available in the IOTC databases (IOTC, 2017).

Key:		
	Species	Species code (Albacore ALB; bigeye tuna BET; black marlin BLM; bullet tuna BLT; blue marlin BUM; narrow-barred Spanish mackerel COM; frigate tuna FRI; Indo-Pacific king mackerel GUT; kawakawa KAW; longtail tuna LOT; striped marlin MLS; southern bluefin tuna SBF; Indo-Pacific sailfish SFA; skipjack tuna SKJ; swordfish SWO; yellowfin tuna YFT)
	%Catch	Contribution (in %) that the catches of the species make out of the total combined catches of all IOTC species, over the entire time series of catch
	Yfirst	Availability and quality of data in the IOTC database for the year, species, and gear
	Ylast	concerned, by type of dataset

e.g.;

Species	%Catch	YearYY
$Species_1^n$	% Catch, as defined above	Availability and quality of **nominal catch** data
		Availability and quality of **catch-and-effort** data
		Availability and quality of **size frequency** data

Key to IOTC Scoring system

Nominal Catch	By species	By gear
Fully available	0	0
Partially available (part of the catch not reported by species/gear)*	2	2
Fully estimated (by the IOTC Secretariat)	4	4

*Catch assigned by species/gear by the IOTC Secretariat; or 15% or more of the catches remain under aggregates of species

Catch-and-Effort	Time-period	Area
Available according to standards	0	0
Not available according to standards	2	2
Low coverage (less than 30% of total catch covered through logbooks)	2	
Not available at all	8	

Size frequency data	Time-period	Area
Available according to standards	0	0
Not available according to standards	2	2
Low coverage (less than 1 fish measured by metric ton of catch)	2	
Not available at all	8	

Key to colour coding

Dark green	Total score is 0 (or average score is 0-1)
Light green	Total score is 2 (or average score is 1-3)
Light orange	Total score is 4 (or average score is 3-5)
Orange	Total score is 6 (or average score is 5-7)
Red	Total score is 8 (or average score is 7-8)

The overall quality of the IOTC datasets also varies by gear type. For purse seiners, the datasets are considered to be of fair to good quality, in particular for tropical and temperate tuna species (Table 3.11). Purse seiners target tropical tunas or neritic tunas, depending on the type of vessel, and area operated. During the last decade, purse seine gears have reported over 26% of the catches of IOTC species in the Indian Ocean, especially tropical tunas (≈37%), neritic tunas (≈14%), and temperate tunas (≈12%, the majority southern Bluefin tuna). During the last forty years (1976-2015), around 91% of the nominal catches, 79% of the catch-and-effort, and 74% of the size frequency statistics of purse seine fisheries recorded in the IOTC database are considered to be of good quality.

Table 3.11 Status of IOTC nominal catch, catch and effort, and size frequency statistics for purse seine fisheries, by year and species (1976-2015) (IOTC, 2017).

For pole-and-line fisheries, these datasets are considered to be of fair to good quality (Table 3.12). Bait-boats target tropical tunas in the Indian Ocean which over the last forty years (1976-2015) accounted for over 90% of bait-boat catches. Over the last forty years (1976-2016), over 90% of the nominal catches, 65% of the catch-and-effort, and 42% of the size frequency statistics of pole-and-line fisheries recorded in the IOTC database are considered to be of good quality.

For gillnets, these datasets are considered to be of poor to fair quality, depending on the fleet and time period (Table 3.13). During 1976-2015, around 62% of the gillnet catches were composed of neritic tunas and 32% of tropical tunas. During the last decade, gillnet gears caught around 32% of the IOTC species in the Indian Ocean, especially neritic tunas (55%), billfish (36%) and tropical tunas (20%). For the period 1976-2015, approximately 65% of the nominal catches, 15% of the catch-and-effort, and 20% of the size frequency statistics of gillnet fisheries recorded in the IOTC database are considered to be of good quality.

Table 3.12 Status of IOTC nominal catch, catch and effort, and size frequency statistics for pole and line fisheries, by year and species (1976-2015) (IOTC, 2017).

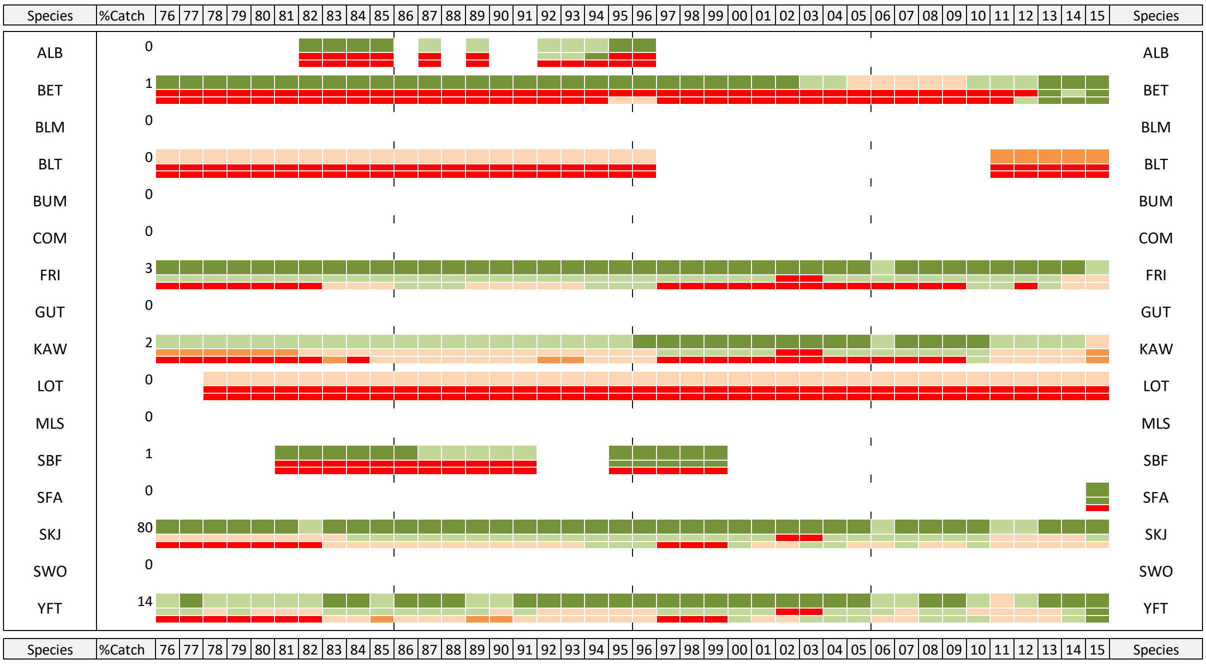
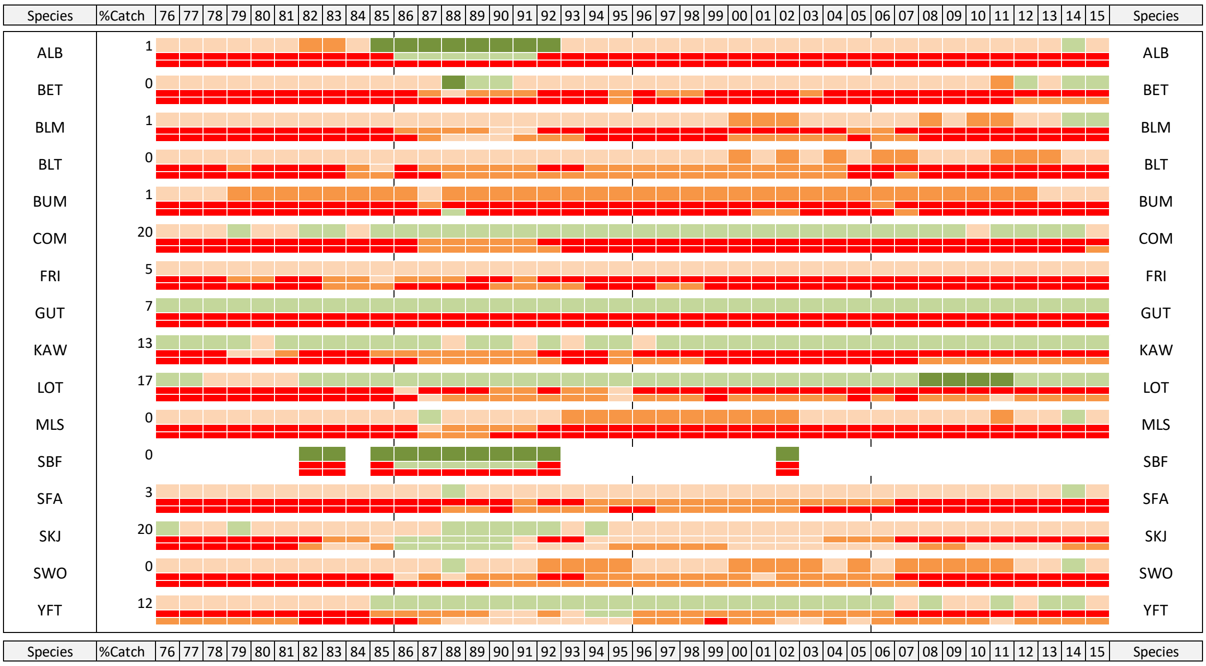
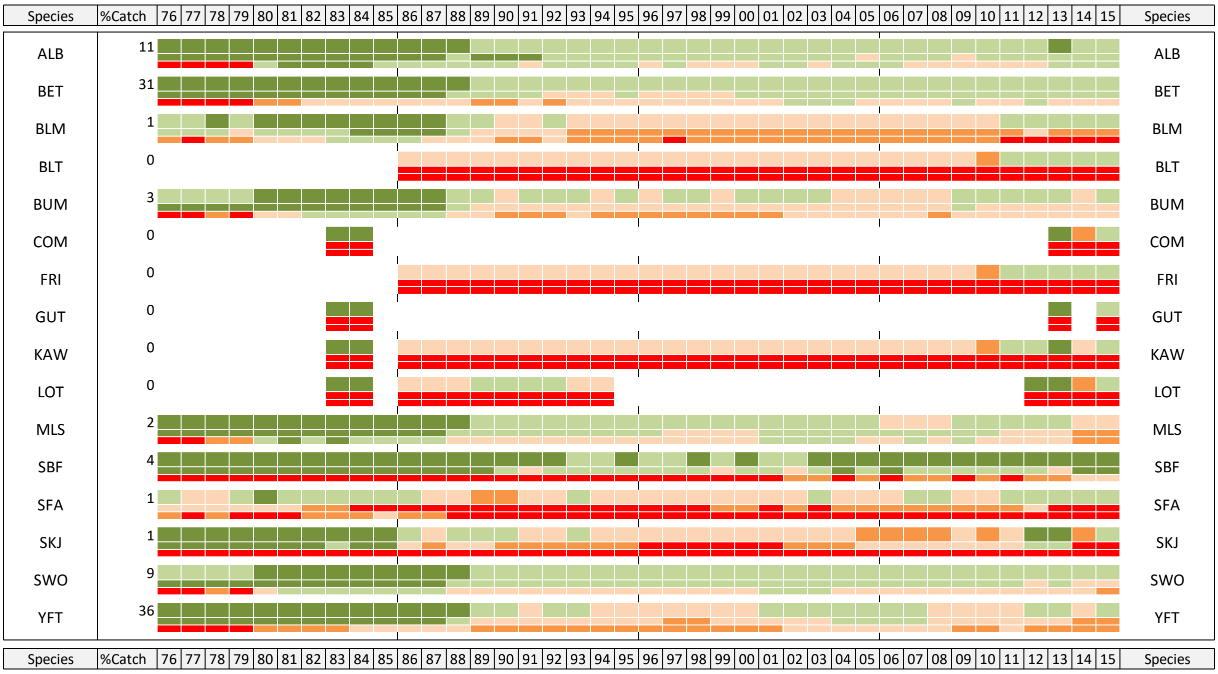


Table 3.13 Status of IOTC nominal catch, catch and effort, and size frequency statistics for gillnet fisheries, by year and species (1976-2015) (IOTC, 2017).



For longliners, these datasets are considered to be of good quality until the late-1980's and fair quality since then, for most species (Table 3.14). During 1976-2015, 68% of the longline catches were made of tropical tunas, 15% of temperate tunas and 16% of billfish while in the last decade, longline gears caught around 15% of the IOTC species in the Indian Ocean, especially temperate tunas (81%), billfish (53%) and tropical tunas (16%). During 1976-2015, around 80% of the NC, 72% of the CE, and 51% of the SF statistics of longline fisheries recorded in the IOTC database are considered to be of good quality. However, the quality of statistics in recent years has worsened, in particular availability of catch-and-effort and size frequency data because of lower reporting.

Table 4.14 Status of IOTC nominal catch, catch and effort, and size frequency statistics for longline fisheries, by year and species (1976-2015) (IOTC, 2017).



For the rest of the gears including catches of hand and troll lines, coastal gillnets, hand line, trolling and other minor artisanal fisheries, these datasets are considered to be of poor quality (Table 3.15). Over the last forty years (1976-2015), over 40% of catches under line fisheries were made of neritic tunas and over 50% of tropical tunas. For 1976-2015, 53% of the NC, 14% of the CE, and 9% of the SF statistics of these fisheries recorded in the IOTC database are considered to be of good quality.

Table 3.15 Status of IOTC nominal catch, catch and effort, and size frequency statistics for the rest of minor fisheries, by year and species (1976-2015) (IOTC, 2017).

Task II Catch Distribution (CatDis)/Effort Distribution (EffDis) Databases

The CATDIS and EFFDIS datasets are only prepared in ICCAT. The Task II Catch Distribution (CatDis) dataset correspond to the Task II catch effort data raised to total landings with the peculiarity that it is provided by quarter, fleet, gear group, and a spatial resolution of 5x5 degrees. These spatial dataset is prepared for only 9 species of tunas and billfishes. This dataset is quite important to describe the spatial catch distribution of ICCAT species by region which could potentially be used to develop ecosystem indicators by region, thus, monitor the impacts of fisheries by region. The species covered are the main tuna species such as bigeye, skipjack, yellowfin, Atlantic bluefin tuna, albacore, swordfish, blue marlin, white marlin, and sailfish. The data available for these species cover the 1950-2015 period but it is regularly updated. EFFDIS data is available as the number of hooks reported by the CPCs in the Task II 'Catch-and-Effort' data submission. It also covers the period 1950-2015 and is regularly updated. The coverage of Task II catch effort data by species, gear and over time (presented above for ICCAT) is representative of the quality of the rest of Task II datasets including the CATDIS and EFFDIS.

Task II Size Frequency Database

CPCs are responsible to report the actual size frequencies of samples measured for each species by small area (1x1 degree squares for most gears, 5x5 degree squares for longlines), gear, flag and month. Below, the quality fo the size data is summarized for ICCAT, since the quality of the IOTC size data was already presented in the section above.

The ICCAT Task II Size frequency data covers 59 species with very distinct data quality standards (Table 3.16). To get an overview of data completeness, an example of a Report Card of the Task II size frequency data is presented for 2016 (Table 3.17). A total of 52 flag CPCs (70% reporting ratio), including 5 CPCs with submissions after the deadline, have reported the size frequency data.

Table 3.16 Number of species in ICCAT task I catch and task II Size datasets, by species group.

Species Group	# of species in task I	# of species in Task II Size data	Size % of Coverage of species
1-Tuna (major sp.)	10	10	100
2-Tuna (small)	15	11	73
3-Tuna (other)	22	9	41
4-Sharks (major)	3	3	100
5-Sharks (other)	96	23	24
6-Other Species	27	0	0

In terms of spatial coverage of the ICCAT Task II size frequency dataset, the Secretariat has noticed an improvement over time with a finer spatial resolution (5x5° and/or 1x1° squares) since 2000, whereas previously, the size frequency was mostly submitted at a larger spatial stratum making it difficult to compare between years (Figure 3.6). This might affect the estimation of the baseline of several indicators that work at a finer scale.

An additional layer of complexity relies in the submission of the Task II size frequency data since not all the measurements are submitted in units of size. At least 10% of the samples submitted are measured in weights of fish and 1% are given by age (Table 3.18).

In terms of the temporal coverage of the ICCAT Task II size frequency dataset, it can be observed that the number of samples have increased in the most recent years for most species groups (Figure 3.7), most tuna species (Figure 3.8) and shark species (Figure 3.9). Surprisingly there is a decrease in the number of samples reported for shark for the period 2000-2013 (Figure 3.8).

Table 3.17 ICCAT Task II size information submission status for 2016 data ("green": before deadline; "yellow": after deadline; "orange": has not passed filer; "blank": not submitted or no sampling) (IOTC, 2017).

			Deadline (+1 day tolerance): 2017-08-01													
			Tuna (major sp.)										mall tun	Sharks (major sp.)		
Status	Party	Flag	ALB	BET	BFT	BUM	SAI	SKJ	SPF	SWO	WHM	YFT	ny of 14 s	BSH	POR	SMA
CP	ALBANIA	Albania			1											
	ALGÉRIE	Algerie			1											
	ANGOLA	Angola											1			
	BARBADOS	Barbados		1		1					1	1				
	BELIZE	Belize	1													
	BRAZIL	Brazil														
	CANADA	Canada	1	1	1					1	1	1				1
	CAP-VERT	Cape Verde														
	CHINA PR	China PR	1	1	1					1		1		1		
	CÔTE D'IVOIRE	Côte d'Ivoire														
	CURAÇAO	Curaçao	1	1				1				1	1			
	EGYPT	Egypt			1											
	EL SALVADOR	El Salvador		0				0				0	0			
	EUROPEAN UNION	EU.Bulgaria														
		EU.Croatia			1											
		EU.Cyprus	1		1					1						
		EU.Denmark														
		EU.España	1	1	1			1		1		1	1	1		
		EU.France	1	1	1			1				1	1			
		EU.Germany														
		EU.Greece														
		EU.Ireland	1													
		EU.Italy	1		1					1			1			
		EU.Latvia														
		EU.Lithuania														
		EU.Malta	1		1					1			1	1		
		EU.Netherlands														
		EU.Portugal	1	1	1	1	1	1		1	1	1	1	1	1	1
		EU.United Kingdom												1	1	1
	FRANCE (St-Pierre et Miquelo	FR.St Pierre et Miquelon														
	GABON	Gabon														
	GHANA	Ghana														
	GUATEMALA	Guatemala	1	1				1				1	1			
	GUINEA BISSAU	Guinea Bissau														
	GUINEA ECUATORIAL	Guinea Ecuatorial														
	GUINÉE REP.	Guinée Rep.														
	HONDURAS	Honduras														
	ICELAND	Iceland			1											
	JAPAN	Japan	1	1	1			1		1		1				
	KOREA REP.	Korea Rep.	1	1	1					1		1		1	1	1
	LIBERIA	Liberia														
	LIBYA	Libya			1											
	MAROC	Maroc			1					1		1	1			1
	MAURITANIA	Mauritania														
	MEXICO	Mexico		1	1	1	1			1	1	1				
	NAMIBIA	Namibia	1	1				1								
	NICARAGUA	Nicaragua														
	NIGERIA	Nigeria														
	NORWAY	Norway			1											
	PANAMA	Panama	0	0				0				0	0			
	PHILIPPINES	Philippines														
	RUSSIA	Russian Federation						0					0			
	S. TOMÉ E PRINCIPE	S. Tomé e Príncipe														
	SENEGAL	Senegal		1		0	0	1				1	1			
	SIERRA LEONE	Sierra Leone														
	SOUTH AFRICA	South Africa	1	1						1		1		1		1
	St VINCENT & GRENADINES	St. Vincent and Grenadine	1													
	SYRIA	Syria			1											
	TRINIDAD and TOBAGO	Trinidad and Tobago		0						0		1				
	TUNISIE	Tunisie			1											
	TURKEY	Turkey			1					1						
	UNITED KINGDOM (O.Territori	UK.Bermuda														
		UK.British Virgin Islands														
		UK.Sta Helena														
		UK.Turks and Caicos														
	UNITED STATES	U.S.A.	1	1	1	1	1	1		1	1	1	1	1	1	1
	URUGUAY	Uruguay														
	VANUATU	Vanuatu														
	VENEZUELA	Venezuela		1				1		1		1	1			
NCC	Bolivia	Bolivia														
	Chinese Taipei	Chinese Taipei	1	1		1	1	1	1	1	1	1		1		1
	Costa Rica	Costa Rica														
	Guyana	Guyana														
	Suriname	Suriname														

NOTES:

NO FISHING ACTIVITY (flags in green, 12 flags): Bolivia, Costa Rica, FR.St Pierre et Miquelon, Guinea Ecuatorial, Nicaragua, Nigeria, Philippines, Suriname, UK.British Virgin

NO TARGETTING ACTIVITIES (some bycatch): Angola (small traps), EU.Germany, EU.Netherlands

ERRORS / INVALID FORMATS: Côte d'Ivoire, EU-France, EU-España, EU.Netherlands, etc.

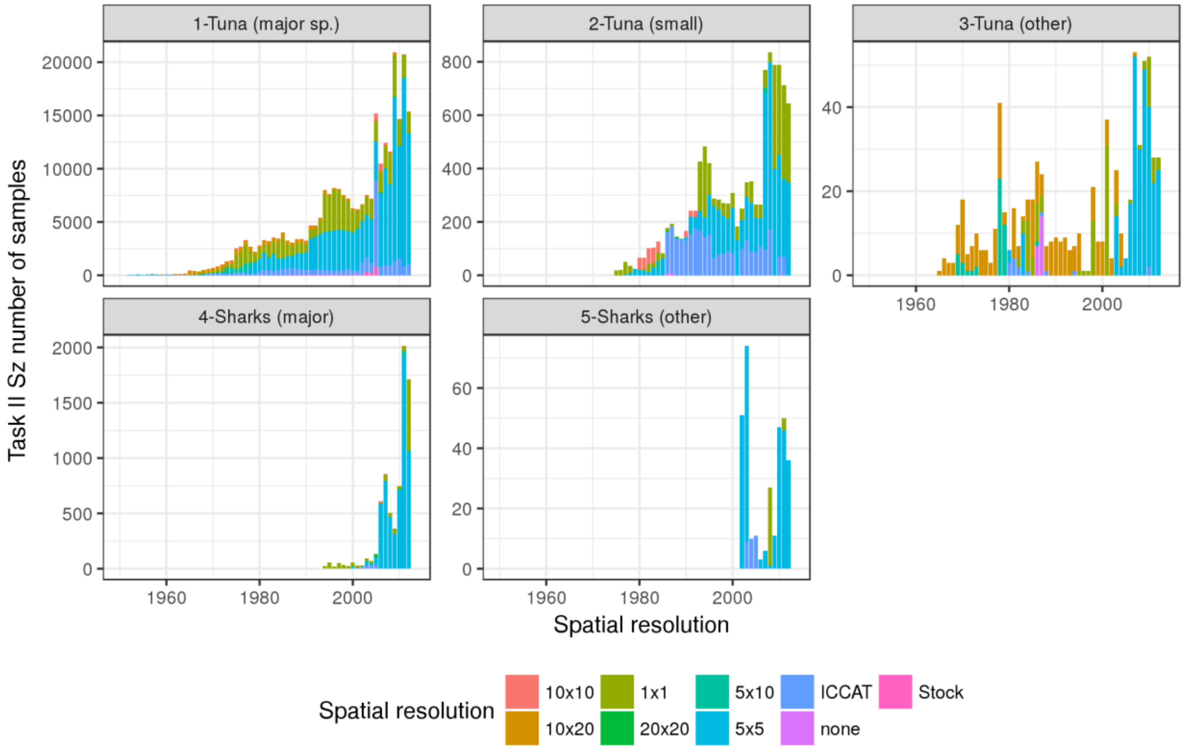


Figure 3.6 Number of samples available in ICCAT Task II size frequency by group of species, spatial resolution, and year.

Table 3.18 Type of measure available in the ICCAT task II Size dataset.

Measure type	% of the size
Lower Jaw TO Fork Length (FL)	52
Lower Jaw TO Fork Length (billfish) (LJFL)	18.1
Weight of fish (WGT)	10.7
Curved measurement of Fork Length (CFL)	4.7
Posterior edge of eye socket to Fork Length (EYEFORK)	3.7
Weight of Head and Gutted fish (HGTW)	3.2
Conversion: LD1 -> FL (LD1-FL)	2.7
Conversion: WGT -> FL (WGT-FL)	2
Total length (TL)	1.5
Age of fish (AGE)	0.5
Lower Jaw TO 1st Dorsal Length (LD1)	0.3
PCL	0.4
Opercule to Keel (OPKELL)	0.3
Cleiteron to Keel (CLKL)	0.1
SFL	0.1

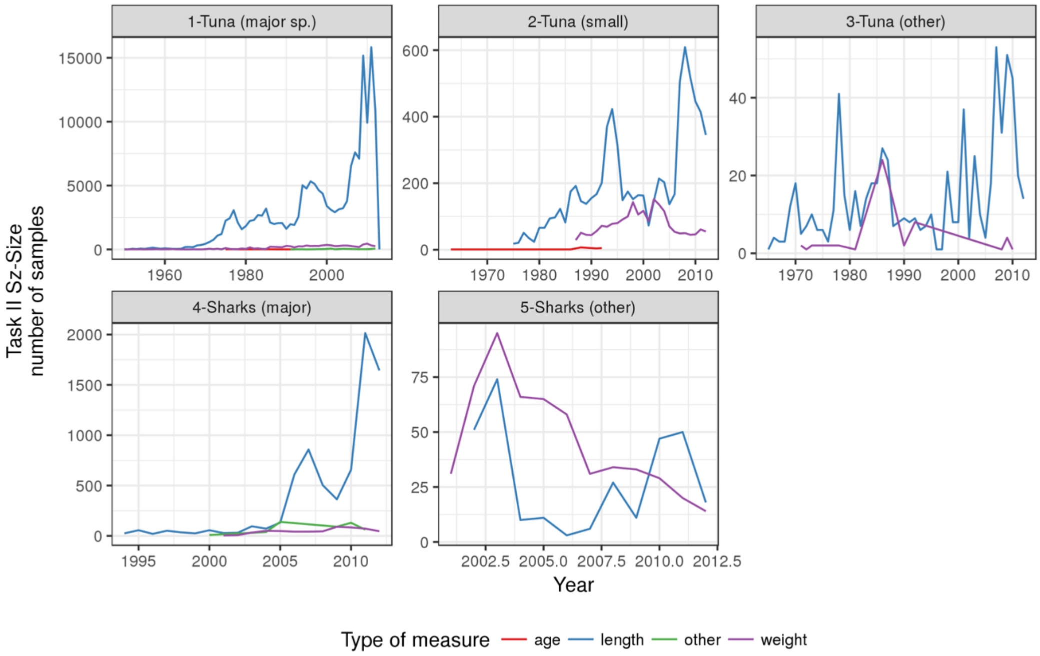


Figure 3.7 Annual number of samples over time in ICCAT Task II Size dataset by type of measurement and major groups of species.

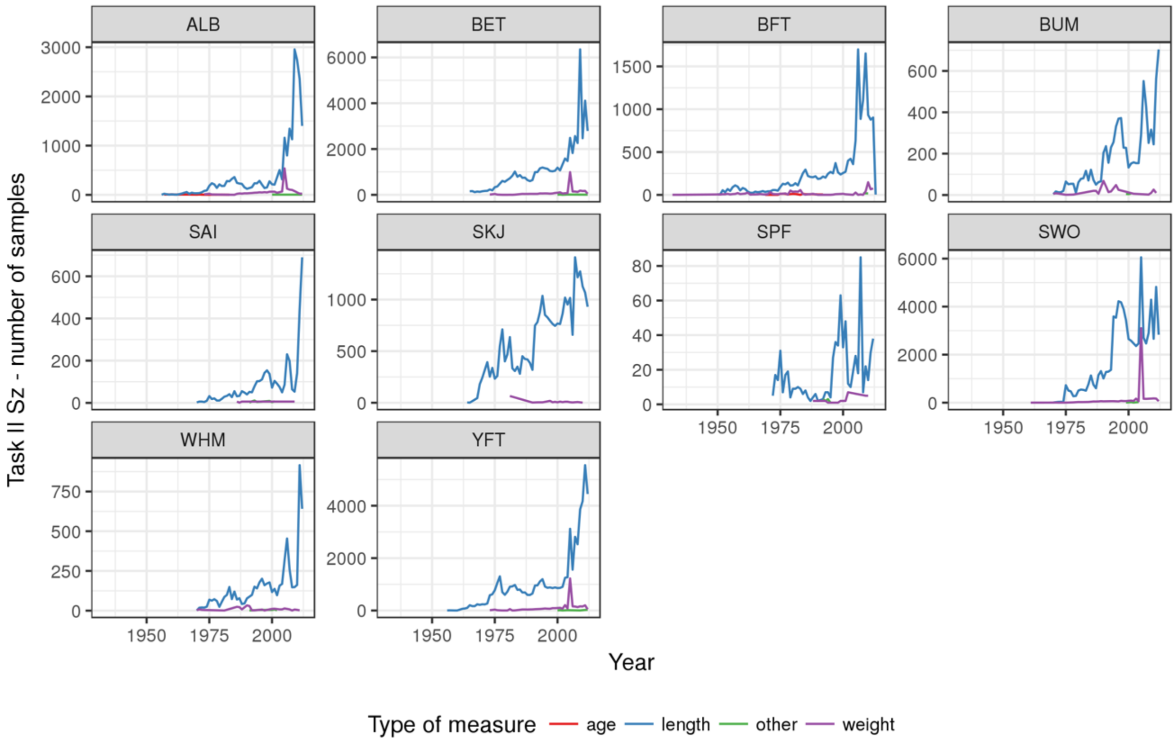


Figure 3.8 Annual number of samples over time in ICCAT Task II Size dataset for main tuna species. Species codes in Table 3.2.

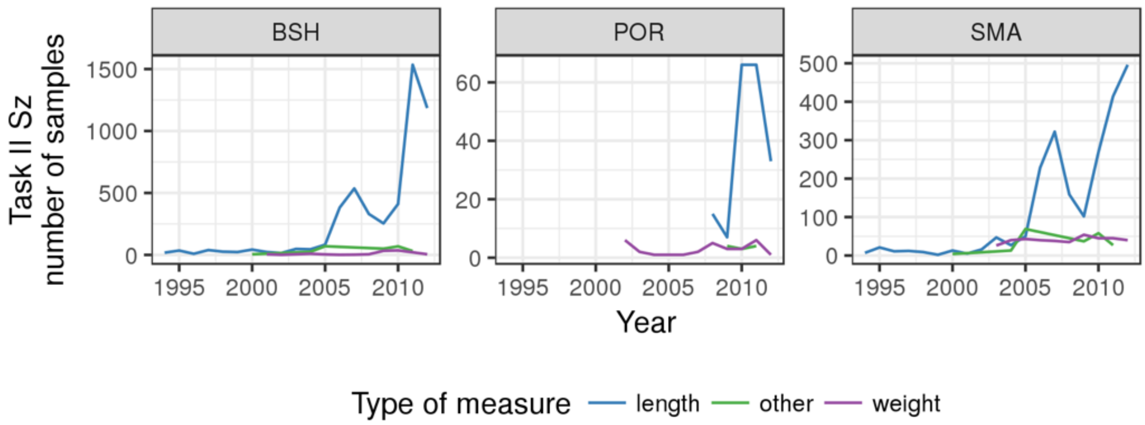


Figure 3.9 Annual number of samples over time in ICCAT Task II Size dataset for main shark species (BSH – Blueshark, POR – Porbeagle, and SMA – Shortfin Mako sharks).

Catch at Size (CAS)/Catch-at Age (CAA) databases

Using the Task I nominal catch data and Task II size frequency data, the ICCAT and IOTC Secretariat also construct the Catch-at-Size (CAS) matrix extrapolated to the total nominal catch to be used in the stock assessments for the major tunas, billfishes and sharks. Similarly, they construct the Catch-at-Age (CAA) matrix. In addition, the CPCs also produce and submit to ICCAT and IOTC catch-at-size data for their catches (i.e. the size samples in a given strata raised to total catch of the particular flag state in that strata). The quality and completeness of the flag state catch-at-size data is similar to the information presented above for Task II size frequency data and, therefore, it is not presented here.

National Observer Programme Databases

ICCAT and IOTC CPCs have the obligation to run observer program to monitor the catch, bycatch, and discards of their fisheries from 2010 onwards. Before 2010, observer programs were run voluntarily by the CPCs. Under these recommendations, each Member State shall ensure the following:

- A minimum of 5% observer coverage of fishing effort with a representative temporal and spatial coverage;
- Report upon the fishing activity: quantifying total target catch and by-catch (including sharks, sea turtles, marine mammals, and seabirds), size composition, disposition status (i.e., retained, discarded dead, released alive), and the

collection of biological samples for life history studies (e.g., gonads, otoliths, spines, scales);

- Fishing operation information including: area of catch by latitude and longitude, date of each fishing operation, and fishing effort information (e.g., number of sets, number of hooks, etc.).

Each year, CPCs shall report information collected under domestic observer programs to the Scientific Committees of ICCAT and IOTC for stock assessment and other scientific purposes, and the reporting should be consistent with domestic confidentiality requirements.

ICCAT and IOTC are currently working to develop a database of observer data (ST09), which has been tested for few years now. Since their mandatory implementation, the implementation of observer programmes as well as submission of data has been slow and very poor in both ICCAT and IOTC. For example, in 2017, ICCAT received submissions of observer data from 16 CPCs (an increase of 2 from 2016). The majority of the submissions included very little information, which limits the use of these datasets. For example, estimates of levels of discards are not available for all fleets and species groups (main tuna and billfishes, sharks, seabirds, marine turtles, marine mammals, and other marine species) with acceptable temporal and spatial resolutions. Therefore, the National Observer Programme datasets available in the ICCAT and IOTC public domain cannot be used, at the present state, to derive ecosystem indicators in ICCAT and IOTC. Yet, these datasets are essential to estimate many of the ecosystem indicators identified under task 2.1.

Although the minimum coverage for their fleets with an observer program is 5% for each state, some CPCs have larger coverages. For example, since late 2014, the observer coverage of EU purse seiners has increased to 100% and, hence, these datasets would be very valuable to develop ecosystem indicators in the future. Before 2014, the observer coverage of EU purse seiner fleet was around 10% (1998-2014). Other fleets observer coverage (particularly for industrial longline fleet) is lower than 5% which makes it difficult to run any analysis in relation to the interaction of the industrial longline with bycatch species. The US longline fleet reported, and made publicly available, observer data for the period 1992-2000.

Biological information

Biological information on the individual tuna and billfish species and sharks are also collected under National or International Research and Monitoring Programs. The biological data collected are usually used to derive the equations necessary to convert non-standard measurements to standard measurements, for each species/fishery and time-period. It is also used to calculate the proportion of specimens by sex (sex ratio) for each species, length class by fishery and time-period. These programs also collect samples to estimate the maturity and fecundity of species as well as growth. The ICCAT and IOTC secretariats prepare a written summary of the main biological information for each species. The IOTC Secretariat also compiles the resulting studies derived from these biological samplings and conducted by the CPCs for the main IOTC species. The biological information of species is essential to develop and interpret many of the ecosystem indicators identified under Task 2.1.

Tagging data

ICCAT and IOTC maintain a database of conventional tagging data and an electronic tagging inventory for Atlantic and Indian tunas and tuna-like species. Both have coordinated and supervised several major tuna tagging programmes in the past (ICCAT, 2008). For example, IOTC coordinated a seven-year Indian Ocean Tuna tagging Programme between 2002 and 2009 and it was the first major program implemented at the Ocean scale. ICCAT has a longer history coordinating multiple tagging programs of different durations and scales. Recently ICCAT supervised a large scale Regional Tuna Tagging Programme funded by the EU which mainly focused on tropical tuna species (period 2016-2017).

The specific objectives of the tagging programmes have traditionally been to reinforce the scientific knowledge of major tuna stocks (growth, movements, natural mortality of species) and estimate fisheries interactions and the rate of exploitation in the Atlantic and Indian Ocean by obtaining the crucial model parameters for stock assessment. The tagging dataset provides information of the individual fish when the initial catch occurred and at the time of release, including the location and date of the release of the species, length (or weight) of the fish, information about the tag used and the tagging program, and if the fish is recovered, information of position, date and length/weight of the fish recovered. All the tagging and recapture data are hosted at ICCAT and IOTC and are in the public domain. The biological information of species derived from tagging programs is essential to develop and interpret many of the ecosystem indicators identified under Task 2.1.

Fishing vessel information

Both ICCAT and IOTC have datasets with records of vessels authorized to operate in their convention areas. ICCAT maintains a record of fishing vessels[11] that are 20 meters or greater, established by Rec 13-13 and 14-10. IOTC also maintains a record of fishing vessels[12] that are larger than 24 meters in length overall or in the case of vessels less than 24m, those operating in waters outside the economic exclusive zone of the flag state, as established by resolution 15/04. Foreign vessels chartered by or under joint venture arrangements with the reporting country are reported separately. The datasets are organized by LOA (overall length) size categories. The vessel registry datasets are needed to estimate some of the ecosystem indicators identified under Task 2.1.

FAD Management plans and FAD activities data

The Recommendation by ICCAT on a Multi-Annual Conservation and Management Programme for Tropical Tunas [Rec. 16-01[13]] states that each year, by 31 January, CPCs with purse seine and bait-boat vessels fishing for bigeye, yellowfin and skipjack tunas in association with objects that could affect fish aggregation, including FADs, shall submit Management Plans to the Executive Secretary. The elaboration of the plan in Annex 6 of Rec. 16-01 provides an extensive list of criteria that must be included in the Plan. Belize, Curaçao, Ghana and the EU have submitted FAD management plans for the reporting period. Moreover, ICCAT Recommendation 16-01 established the requirements for FAD activity data (number of FAD deployed, number of FAD activated/deactivated by month, fishing activities and statistics on FADs) which CPCs are starting to provide. These FAD activity requirements are quite recent (since 2014-2015) and will require some years before the submission of FAD fishery activities and utilisation are done routinely. Therefore, it is premature to predict how these datasets could be used to support the development of ecosystem indicators.

Similarly, in IOTC, in accordance with Resolutions 15/08 and 15/02 FAD information has to be submitted to the Secretariat. By 2016 FAD information has been submitted by six CPCs (Spain, France, Seychelles, Japan, Korea and Mauritius) for a varying time range included in the 2013 – 2015 period (Table 3.19).

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[11] https://iccat.int/en/vesselsrecord.asp
[12] http://www.iotc.org/vessels
[13] Recommendation 16-01 by ICCAT on a multi-annual conservation and management programme for tropical tunas.

Others

Apart from those databases that are mandatory to be collected and submitted to ICCAT/IOTC, there are also catch/bycatch/discard and biological information available on ICCAT/IOTC Scientific Reports available on the public website (SC documents, Working parties, Scientific documents, Resolutions, etc.).

Table 3.19 Overview of the time-coverage and density of information (records per year) for all submitted FAD effort data by CPC and year in IOTC: Japan and Mauritius are the only two CPCs that have been providing partial information (for only a fraction of the calendar year) for at least one year in the period whereas other CPCs – namely France and Spain – have provided information for 2014 and / or 2015 only.

	Year coverage			**Reported number of records**		
CPC	**2013**	**2014**	**2015**	**2013**	**2014**	**2015**
ESP			Q1-4			**16114**
FRA		Q1-4	Q1-4		832	895
JPN	Q4	Q1,3,4	Q1,4	107	213	337
KOR		Q1-4	Q1-4		1001	701
MUS	Q4	Q1-4	Q1-4	28	468	500
SYC	Q1-4	Q1-4	Q1-4	1354	1737	956

3.4.2. Non-traditional data sources in ICCAT and IOTC

In addition to the traditional data sources mentioned above, some ecosystem indicators identified under Task 2.1 required the use of non-traditional sources of data. Below, some non-traditional data sources are summarized (Table 3.20), and for each of them, some products are presented that could potentially assist in the development and interpretation of indicators identified under Task 2.1

Table 3.20 List of non-traditional data sources which could be of interest to this project.

Name dataset
Remote/in situ sensing and model products
Echo-sounder buoy data attached to FADs
Vessel tracking
Commercial ships as data recording platforms
Electronic monitoring systems
Scientific surveys for fish

Remote/in situ sensing and model products

Understanding species–habitat relationships is key for species management, as they provide information on habitat requirements, distribution, and potential impacts of anthropogenic activities. Oceanographic data are collected using both in situ methods and remote sensing ones. The most obvious remote sensing platforms are satellites, while the most useful in situ ocean observations come from different sources, with varying degrees of quality (e.g. CTD, instrumented buoys). Carefully calibrated and adjusted satellite data, sometimes put together with in situ observations for the data processing procedure, provide the best assessment of global ocean conditions at different scales. Thus, combined in situ, model, and satellite remote-sensing observations should be used to define environmental indicators and determine potential species-habitat relationships. These indicators can include measures of both the physical (e.g. climate, topography, temperature, currents) and biological environment (e.g. primary production, chlorophyll) at different spatial-temporal resolutions, from meters to km and from daily to monthly, and even annually, measures and indicators. The resolution and indicators used in each study would be dependent on the nature of the investigation and the spatial-temporal window considered in it. Because the main environmental processes to be considered at ecosystem-scale are usually medium-long term processes, similar spatial-temporal scale indicators should be used to infer ecosystem-environment relationships. The list below considers some of the most interesting environmental indicators to be used for that purpose:

- Sea Surface Temperature:

Sea surface temperature (SST) is used as a proxy for upper ocean temperature and is often assumed to represent the temperature in mixed water columns or the upper layer of stratified waters. It is thus considered as a proxy for the identification of suitable habitats and distribution of species and is pertinent when considering scenarios of changing ocean temperature due to climate change.

- Water column descriptors (e.g. mixed layer depth):

Derived from wind vectors, the mixed layer depth (MLD) is the depth of mixing that is influenced by surface heating and cooling processes by wind. The MLD can constrain prey species to depths below the mixed layer, and these prey species can be accessed by surface feeding animals or fisheries.

- Chlorophyll concentration:

Primary production forms the base of the food chain and can consequently also be a proxy for the density of prey organisms. Chlorophyll concentrations are often used as a proxy for primary production in a specific area. Chlorophyll content values and fluctuations may be indicators of the ecosystem health and raw food availability but, if possible to determine, production rates are preferred.

- Chlorophyll concentration and seas surface temperature gradients (Fronts):

The computation of spatial-temporal gradients of chlorophyll and sea surface temperature provides useful information on the productivity trends of an area at different scales, and may help identify mesoscale processes like eddies, seasonal or permanent upwelling systems, or more importantly, the presence of fronts. Water masses meet at fronts, which can aggregate passive prey, making them important foraging grounds for a range of species.

- Sea Level Anomaly

Sea surface height (SSH) indicates water motion, and thus may represent the presence of upwelling or downwelling structures such as eddies.

- Eddie Kinetic Energy

Derived from current vectors, the Eddy Kinetic Energy (EKE) reflects energy in water motion that can lead to enrichment and subsequent productivity increases (and thus prey and food availability).

- Dissolved Oxygen concentration

Dissolved oxygen is necessary to many organisms including fish, invertebrates, bacteria and plants and thus, can be a limiting factor for the correct development and life of many animals and the ecosystem. In addition to its importance in assessing water quality, the concentration of dissolved oxygen in the ocean provides a sensitive early warning system for trends that climate change is causing.

Several databases are publicly available to extract environmental information with different spatial-temporal resolutions to be used for the ecosystem indicators analysis. For example:

- Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/)
- NOAA Environmental Research Division's Data Access Program (ERDDAP) (http://coastwatch.pfeg.noaa.gov/erddap/)
- Bio-ORACLE - Marine data layers for ecological modelling (http://www.bio-oracle.org/)
- WorldClim – Free climate data for ecological modelling and GIS (http://www.worldclim.org/)

Echo-sounder buoy data attached to Fish Aggregating Devices

Thousands of FADs are deployed annually by the fleets targeting tropical tuna in the Indian, Atlantic and Pacific Oceans. Since about a decade, the vast majority of them are equipped with satellite linked echo-sounder buoys, which provide fishers with accurate geo-location information and rough estimates of the biomass aggregated underneath the floating object. The information recorded by this tool, regularly and systematically collected by fishers, may be of extreme interest for scientists to develop abundance indicators of FAD-associated species. FADs, due to their attracting power, are used to facilitate the catch of target species. Echo-sounder buoy (acoustic) information may be used to develop alternative abundance indicators of tuna species at different spatial-temporal scales, which would be complementary to the abundance indicators based on traditional data. Although they are still in the development stage, progress is being made with echo-sounder buoys to discriminate species remotely. Ideally, future versions of echo-sounder buoys may help providing biodiversity indicators by area and time window. Therefore, the most interesting FAD derived indicator is the abundance of FAD-associated species.

Vessel tracking

Many vessels moving and operating in the oceans are monitored with a variety of tracking systems, such as AIS (Automatic Identification System; open VHF-based radio system) or VMS (Vessels Monitoring System; proprietary Satellite-based system). While very promising, VMS data are usually confidential and of limited access to national scientists. International portals like Global Fishing Watch (globalfishingwatch.org) or AIShub (www.aishub.net) are under development and indicators could be potentially viable in the long term. Despite the significant differences in the data collection and transmission of AIS and VMS, the information obtained can be post-processed to infer traffic parameters and fishing effort and pressure for a particular area and time window.

- Traffic parameters:

Shipping belongs to the main sources of human induced disturbances in the ocean like underwater noise, pollution, and potential interaction with sensitive fauna and ecosystems. The analysis of this data may provide valuable information on these types of anthropogenic indicators and would help assessing the risk of certain shipping activities on the ecosystem.

- Fishing effort and pressure:

Vessel monitoring information could be used to describe fishing pressure by vessels exceeding a particular length (i.e. depends on international and domestic legislation) by post processing tracking data with fleet-specific developed algorithms and methodologies. The fishing effort indicators derived from these sources would still need to be validated with traditional fisheries data.

Commercial ships as data recording platforms

Professional ocean users travel oceans and coastal zones with different purposes, from fishing to transportation. Scientists may benefit from collaboration with these users by collecting a number of data that can be used later to develop a set of ecosystem indicators, from abundance to environmental. As chartered research vessels are expensive and time consuming, the use of volunteer vessels as oceanographic samplers while underway is a cost-effective way of obtaining valuable data. Naturally equipped with various sampling instrumentation when transiting between regions (e.g. echo-sounders, sonars), these vessels can automatically collect information on a large variety of parameters along their routes while undertaking their regular business. Some examples of it are listed below:

- Continuous plankton recorder

The Continuous Plankton Recorder (CPR) is one of the longest running marine biological monitoring programmes in the oceans designed to capture plankton samples over huge areas of ocean. The CPR is usually towed from the stern of volunteer merchant ships such as RoRo and Container Ships. However, this versatile recorder has also been deployed from large sailing vessels, fishing boats and super tankers. The CPR has the potential to provide environmental indicators for food-prey (zooplankton) availability. Several databases are available on phytoplankton and zooplankton records which can be made available for Ecosystem analysis (https://www.sahfos.ac.uk/publications/scientific-reports/ecostatus-reports). The North Atlantic is the well covered by CPR route with many decades of data, while the Pacific now has >10 years of data (data are available for the eastern oceanic subarctic gyre since 2000 and the Alaskan shelf since 2004) albeit with much less sampling there than in the Atlantic (Edwards et al. 2016). Work is underway to develop a survey in the Indian Ocean.

- Acoustic records

Echo-sounders and sonars are very broadly installed and used tools in both fishing and shipping vessels that allow for the detection and identification of fish and the determination of depth of water and nature of the seabed. Accessing to this data would allow to progress on the development of abundance indicators of a variety of species (or biomass in general) at different scales, but would also provide habitat indicators as they are able to measure the different types of seafloor.

- Radars

Radar is an on-board apparatus that detects other ships and masses, even during periods of low visibility. This information could be used to develop indicators of ship-human activity, as well as to derive indicators of abundance of some species like seabirds.

- Animal sightings

Cooperative sighting from commercial vessels will provide information about population sizes, breeding rates and movement patterns of marine mammals and seabirds, and should consequently aid to develop more effective abundance indicators for species in these groups.

Electronic monitoring systems

Recently, some fleets targeting tuna (e.g. purse seiners, longlines) have installed cameras on board to increase their observer coverage (either for compliance or surveillance purposes). The data obtained through this means would significantly improve the data collection of both target and non-target species, providing abundance indicators for each group at relevant spatial-temporal scales.

Scientific surveys for fish

A range of scientific surveys (acoustic, aerial, larval surveys) have been used, or are currently being used, to record independent information to better assess the abundance of species of interest, such as tunas, anchovies or other pelagic species. These data are processed specifically to obtain abundance indices of the species investigated, but can also be re-analysed to develop additional indicators of abundance of other species of interest occurring in the area.

3.5. Subtask 2.4 - Ecosystem indicator summary table

This section summarizes and ranks in order of priority for development a subset of 36 indicators selected in subtask 2.1 to monitor the impacts of fisheries on target species and communities they form, bycatch and threatened species (marine mammals, seabirds, sharks and turtles), pelagic habitats (plankton indicators), and trophic relationships (primary production, predatory-prey relationships) (Table 3.21). Only 2 indicators were scored with a maximum score of 8 (meeting all the quality criteria): Group spawning stock biomass relative to a reference level (e.g. B_{MSY} or proxies) and Group fishing mortality relative to a reference level (e.g. F_{MSY} or proxies). No other indicator was considered to have all relevant data available, since even simple indicators such as those based on catch and catch-at-size data would suffer from incomplete information for target and non-target species (Table 3.21). Often the catch data (and associated size data) reported to tuna RFMOs by CPCs focuses on the most economically important species (i.e. the principal market tunas and some of the billfishes). The catch data of commercially less important fish species, for which catch is also often retained, is highly under-reported. Additionally, the catch data (and associated size data) also often lack the spatial information required to estimate indicators on a regional basis.

Key attributes (biomass, size structure and spatial distribution) of the pelagic species of relevance to tuna RFMOs are captured well by the top performing indicators (score > 6). Specifically, we prioritise the simple integrative indicators (group spawning stock biomass and associated pressure indicator group fishing mortality) for the assessment of the biomass of multiple stocks of commercially fished species relative to management reference points. These indicators have been adopted by multiple international organisations and are widely implemented by numerous EU coastal CPCs. These commercial fish indicators should be complemented by single species biomass/abundance/catch-rate indicators for non-target species and unassessed target species, prioritizing vulnerable species, in order to monitor the impact of the fisheries.

Integrative indicators derived from ecosystem modelling also scored highly (scores of 7 including: mean trophic level and size-based indicators), particularly in lieu of extensive monitoring by scientific surveys, since these indicators are able to demonstrate the likely wider effects of fisheries in the ecosystem. While targets for such indicators are not appropriate unless supported by extensive pressure-state modelling, trend-based analyses can nevertheless provide an early warning of cascading effects throughout the food web due to exploitation of the fished species. Ecosystem models are only as good as the data available to support them so catch information along with knowledge of demographic parameters would need to be complemented by a range of information including knowledge of diet-preference, spatio-temporal overlap between species, life-history parameters and production/mortality rates per species along with an estimate of expected biomass in the region. While much of this supplementary information can be found in the scientific literature or from online databases such as Fishbase.org, additional data collection to support model development is recommended.

Catch-based indicators (scores 6.5 to 7) can be particularly useful to RFMOs since much of the data (although not all) are readily available. These include total catch of all species as a pressure indicator and catch by feeding guilds (e.g. piscivores and planktivores) to highlight where in the food-web the impact of fisheries is greatest. Similarly, the mean trophic level indicator can be used to interpret changes in how the fisheries impact the food-web or potentially change in the ecosystem itself if the fishery has not changed its behaviour. Community size-based indicators can also detect the wider impacts of fisheries on the ecosystem since larger individuals are typically high trophic level piscivorous predators and highly fecund, yet particularly vulnerable to over-exploitation.

Additional pressure indicators that focus on non-target species (frequency of bycatch and population level mortality) are of great relevance to the ecosystem approach to fisheries and should be prioritised (score 6.5). However, such indicators are hampered in their diagnostic capacity if they are not coupled with costly assessments of status (i.e. spawning stock biomass). Observer datasets are increasingly being used to conduct data-poor assessments and estimate the state of sensitive species and this may provide a means to interpret the impact of observed bycatch frequency data. However, the temporal and spatial coverage of observer programs are often incomplete due to low observer coverage for most CPCs. In other cases, the observer data might be reasonable (in terms of observer coverage and temporal and spatial coverage) but the data might not be publicly available. Trend based assessments of incidental mortality (i.e. acceptable if decreasing) are not acceptable for bycatch species without absolute target values since the indicator may decrease as the bycatch species abundance reaches very low levels simply because the species becomes rare and less likely to be caught. Additionally, recovery of a depleted species may result in an increase in bycatch rates despite the improving conditions for the species. Without independent estimates of bycatch species abundance, only a zero-tolerance approach would be suitable with a target of zero or as near zero as practicable.

Distributional metrics capturing changes in the extent of a species range or change in patterns within their range were also scored as highly performing indicators (score 6). These distributional metrics may highlight impacts on target and bycatch species and their predators that traditional fishery stock assessment models may miss. Spatial changes in the ecosystem, perhaps due to climatic effects on a species distribution, should be monitored so that management of fishing fleets can be adapted where necessary.

Indicators of pelagic habitats and trophic relationships (e.g. primary production and zooplankton biomass), other than model derived or catch-based, scored no higher than 6 in the evaluation, either due to limited data availability or due to a lack of clear responsiveness to pressures and thus difficulty of setting acceptable targets. Nevertheless, an ecosystem assessment would not be complete without indicators capturing these ecological components. Simple biomass and abundance metrics (potentially using Continuous Plankton Recorder data or satellite data for chlorophyll) for planktonic groups were considered to be the best indicator of pelagic habitats. While these indicators may not be responsive to fishing pressures, they do possess ecosystem relevance that can be beneficial in interpreting why change in the upper trophic levels may be occurring in the ecosystem. For example, if the spatial distribution of planktivorous species is moving this may be attributed directly to change in plankton regionally. If so, an indicator of the plankton would avoid any misdiagnosis that may occur, i.e. overfishing in some parts of the spatial range of the target species. In either case, spatial management of the fishery would be required, but the motivation would be different (action in response to environmental change to avoid overexploitation rather than overexploitation being the cause) and likely lead to differing measures and differing responses by the public. Notably, the NPFMC and NAFO have considered measures of ecosystem productivity that can be used to set limits of the total catch that can be taken by fisheries to avoid ecosystem-over-exploitation. Such an indicator may prove to be a powerful, but controversial, measure to aid ecosystem assessments. Food web modelling studies, which can estimate the proportion of primary production required to support catches (Lynam & Mackinson, 2015), can be used to inform on acceptable target ranges for ecosystem exploitation (Rossberg *et al.*, 2017). Once acceptable ecosystem targets are chosen, these limits would enable modellers to advise managers on whether or not management plans are precautionary through a Management Strategy Evaluation (MSE) (Lynam *et al.*, 2016). MSE uses simulation to compare the relative effectiveness of differing strategies for achieving objectives given sources of variation and uncertainty in data and processes leading to management actions (Punt *et al.*, 2016; Mackinson *et al.*, 2018).

Trophic interactions can be investigated through multi-species modelling (predation mortality) or based on an assessment of the biomass of specific feeding guilds (including by-catch and non-target species). Guild based assessments can demonstrate how biomass is accumulating within the food web as a result of predator-prey interactions and can be used to estimate the effect of change within the food web on the balance of biomass between guilds. By setting the biomass of targeted species within the context of change in guilds (i.e. functional groups of piscivores, planktivores, etc.), it should be possible to demonstrate impacts of fishing on the functioning of the food web. For example, overfishing of apex piscivorous predators (tuna) may lead to increases in mid-trophic level fish (such as Snake mackerel) (Polovina *et al.*, 2009). Similarly, changes in the food web due to ecosystem wide responses to the environment may be recognised: such as climate driven change in primary production leading to decreases in planktivores and subsequently effects on piscivores (including target species and thus may impact upon fisheries yields). Where available, spatial information (catch data and observer data) associated to these guild-based indicators could be used to identify areas where interactions between predators and prey are important to support ecosystem functioning and thus support spatial planning. Further study could highlight where interactions between species act in synergy or antagonistically with fishing impacts leading to an exacerbation or mitigation of fishing effects.

3.6. Research recommendations for future work

A great number of the indicators reviewed are not currently calculable in the oceanic areas due to lack of scientific surveys. If it was considered possible to calculate indicators using fisheries dependent catch data, we evaluated them on this basis, while acknowledging that the indicator had not been calculated in this way before. Scientific surveys are costly but would be of great benefit to the successful application of an ecosystem approach, since fisheries dependent data are subject to a range of biases that can lead to changes in state being missed by an indicator based on such data.

We include a set of research recommendations for future work:

- Indicators prioritized here should be developed and tested using data available from the tuna RFMOs
- Indicators based on non-traditional data sources should be developed through specific projects involving scientists from tuna RFMOs and academics
- Ecosystem models should be developed to support the development of model-based ecosystem indicators.

Table 3.21 Ranked list of candidate indicators evaluated using Queirós *et al.* (2016).

INDICATOR NAME	SCORE (max = 8)	IQ1 *Scientific Basis*	IQ2 *Ecosystem Relevance*	IQ3 *Responsiveness*	IQ4 *Targets?*	IQ5 *Early-warning*	IQ6 *Concrete*	IQ7 *Cost-effective*	IQ8 *Data available*	Ecological component
Group Spawning Stock Biomass relative to a reference level (e.g. Bmsy or proxies)	8	1	1	1	1	1	1	1	1	target species
Group Fishing mortality relative to a reference level (e.g. Fmsy or proxies)	8	1	1	1	1	1	1	1	1	target species
Single species biomass/abundance/catch rate indicators	7.5	1	1	1	1	1	1	1	0.5	target and non-target species
Total catch (total, by guild)	7	1	1	1	0.5	1	1	1	0.5	target and non-target species
Mean Trophic Level Indicators (model derived)	7	1	1	1	1	1	1	0.5	0.5	trophic relationships
Community size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (model based)	7	1	1	1	1	1	1	0.5	0.5	target and non-target species/trophic relationships
Size spectra (total, by guild/community) (model based)	7	1	1	1	1	1	1	0.5	0.5	trophic relationships
Frequency of bycatch and total number of interactions	6.5	1	1	0.5	1	1	1	0.5	0.5	non-target vulnerable species
Population level mortality (non target species)	6.5	1	1	1	1	1	1	0	0.5	non-target species
Community size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (catch based)	6.5	1	1	0.5	1	0.5	1	1	0.5	target and non-target species
Mean Trophic Level Indicators (catch)	6.5	1	1	1	1	0.5	0.5	1	0.5	trophic relationships
Predation mortality from multispecies models	6.5	1	1	1	0.5	1	1	0.5	0.5	trophic relationships
Distributional range (including extent, centre of gravity, pattern within range and pattern along environmental gradients)	6	1	1	0.5	0	1	1	1	0.5	target and non-target species
Proportion of non-declining exploited species	6	1	0.5	1	1	0.5	1	0.5	0.5	target and non-target species
Recovery in the Population Abundance of Sensitive Fish Species	6	1	0.5	1	1	0.5	1	0.5	0.5	target and non-target species
Single Species Spawning Stock Biomass relative to reference level (e.g. Bmsy or proxies)	6	1	0	1	1	1	1	0.5	0.5	target and non-target species
Single species fishing mortality relative to a reference level (e.g. Fmsy or proxies)	6	1	0	1	1	1	1	0.5	0.5	target and non-target species
Single species size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation)	6	1	0	0.5	1	1	1	1	0.5	target and non-target species
Zooplankton biomass and/or abundance	6	1	1	0	1	1	1	0.5	0.5	pelagic habitats/trophic relationships
Primary production	6	1	1	0	1	1	1	0.5	0.5	pelagic habitats/trophic relationships
Biomass indicators (total, guild/community) including fish, marine mammals and seabirds	5.5	1	0.5	1	1	1	1	0	0	target and non-target species/trophic relationships
Mean maximum length of fish and elasmobranchs (catch data)	5.5	1	0.5	1	0.5	0	1	1	0.5	target and non-target species
Mean maximum length of fish and elasmobranchs (model derived)	5.5	1	1	1	0.5	0	1	0.5	0.5	target and non-target species
Single species catch (Length-frequency; Catch sex and maturity composition)	5.5	1	0	0.5	0.5	1	1	1	0.5	target and non-target species
Proportion of predatory fish or "Large Species Indicator" (model derived)	5	1	0.5	1	0.5	0.5	0	1	0.5	target and non-target species
Proportion of predatory fish or "Large Species Indicator" (catch data)	5	1	0.5	1	0.5	0.5	0	1	0.5	target and non-target species
Fish condition (length-weight residuals) for main commercial species	5	1	1	0.5	0	0	1	1	0.5	target and non-target species/trophic relationships
Single species age-based indicators	5	1	0	0.5	0.5	1	1	0.5	0.5	target and non-target species
Zooplankton biomass and size structure	5	1	1	0	1	1	1	0	0	pelagic habitats/trophic relationships
Abundance-Biomass Comparison (ABC) curves	4.5	1	1	1	0	1	0.5	0	0	target and non-target species
Species diversity indices (Shannon/Simpson/Evenness/Richness) (model derived)	4.5	1	1	0	0.5	0	1	0.5	0.5	target and non-target species
Ichthyoplankton abundance indices	4.5	1	1	0	0.5	1	1	0	0	target and non-target species
Species size at first sexual maturation	4	1	0	0	0.5	1	1	0.5	0	target and non-target species
Species diversity indices (Shannon/Simpson/Evenness/Richness) (catch data)	3.5	1	0.5	0	0.5	0	0	1	0.5	target and non-target species
Discard survival	2.5	0	1	0	1	0	0.5	0	0	non-target vulnerable species
Population genetic structure (single species)	0	0	0	0	0	0	0	0	0	target and non-target species

4. TASK 3 – DEFINE THE GEOGRAPHICAL SCALES TO GUIDE THE OPERATIONALISATION OF AN EAFM

Key message

- The operationalisation of an EAFM in the high seas lags behind compared to national implementations.
- The lack of well-established ecologically-meaningful regions or ecoregions within the vast and diverse high seas is impeding its operationalisation.
- Seven candidate ecoregions for ICCAT and two ecoregions for IOTC are proposed based on three pillars of information, the biogeography of the region, fish communities, and the dynamics of main fisheries.
- The proposed ecoregions aim to regionalise ecosystem planning, research, assessments, and ultimately ecosystem advice.
- The proposed ecoregions aim to be a solid starting point to foster a consultative process in ICCAT and IOTC about the need to regionalise the EAFM.

4.1. Objectives

ICCAT and IOTC are currently exploring approaches to facilitate the implementation of an EAFM in their Convention Area. For this, the identification of ecoregions that are ecologically and biologically meaningful is an essential component (Grant *et al.*, 2006; UNESCO, 2009; Rice *et al.*, 2011). The identified areas would also need to be consistent, at least to some extent, with current fisheries management systems.

The objective of this task is to define the appropriate geographical scales to guide ecosystem planning, indicator-based assessments, and ecosystem research in ICCAT and IOTC, ultimately to support the operationalisation of an EAFM.

To accomplish this, Task 3 is divided into the following sub-tasks:

Subtask 3.1 – Review of existing delineation systems in marine pelagic ecosystems and their relevance for HMS

Subtask 3.2 - Identification of spatial fisheries management units for HMS in ICCAT and IOTC

Subtask 3.3 - Definition of criteria to identify “High Sea” ecological regions and proposal of candidate ecoregions

4.2. Sub-task 3.1 – Review of existing delineation systems in marine pelagic ecosystems and their relevance for highly migratory species

Biogeographic classifications are increasingly gaining importance in the fisheries policy sector since, commonly, the first step of any policy implementation requires setting appropriate spatial scales and identifying representative areas for management (Rice *et al.*, 2011). The delineation of ecoregions is a necessary element for the implementation of an EAFM (Secretariat of the Convention on Biological Diversity, 2005; Link, 2010). Biogeographic classifications can facilitate the identification of meaningful ecoregions, which can then be used to guide ecosystem planning, the development of ecosystem assessments, indicator-based report cards, and ecosystems research. Having well-defined, ecoregions help highlight potential differences in environmental drivers, biological attributes and productivities among regions that in turn could explain the differences in species compositions or even fishery production potential among regions (NAFO, 2014). An area-based ecosystem assessment would allow monitoring the state of different components of the ecosystem at a regional basis, where the environmental drivers and fisheries impacts on each region would be presumably different. This would allow focusing management actions on specific regions, species, and issues, and would provide a framework for monitoring and measuring success of specific spatially based management measures.

Partitioning the pelagic ocean into areas with unique physical and biological attributes makes ecological sense if fishery data reporting is to be tailored to these areas. Fisheries reporting might reflect the spatial dynamics of fisheries and fleets. Then the ecoregions may need to be reconfigured to account for additional considerations such as jurisdictional boundaries and legal issues, and the operationalisation and application of management measures. This opens up a discussion on what could be considered the ideal versus practical ecoregions to assist in the implementation of an EAFM in ICCAT and IOTC.

In this task, we review and compare a total of six marine biogeographic classifications for their potential relevance in informing the choice of ecoregions in the Atlantic and Indian Ocean in order to support the management and conservation of highly migratory species in line with an EAFM (Table 4.1). We briefly describe each of them by highlighting main drivers and purpose for its development, criteria and methodology used, type of data considered, and their current use in marine conservation and management projects. We then compare them and briefly discuss their potential relevance for the management of HMS in line with an EAFM (Table 4.1). A detailed description of each biogeographic classification can be found in Appendix 3.1.

Table 4.1 Comparative review of existing marine biogeographic classifications of pelagic waters

Biogeographic classification	Type of input data	Spatial scale	Resulting classification	Type of boundaries	Main purpose of classification
Large Marine Ecosystems (LMEs) (Sherman & Duda, 1999)	Expert derived-system. Focuses on oceanographic processes and ocean productivity. Informed by hydrography, bathymetry, productivity, trophically dependent populations, fisheries and geopolitical considerations.	Coastal classification (omits some coastal areas of islands in the Pacific and Indian Oceans). Includes the benthic and pelagic environments.	66 regions	Static boundaries	Transboundary governance and management of resources (fish and fisheries, pollution, socioeconomics, governance)
Longhurst Biogeochemical Provinces (BGCP) (Longhurst, 1998)	Informed by satellite chlorophyll and physical variables associated with large-scale circulation patterns including sea surface temperature, ice fraction, and maximum mixed layer depth.	Coastal and Oceanic classification. Includes the epipelagic environment.	4 biomes, 57 provinces	Static boundaries	Partitioning of the global oceans into ecosystems to facilitate their future quantitative studies
Marine Ecoregions of the World (MEOW) (Spalding *et al.*, 2007)	Expert-derived system based on a critical review of existing classifications. Informed by biodiversity attributes (including taxonomy, patterns of dispersal and isolation of species, and their evolutionary history) and oceanographic processes.	Coastal classifications. Includes pelagic and benthic environment.	12 realms, 58 provinces and 232 ecoregions	Static boundaries	Management of resources and conservation planning in the coastal areas.
Pelagic Provinces of the World (PPOW**)** (Spalding *et al.*, 2012)	Expert-derived system based on a critical review of existing classifications. Informed by oceanographic processes, ocean productivity, and biodiversity patterns of species distributions and communities.	Oceanic classification including some coastal areas. Omits some coastal areas which are covered by the MEOW classification. Includes the epipelagic environment.	4 realms, 7 biomes, 37 provinces	Static boundaries	Support analysis of patterns of marine biodiversity, direct marine resource management and conservation

Biogeography of tuna and billfish communities and derived provinces (TBPs) (Reygondeau *et al.*, 2012)	Informed by tuna and billfish species distributions derived from fisheries statistical data (catch per unit effort of major longline fleets targeting tuna and billfish species)	Coastal and Oceanic classification. Includes the epipelagic environment.	9 distinct communities distributed globally	Static boundaries	Identify global tuna and billfish communities and link them to environmental drivers
Global open-ocean biomes (GOOBs) (Fay & McKinley, 2014)	Informed by satellite chlorophyll and physical variables associated with large-scale circulation patterns including sea surface temperature, ice fraction, and maximum mixed layer depth.	Oceanic classification. Includes the epipelagic environment.	17 Biomes including mean biomes and core biomes	Static and dynamic boundaries	Identify regions with common biogeochemical functions at the largest possible scale in order to oceanic biogeochemical, studies.

4.2.1. Review of existing marine biogeographic classifications

LARGE MARINE ECOSYSTEMS (LME) -The Large Marine Ecosystem Classification (Figure 4.1) was proposed as an ecosystem oriented management regime (Sherman, 1991 ; Sherman, 1994). It aimed to delineate all the coastal areas into regions of appropriate scale to be practical for policy development, management, and monitoring of fishery resources due to growing anthropogenic pressures in the marine realm. The LME regions are based on a set of oceanographic features including bathymetry and hydrography, and a set of community features including productivity and trophic relationships, as well as ecosystem health indices, which are then revised through extensive expert consultations (Sherman, 1994). They also have a strong socioeconomic component and a strong management context which makes it helpful for stakeholders. The LMEs are based on extensive research and analyses, that has currently resulted in the classification of 66 regions (Figure 4. 1) (NOAA, 2017). The LME delineation is a continuously evolving process, which has tried to combine oceanographic and biological analysis with geopolitical features. Since its creation, the LME classification system has been used to direct research on fisheries management and transboundary management of fisheries, pollution handling, habitat restoration and protection, and in general, marine governance (Watson *et al.*, 2004 ; Sherman *et al.*, 2010).

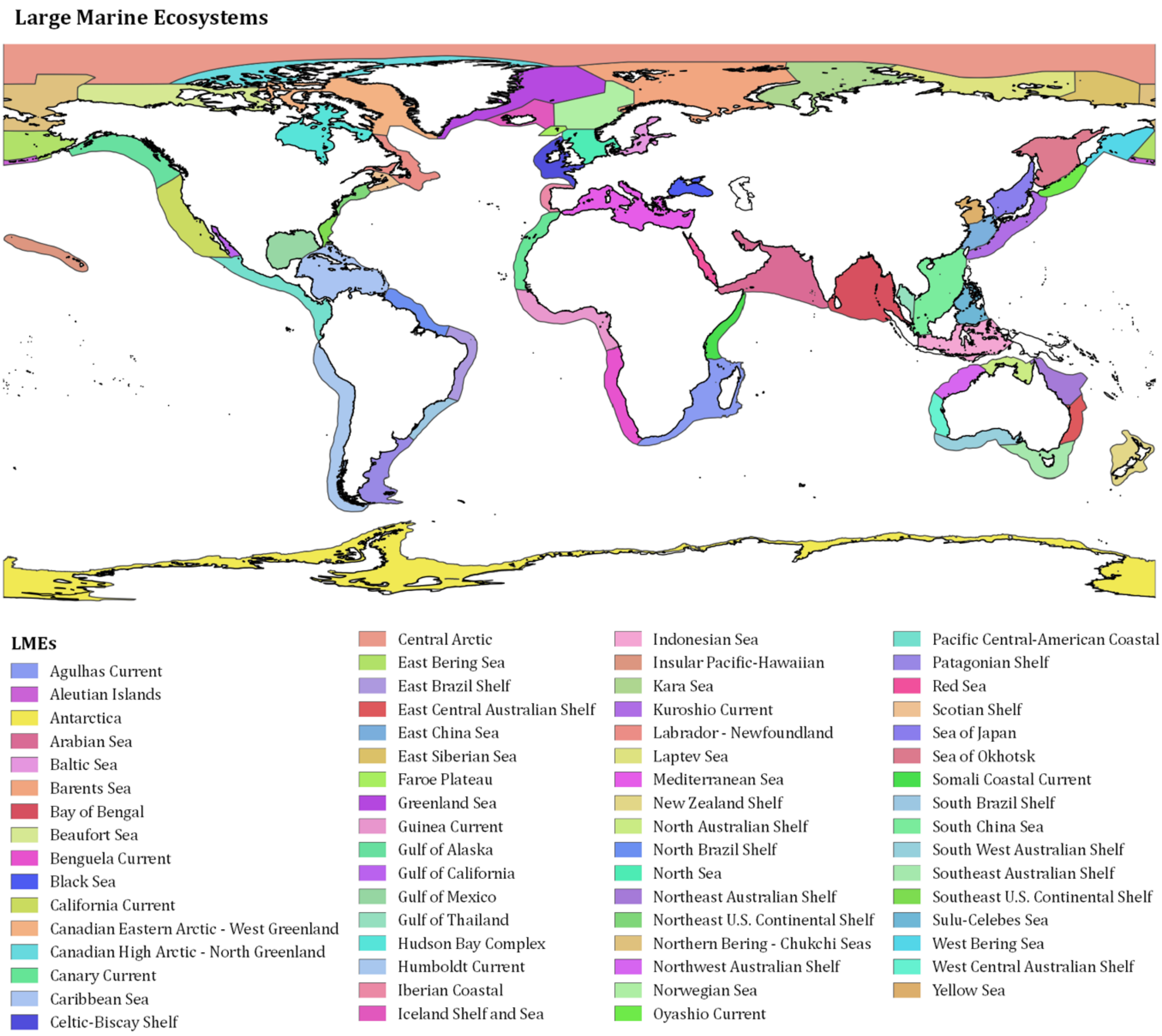


Figure 4.1. Large Marine Ecosystems division including 66 ecosystems encompassing all coastal areas globally.

LONGHURST BIOGEOGRAPHICAL PROVINCES (BGCP) – The Longhurst's classification system into biogeochemical provinces provides ecologists with a thorough manual on regional oceanography to facilitate study of ocean ecosystems on a quantitative level (Longhurst, 2007). This classification uses available physical and biological oceanographic datasets in order to make it more measurable and replicable, but it does not make use of expert opinions (Longhurst 1998, Costello 2009, UNESCO 2009) (Longhurst, 1998 ; UNESCO, 2009). The physical oceanographic data used reflect the discontinuities in physical processes in the ocean, like nutricline depth, mixing, fronts, which delineated the main biomes in the classification - Polar, Westerlies, Trades and Coastal biomes (Figure 4.2). The biological datasets analysed include phytoplankton distribution and concentration, and primary productivity which were used to further partition the biomes into 57 provinces, out of which 22 are coastal (Figure 4.2). Other parameters such as mixed-layer depth and photic depth, were also used to further partition the biomes. Longhurst´s BGCPs have also been used extensively in various research topics e.g. in relation to fisheries management (Watson *et al.*, 2000), as units for plotting biodiversity variations in the oceans (Olson & Dinerstein, 2002), for predicting species habitats (Mannocci *et al.*, 2014), as well as in ecosystem and community research (Reygondeau *et al.*, 2012).

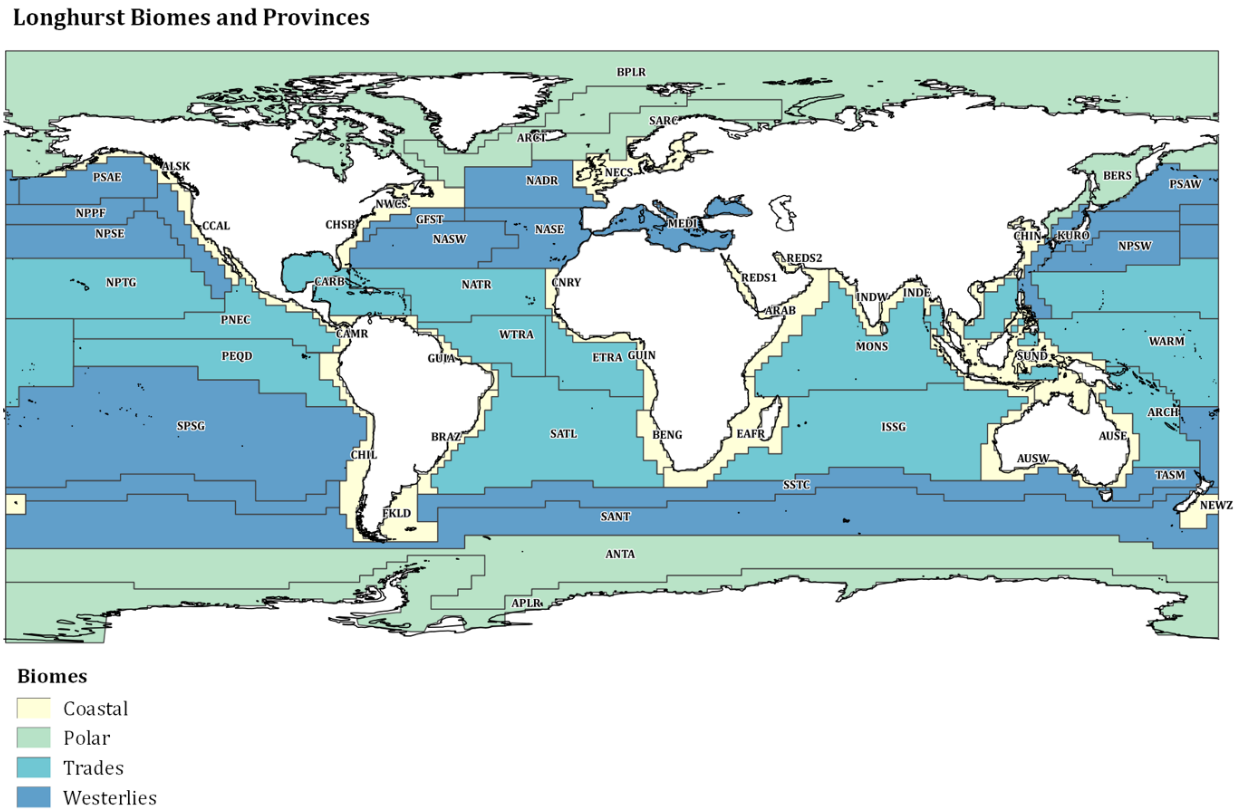


Figure 4.2 Longhurst Biogeochemical provinces (BGCPs) delineated with black lines, and the biomes to which they belong are color-coded.

MARINE ECOREGIONS OF THE WORLD (MEOW) -- The marine ecoregions of the world (MEOW) were created in 2007 with the main purpose of reconciling the differences between the existing coastal classifications (Briggs's provinces, LMEs, Sullivan Sealey and Bustamante's provinces, Boschi provinces) and in order to provide a more global, comprehensive classification of the coastal areas (Spalding *et al.*, 2007). It aims to provide a system that is appropriate for management of resources, conservation planning and other actions, allowing multiscale analyses, while respecting the natural boundaries. This classification is largely based on reviews and synthesis of existing biogeographic boundaries based on various taxonomic and oceanographic data inputs, which were chosen in the first, data-gathering phase, then finally selected based on data availability. A large expert group also provided further insights and exchanged opinions to inform the final biogeographic boundaries. This classification is therefore not simply the result of modelling different relevant physical and biological datasets, but of a more comprehensive process that uses expert knowledge to finalise the classification, resulting in more qualitative and less replicable classification system. The resulting classification is nested hierarchically. It consists of 12 realms, 58 provinces and 232 ecoregions (Figure 4.3). The outer boundary for the system was set at the 200m isobaths. The MEOW classification is also often used, together with LMEs and BGCPs classifications, in applied studies requiring knowledge on biogeographic classifications of marine resources to inform management and conservation (Costello, 2009 ; UNESCO, 2009).

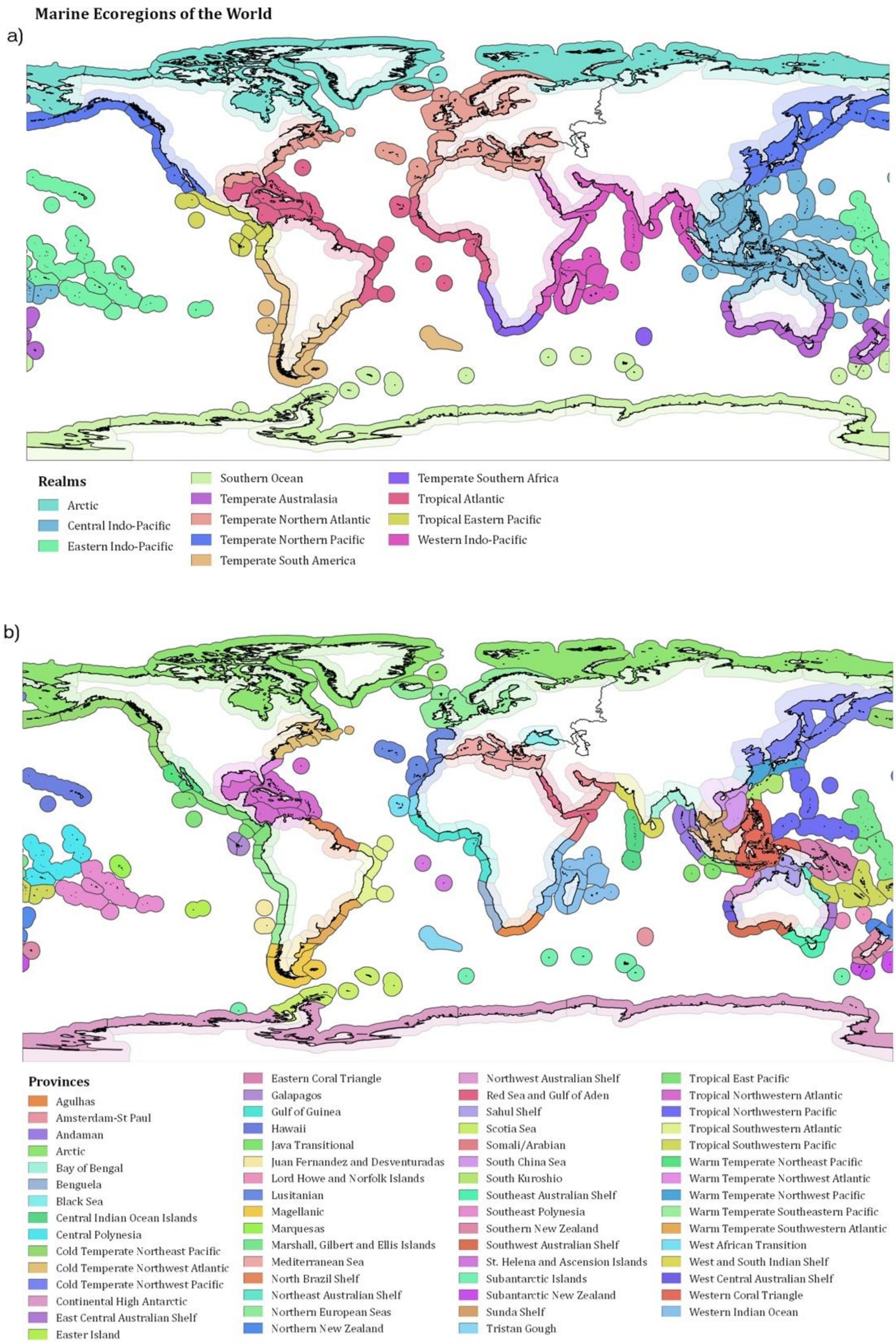


Figure 4.3. Marine ecoregions of the world. (a) Marine realms of the MEOW classification and (b) Marine provinces of the MEOW classification. Ecoregions are further subdivisions of the provinces and are delineated with black lines.

PELAGIC PROVINCES OF THE WORLD -- After the development of the MEOW classification and the recognition of the increasing anthropogenic pressures upon the high seas, Spalding and colleagues developed a classification covering the pelagic regions of the open ocean that builds up on MEOW in 2012 (Spalding *et al.*, 2012). The classification is based on various qualitative inputs of data (physical and biological) and principles, similar to the MEOW classification, with the main difference being that it had to compensate for the biological data gaps that occur in open ocean as well as to use different community variables. This classification focused completely on the oceanographic drivers and the patterns of species distributions they produce. The PPOW classification was also broadened to include coastal boundary currents and semi-enclosed seas in order to include biota that is occurring in both open ocean and coastal environments. Therefore, the PPOW classification is entirely based on a synthesis of existing and expert knowledge built from a series of workshops. The PPOW classification (Figure 4.4) delineates open ocean pelagic waters up to 200m depth. It includes 37 pelagic provinces that are broadly grouped into four realms (Northern Coldwater, Indo-Pacific Warm water, Atlantic Warm water and Southern Coldwater) or into seven major biomes (polar, gyre, eastern boundary currents, western boundary currents, equatorial, transitional and semi-enclosed seas). Considering the growing importance of applying EAFM on the high seas, this classification could have many applications (Ardron *et al.*, 2008; Ban *et al.*, 2014).

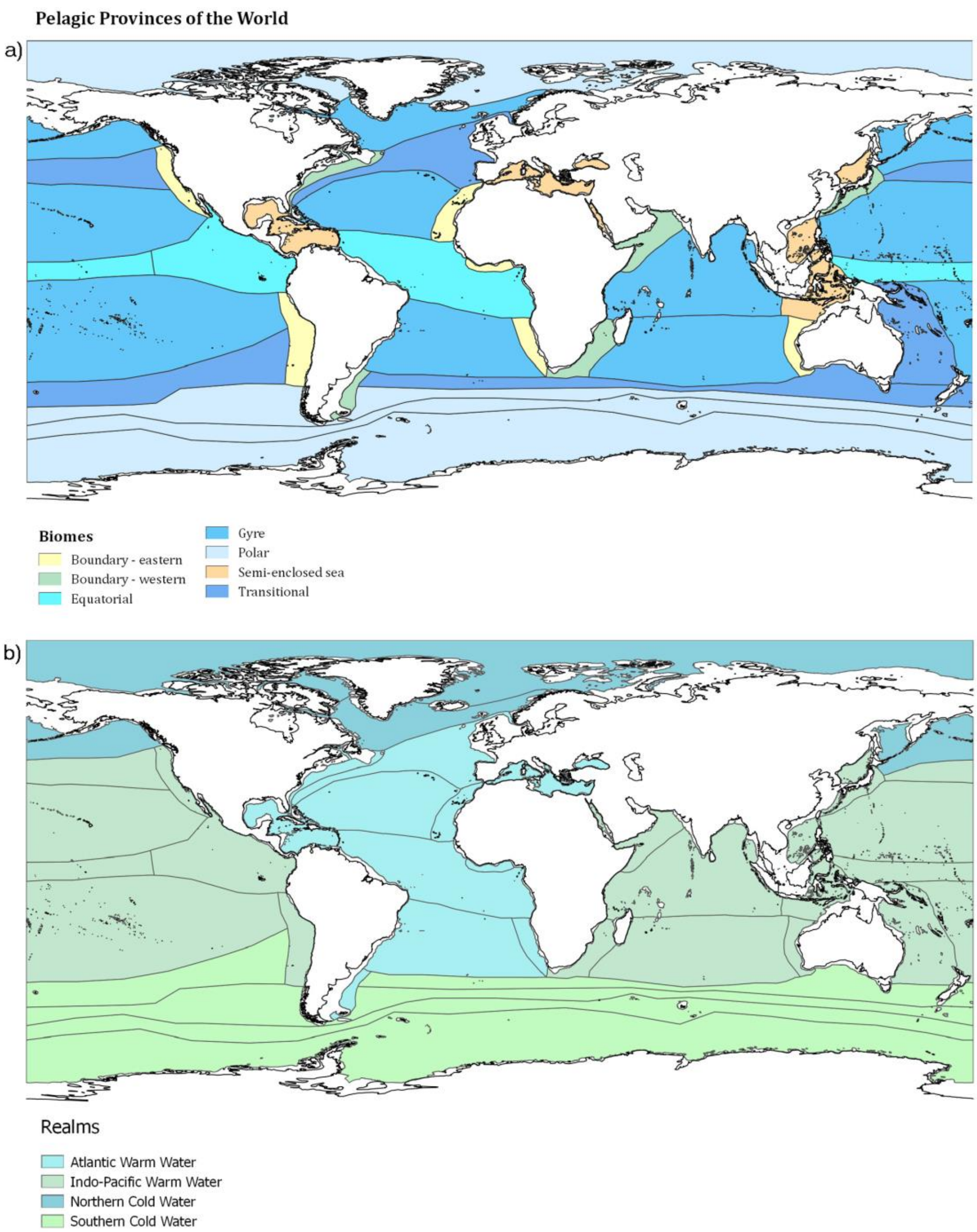


Figure 4.4 –Pelagic provinces of the world classification a) Pelagic biomes of the world, and b) Pelagic realms. Individual provinces are delineated with black line.

REYGONDEAU´S BIOGEOGRAPHY OF TUNA AND BILLFISH COMMUNITIES –

This study divided the oceanic biosphere into ecoregions based on tuna and billfish spatial patterns of catch per unit effort of major fishing fleets, the Japanese and Korean longline fleets (Reygondeau *et al.*, 2012). Furthermore, it described the physical environment for each ecoregion, and compared the identified ecoregions with Longhurst's BGCPs. This study identified nine ecoregions of the world's oceans based on the tuna and billfish distributions and catches (Figure 4.5). It demonstrated that despite the highly migratory nature of tuna and billfish species, these species have a clear spatial partitioning into well-defined communities or ecoregions. The ecoregions were characterised by either single or multiple species dominance, or diversified communities where there were no dominant species.

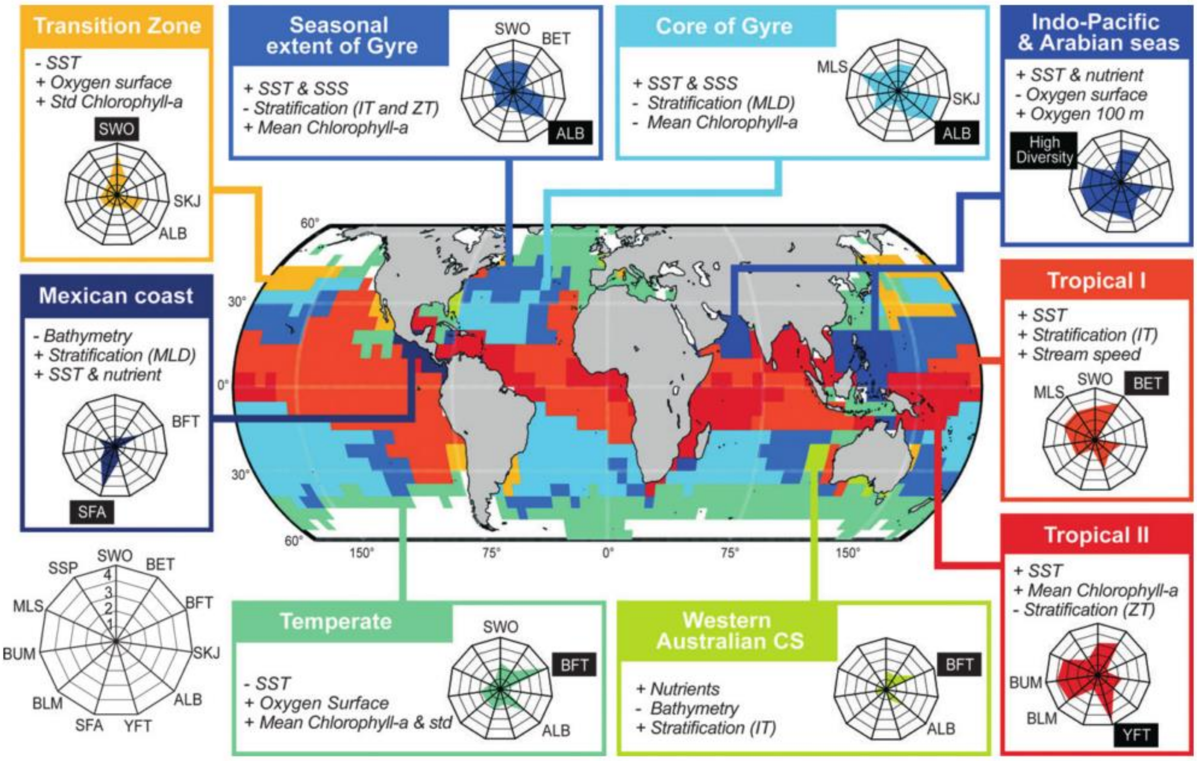


Figure 4.5 Biogeography of tuna and billfish communities. Ecoregions are illustrated with different colours and the species communities in each ecoregion are described on the radar plots. Figure extracted from Reygondeau *et al.* (2012).

GLOBAL OPEN-OCEAN BIOMES – This study aimed to partition the global open ocean into biogeochemical biomes that are as large as possible (Fay & McKinley, 2014). The classification is based on geochemical properties and aims to differentiate between areas that are bio-geochemically active and areas which have more stable properties and distinct enough to be divided into biogeochemical biomes. This classification uses oceanographic data such as maximum mixed layer depth, spring/summer chlorophyll a concentration, sea surface temperature, and sea ice fractional coverage. The authors first divided the ocean into basins (Atlantic, Pacific, Indian, and Southern Ocean) and then these basins into 17 biomes (Figure 4.6). This classification aims to be useful for future studies in ocean biogeochemistry and carbon cycling.

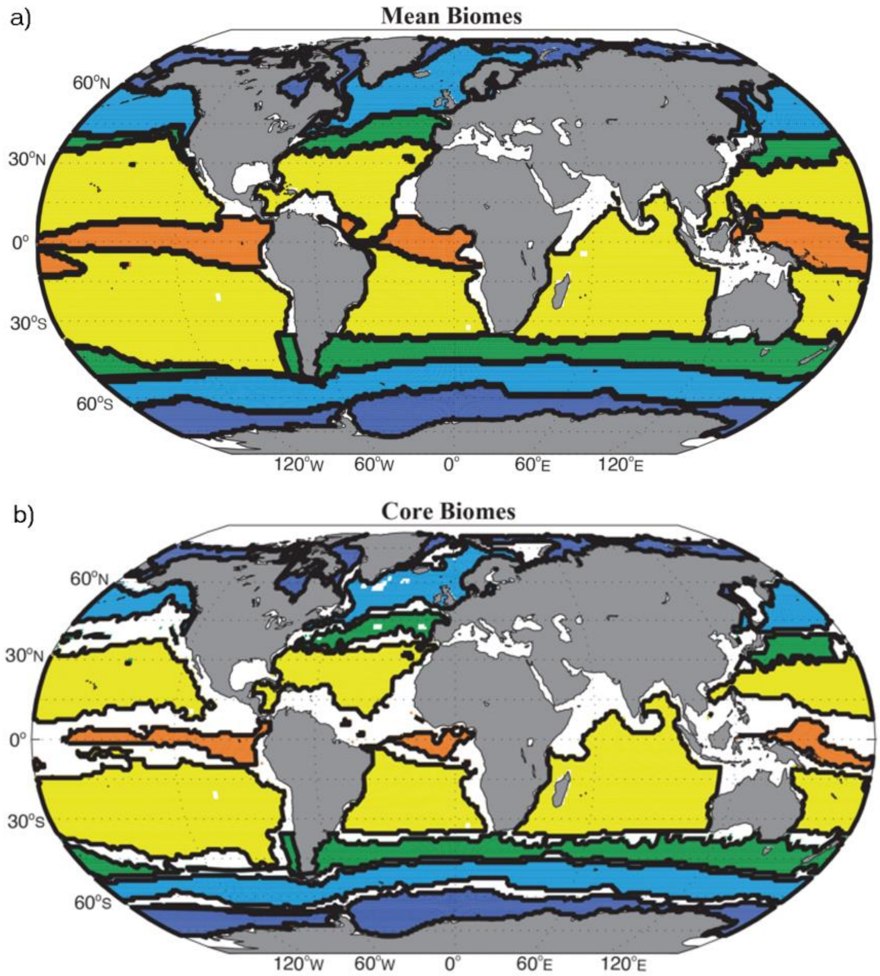


Figure 4.6 Global open ocean biomes. a) Mean biomes (each unit is one biome) and, b) Core biomes. Mean biomes were calculated using the mean values of the variables during the study period, while core biomes were created by selecting only the grid cells that had remained within the same biome definition in all the 13 years of time-varying biomes. Colour legend: dark blue - ice biomes (ICE); cyan - subpolar seasonally stratified biomes (SPSS); green - subtropical seasonally stratified biomes (STSS); yellow - subtropical permanently stratified biomes (STPS); orange - equatorial biomes (EQU). Figure extracted from Fay and McKinley (2014).

4.2.2. Comparative analysis of the reviewed biogeographic classification systems

The marine biogeographic classifications reviewed are based on a wide array of data inputs, depending on whether the classification system is intended to be for coastal or oceanic regions (Table 4.1). The coastal and oceanic regions are differentiated by very contrasting physical and biological attributes, as well as by different biota. Coastal regions are shallower, so the environment is drastically different compared to the oceanic regions where waters are divided into an upper and more dynamic layer, generally up to ~200-300 m depth, and a deeper layer spanning up to ~12km depth. The biogeographic classifications reviewed generally use various biological and physical data inputs to identify broad patterns of co-occurrence of species, habitats and ecosystem processes in order to partition the pelagic ocean into regions that are relatively homogeneous. The most common physical and environmental data used to inform marine biogeographic classifications are temperature, stratification of water column, mixed layer depth, circulation patterns and bathymetry. On the other hand, the most common biological data are primary productivity of surface waters, as well as the taxonomic and community attributes of the pelagic compartment, such as the spatial distribution and abundance of species. Many biogeographic classifications have used both sources of data, combining biological as well as physical features and processes to delineate relatively distinct regions or regions from adjacent zones (Longhurst, 1998; Spalding *et al.*, 2012) (Table 4.1). Some biogeographic classifications, such as the Large Marine Ecosystem, also use expert opinion to provide further insights until the classification is finalised.

The temporal and spatial scales of the data analysed also contribute to the development of biogeographic classifications. The temporal scales of the classifications are generally difficult to set due to shifting conditions in the marine environment, so they are commonly set as static in time in order to establish physical and biological boundaries that do not change over time. However, recent work has developed biogeographic classifications with dynamic boundaries between regions (Fay & McKinley, 2014). Biogeographical classifications with dynamic boundaries tend to be impractical for management purposes as it is harder to set management measures on dynamic boundaries that change seasonally or over time (Spalding *et al.*, 2012).

Regarding the setting of the spatial scale, coastal biogeographic classifications usually subdivide the coastal area into many distinct sub-regions due to the high variability of the environmental conditions in the coastal areas; while oceanic classifications commonly subdivide the open ocean into a smaller number of larger areas due to their greater homogeneity (Table 4.1). Consequently, the choice of the spatial scale can affect the potential uses of each classification. On one hand, the smaller the scale, the bigger the accuracy of the observed patterns and processes to be analysed, and included, in the classification system. On the other hand, an increase in the spatial scale leads to higher possibilities of trans-boundary management, important for the management of trans-boundary species in oceanic regions, at the expense of accuracy of observed patterns and processes. The choice of different levels of spatial divisions can be resolved by making the classifications hierarchical. Larger areas can be subdivided into smaller ones in order to align the different spatial scales to fit different purposes (Longhurst, 1998; Spalding *et al.*, 2007; Spalding *et al.*, 2012) (Table 4.1). Therefore, the hierarchical classifications allow addressing different issues, which are dependent on a specific spatial scale. This is an advantage when the strategic goals are set at national or regional level, but the implementation takes place at more local scales. Consequently, hierarchical classifications will accommodate different management needs and uses, while remaining ecologically meaningful.

4.2.3. Relevance of the reviewed biogeographic classifications for the management of tuna-and like species within an ecosystem approach

The LMEs and MEOW classifications have a limited spatial coverage as they do not cover the open ocean areas. Therefore, it has a limited direct application in identifying potential ecoregions to monitor the impacts of HMS of tuna and billfish fisheries which are manly distributed in oceanic systems. However, in addition to the principal market tunas and billfishes, ICCAT and IOTC are also in charge of managing and conserving some coastal species such as small tunas, bonitos, and Spanish mackerels. Therefore, potentially these classification systems could be used to identify more coastal ecoregions to better manage them in line with an EAFM. Yet this study focuses mainly on HMS of oceanic tunas and billfishes and does not cover the small neritic tunas and mackerels. Despite not being fully relevant to inform fisheries management of HMS of oceanic tunas, billfishes and sharks, some best practices and advice can still be derived from the LME and MEOW classifications:

1. The division into provinces that are both ecological and practical is the result of a long interactive process where expert knowledge and feedbacks from fisheries managers and conservation practitioners is needed.
2. It is important to start the process, making informed decisions based on the best science available and following the precautionary approach: further improvements and additions can follow and included over time.
3. The hierarchical and nested classification system of the MEOW classification, with appropriate scales of features that enter the hierarchy at the scale that is known to affect the species distributions, is also an advantage. The different spatial levels and

subdivisions could potentially be used for different management purposes and planning.

The Longhurst BGCP and the Spalding PPOW classifications could potentially inform the delineation of potential ecoregions for the management and conservation of HMS in the Atlantic and Indian oceans for a series of reasons:

1. The Longhurst BGCP classifies both the coastal and oceanic environment making it relevant for oceanic tunas and billfishes as well as the coastal species with broad distributions under the purview of ICCAT and IOTC. The PPOW also classifies both the coastal and oceanic environment but focuses more on the oceanic environment leaving out some coastal shelf areas (which are classified under the MEOW classification developed by the same author). Despite its oceanic focus, the PPOW could be useful to inform the management and conservation of species of tunas and billfishes that are predominantly oceanic.
2. The hierarchical and nested classification system of the Longhurst BGCP (biomes and provinces) and PPOW (realms, biomes and provinces) is more advantageous since the different spatial levels and subdivisions could be used for different management purposes. Perhaps, one of the potential drawbacks in the Longhurst BGCP classification could be the large number of provinces within each biome, which might make its use impractical from an operational point of view when developing ecosystem plans and assessments at a regional basis.
3. The Longhurst BGCP and the PPOW classifications both have a strong basis on the oceanographic features of the water column, which is an important factor in determining species distributions as well as informing the delineation of ecosystem-resembling regions with distinct biophysical characteristics. One of the drawbacks of Longhurst BGCP classification system is that it is focused mainly on a set of abiotic properties of the water columns, and it is not based on species and community-based data, except from phytoplankton concentration. The PPOW classification is based on both oceanographic attributes and the patterns of species distributions, which makes it more comprehensive.
4. The PPOW is also based on a detailed review of existing biogeographic classifications for the open ocean, including the Longhurst BGCP, and it uses expert knowledge to reconcile the differences between existing politically and ecologically oriented regional classifications, such as those from some Regional Fisheries Management Organizations and the UNEP Regional Seas. This also makes the PPOW classification more comprehensive.

5. The number of provinces in the PPOW classification is smaller compared to the classification by Longhurst, which potentially makes the operationalisation of an EAFM more practical as the larger the number of provinces the larger the amount of resources needed to monitor and manage them.

The Reygondeau's classification based on the global distributions of tuna and billfish species was reviewed in part because it demonstrates that tuna and billfish species have a clear spatial partitioning into well-defined communities despite their wide distributions and highly migratory behaviour. Therefore, in principle it could potentially be used to inform the current management of HMS in ICCAT and IOTC. However, three drawbacks are observed in their proposed ecoregions for the management of HMS of tunas and billfishes:

1. The main tuna and billfish communities analysed in the Reygondeau's study (and associated ecoregions) do not include or are not representative of all tuna and billfish species found in oceanic ecosystems. By only analysing the catches and catch per unit effort of the two main longline fleets and excluding the catches of purse seiners, important commercial species of skipjack tuna (which is not typically caught by longliners) were not well represented in these communities. In order to have a more representative set of species, the analysis should have taken into account several sources of fisheries data and at least include the main fishing gears and fleets. Additionally, other oceanic fish species such as sharks are also caught by these gears and were not included in their analysis. However, this would be a difficult task as shark catch data are mostly not publicly available.
2. The large number of ecoregions found in each ocean in the Reygondeau's study (for example, 12 in the Atlantic Ocean) compared with the Longhurst BGCP and PPOW classifications, could make their use impractical from an operational point view. The large number of ecosystem plans, ecosystem assessments with a potential set of ecosystem indicators to monitor routinely the impacts of fisheries in each region would be too costly.
3. Reygondeau's classification used fisheries dependent data to infer ecological processes (which was also pointed out by other studies) and the use of these data is not recommended since it can be inherently biased by the changing fishing behaviour of the fleets. However, fishery dependent data for HMS have a better spatial coverage than any costly fishery independent survey aimed at HMS. In fact, few, if any, fishery independent surveys are available for HMS spanning their entire distribution. Therefore, the use of fishery dependent data is a compromise to be

made in order to improve our knowledge of pelagic biological diversity and patterns of species distributions and to inform biogeographic classifications in the open ocean.

The global open ocean biome classification of Fay and McKinley was the last classification review. This classification attempts to differentiate between static areas and dynamics areas on the open ocean. Consequently, it is spatially limited due to the type of data and methods used in the classification, resulting in core biomes that do not cover the entire open ocean. Therefore, this marine biogeographic classification might not be relevant to inform fisheries management for tuna and tuna-like species, or to inform the development of ecosystem indicators and assessments to monitor the impacts of fisheries on oceanic systems. However, some best practices and advice can be derived:

1. Temporal variability is very pronounced in the ocean and this makes setting both dynamic and static boundaries challenging. For fisheries management purposes, it is imperative that static boundaries are defined. Since climate change is changing the ocean environment as well as affecting the species distributions and abundances, it would be necessary for established boundaries (static or dynamic) to be revised in the future to account for that.

In conclusion, it is considered that the Longhurst BGCP and Spalding's PPOWs are best suited to inform the boundaries of ecoregions for the management and conservation of tuna and billfish species in ICCAT and IOTC in line with an EAFM. Therefore, the Longhurst BGCP and Spalding's PPOW classifications are used to carry out further analysis and examine the spatial distribution of tuna and billfish species and the spatial dynamics of the main fishing fleets targeting tuna and billfish species in the Atlantic Ocean and Indian Ocean (see Task 3.2).

4.3. Sub-task 3.2- Identification of spatial fisheries management units for HMS in ICCAT and IOTC

Here, fisheries management units currently used in ICCAT and IOTC are identified and described. Second, spatial patterns in species composition in the ICCAT and IOTC convention area are examined. Third, spatial patterns in species composition and a selected set of existing marine biogeographic classifications are compared to assess their alignment, in order to inform the potential choice of ecoregions in the ICCAT and IOTC Convention Areas.

4.3.1. Identification and description of current fisheries management units in ICCAT and IOTC

Prior to operationalising an EAFM, it is important to understand the current management units used in ICCAT and IOTC. Both ICCAT and IOTC focuses its fishery management on single species and stocks. ICCAT manages nine stocks of principal market tunas and nine stocks of billfishes (Table 4.2), while IOTC manages 4 stocks of principal market tunas and five stocks of billfishes (Table 4.3). The stock assessments are conducted every 1-5 year cycles for each individual stock. While single species management is still the norm in many fisheries organizations, this type of management is incrementally being supported by more integrative management. Modern fisheries management is increasingly recognizing that stocks are part of food webs, and that species interact, co-occur in space, and compete for resources. Therefore, an EAFM justifies and prioritises understanding of species distributions, as well as how species and stocks interact and co-occur in space in order to formulate and inform multispecies fisheries assessment and advice (May *et al.*, 1979; Garcia *et al.*, 2003; Rindorf *et al.*, 2013). To our knowledge, ICCAT and IOTC do not routinely conduct multi-species stock assessment and management advice, even if they do consider species interactions qualitatively in some cases when providing fisheries management advice. To move into a framework for multispecies assessment and advice, which is clearly needed when attempting to operationalise an EAFM, it is imperative to have a clear description of the ecosystem, including how species and stocks are distributed, co-occur, and interact, as well as to identify the most important interactions which affect the management of fisheries.

Table 4.2 Species and stocks of tunas and billfishes managed by ICCAT.

Common name (acronym)	Latin name	Climate group	Number of stocks	Names of stocks with acronyms
Albacore tuna (ALB)	*Thunnus alalunga*	Temperate	3	• Northern (ALB-N), • Southern (ALB-S) • Mediterranean (ALB-M)
Bigeye tuna (BET)	*Thunnus obesus*	Tropical	1	• Atlantic (BET-A)
Atlantic bluefin tuna (BFT)	*Thunnus thynnus*	Temperate	2	• Eastern and Mediterranean (BFT-E) • Western (BFT-W)
Atlantic blue marlin (BUM)	*Makaira nigricans*	Subtropical	1	• Atlantic (BUM-A)
Atlantic sailfish (SAI)	*Istiophorus albicans*	Subtropical	2	• Eastern (SAI-E) • Western (SAI-W)
Skipjack tuna (SKJ)	*Katsuwonus pelamis*	Tropical	2	• Eastern (SKJ-E) • Western (SKJ-W)
Swordfish (SWO)	*Xiphias gladius*	Subtropical	3	• Northern (SWO-N) • Southern (SWO-S) • Mediterranean (SWO-M)
Atlantic white marlin (WHM)	*Tetrapturus albidus*	Subtropical	1	• Atlantic (WHM-A)
Yellowfin tuna (YFT)	*Thunnus albacares*	Tropical	1	• Atlantic (YFT-A)

Table 4.3 Species and stocks of tunas and billfishes managed by IOTC.

Common name (acronym)	Latin name	Climate group	Number of stocks	Names of stocks with acronyms
Albacore tuna (ALB)	*Thunnus alalunga*	Temperate	1	• Indian stock (ALB)
Bigeye tuna (BET)	*Thunnus obesus*	Tropical	1	• Indian stock (BET)
Blue marlin (BUM)	*Makaira nigricans*	Subtropical	1	• Indian stock (BUM)
Indo-Pacific sailfish (SFA)	*Istiophorus platypterus*	Subtropical	1	• Indian stock (SFA)
Skipjack tuna (SKJ)	*Katsuwonus pelamis*	Tropical	1	• Indian stock (SKJ)
Swordfish (SWO)	*Xiphias gladius*	Subtropical	1	• Indian stock (SWO)
Black marlin (BLM)	*Makaira indica*	Subtropical	1	• Indian stock (BLM)
Striped marlin (MLS)	*Tetrapturus audax*	Subtropical	1	• Indian stock (MLS)
Yellowfin tuna (YFT)	*Thunnus albacares*	Tropical	1	• Indian stock (YFT)

4.3.2. Spatial analysis of species composition in the ICCAT and IOTC convention areas

Catch data by species with temporal and spatial information was provided by the ICCAT and IOTC Secretariats, in order to examine the species composition and how catches vary spatially in the ICCAT and IOTC convention areas. The ICCAT CATDIS dataset (i.e. Task II catch data raised to total landings) was used, which included catch data for nine species – five principal tunas (yellowfin tuna, skipjack tuna, albacore tuna, Atlantic bluefin tuna and bigeye tuna) and four billfishes (swordfish, white marling, sailfish and Atlantic blue marlin), with information on gears used, the flag of the country, the fleet, and geographical location on a 5x5 degree strata over the Atlantic Ocean. The IOTC dataset provided by the Secretariat included catch data for five species - four principal tunas (yellowfin tuna, skipjack tuna, albacore tuna and bigeye tuna) and one billfish (swordfish), with information on gears used, the flag of the country, the fleet, and geographical location on a 5x5 degree stratum over the Indian Ocean. The catch data spanned from 1950-2014, but only the data from the last 15 years were used in order to track the latest trends in the species composition and distribution. To examine the species composition over the convention areas, the reported catches of each species per year (across all gears, countries and fleets) were averaged across the last 15 years. Catch data with spatial information were not available for the ICCAT/IOTC managed shark species (blue shark - *Prionace glauca*, shortfin mako - *Isurus oxyrinchus* and porbeagle - *Lamna nasus*), or billfishes other than swordfish in IOTC, and therefore, these species were not included in the analyses.

The spatial patterns of catches by species, species grouped by climates and gears were visualised using pie charts plotted on a 5x5 degree mesh over the Atlantic and Indian Ocean. An examination of catches by species showed some unlikely catches of species caught in areas where they were not supposed to be caught. For example, Atlantic bluefin tuna off-the southern coast of Argentina and sailfish off the coast of Terranova in Canada. Therefore, after expert consultation, these catches were removed from the catch dataset.

There are spatial variations in how species are distributed and co-occur across the Atlantic and Indian Oceans (Figure 4.7, 4.8 and 4.9). In the Atlantic Ocean, the northern temperate region is dominated by temperate and subtropical tuna and billfish species (Atlantic bluefin tuna, albacore tuna and swordfish) (Figure 4.7). In the northern subtropical region, there is more variation as some of the tropical tuna species are also caught (skipjack tuna, bigeye tuna and yellowfin tuna) in that region. The tropical region is mostly dominated by tropical tuna species, with some subtropical billfish species catches (skipjack tuna, yellowfin tuna, bigeye tuna, swordfish tuna and blue marlin). The southern subtropical region, as well as the northern one, shows more variation, with the presence of various species (albacore tuna, swordfish, bigeye tuna and skipjack tuna). Finally, in the southern temperate region are caught mostly temperate species as well as some subtropical species (albacore tuna, swordfish and sailfish). When species were grouped by climate (temperate, subtropical and tropical), the spatial patterns in catches further illustrated that species distributions are associated to specific environmental conditions (Figure 4.8). The tropical region, as well as the northern and southern temperate regions, is occupied by a distinct community of species, while the northern and southern subtropical regions are transitional zones where species presence is more diverse, and both tropical and temperate species co-occur. Similarly, in the Indian

Ocean, the tropical region is mostly dominated by tropical tuna species (skipjack tuna, yellowfin tuna and bigeye tuna), with some subtropical swordfish catches (Figure 4.9). In the temperate region are caught mostly temperate tuna species (albacore tuna) as well as subtropical swordfish and some bigeye tuna.

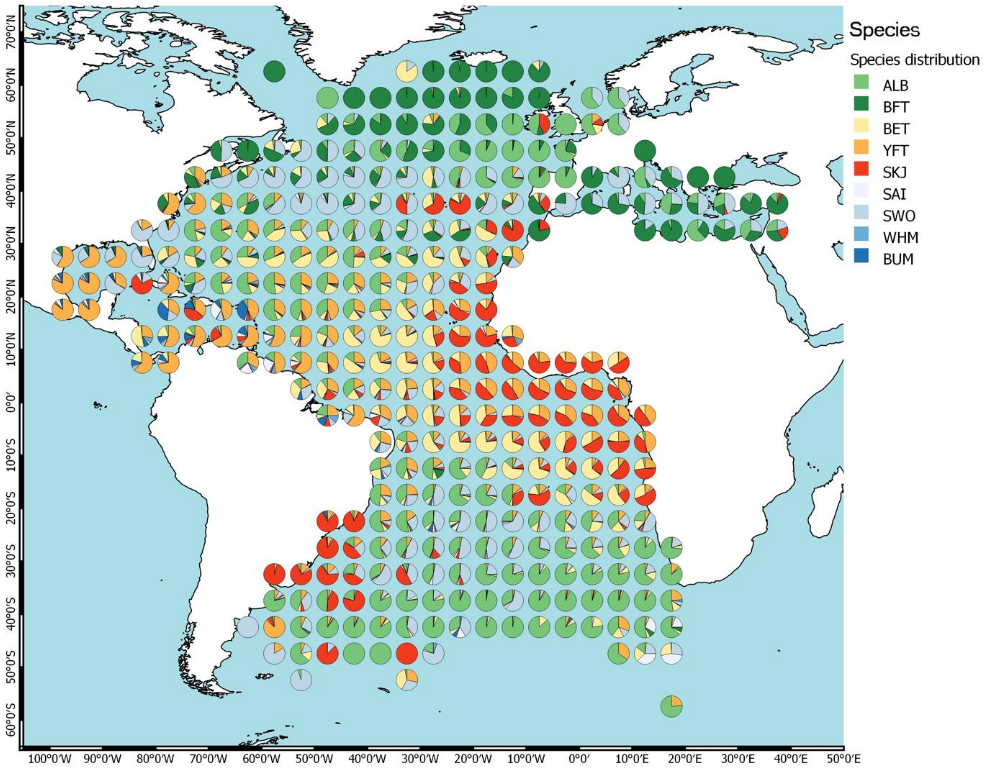


Figure 4.7 Spatial patterns of catches by species in the Atlantic Ocean. The area of each circle has been scaled to unity for each grid point, and the size of each wedge represents the fraction of catch of each species at each grid point. Values are averages for each 5° X 5° grid cell over the period 2000-2014. The colour coding of the species shows temperate tuna species (ALB, BFT) in shades of green, tropical tuna species (BET, YFT, SKJ) in shades of yellow to red, and subtropical billfishes species (SAI, SWO, WHM, BUM) in shades of blue.

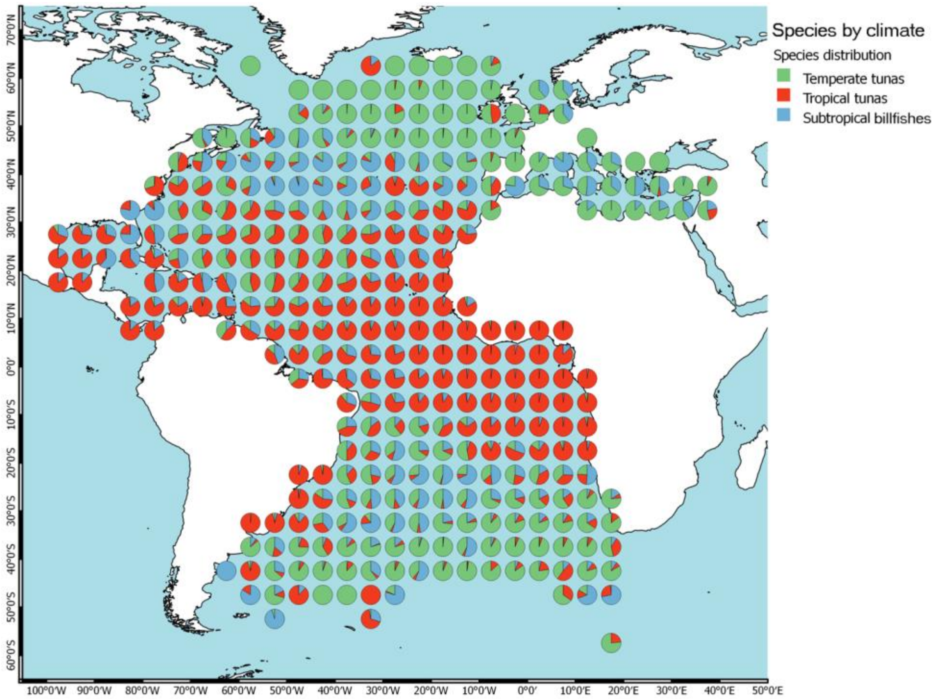


Figure 4.8 Spatial patterns of catches of species grouped by climate (temperate, subtropical and tropical) in the Atlantic Ocean. The colour coding of the species shows temperate tuna species (ALB, BFT) in green, tropical tuna species (BET, YFT, SKJ) in red, and subtropical billfishes species (SAI, SWO, WHM, BUM) in blue. See figure 4.7 caption for a description of the data illustrated in the pies.

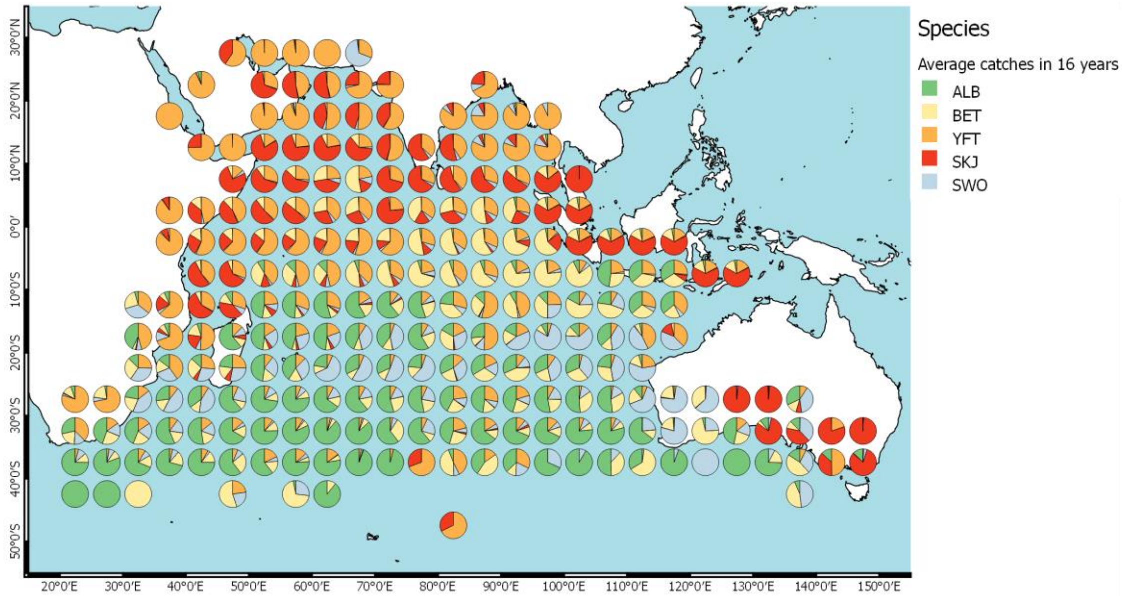


Figure 4.9 Spatial patterns of catches by species in the Indian Ocean. See figure 4.7 caption for a description of the data illustrated in the pies.

4.3.3. Comparative analysis between the spatial patterns in species composition and a selected set of existing biogeographic classifications in the ICCAT and IOTC Convention Areas

The comparative analysis aims to assess the alignment between the spatial patterns in species composition and a selected set of biogeographic classifications, the Longhurst BGCP and Spalding's PPOWs classifications (Figure 4.10-13). The alignment was assessed by plotting pie charts of the catch distributions of species over the selected classifications (Figure 4.14-17). The qualitative assessment of the alignments makes it possible to identify whether communities of tuna and billfish species are linked to specific pelagic biogeographic regions with unique environmental conditions across the Atlantic and Indian Oceans in order to inform potential ecoregions within each ocean.

In the Atlantic Ocean, the spatial patterns of catches of tuna and billfishes over the Longhurst's BGCP suggested some tuna and billfish species are clearly associated to some of the provinces, but the overall alignment was low (Figure 4.14). This might be in part because the BGCPs are numerous and relatively small in comparison to the widespread distributions of tunas and billfishes. While the small number of Longhurst biomes might better fit the widespread distribution of tuna and billfish communities, the alignment of the spatial patterns of catches of tuna and billfishes over the biomes was also low. The alignment was particularly low over the Trades biomes, which occupies most of the tropical and southern subtropical waters of the Atlantic Ocean. With respect to the Spalding's PPOW classification, the spatial patterns of catches of tuna and billfishes over the Spalding provinces showed a better alignment (Figure 4.15). The distributions of tropical tuna species (SKJ, YFT and BET) were largely associated with the Guinea Current, Canary Current and Equatorial Atlantic provinces in the equatorial region. However, there were also some exceptions; catches of the tropical skipjack tuna off the coast of Brazil and Argentina were a bit off, since they do not follow the general expected pattern. It is suspected that these skipjack catches have been misplaced in the ICCAT dataset. Furthermore, it was also observed that subtropical billfishes such as swordfish showed widespread distribution covering a large number of provinces, but some billfish species show more dominance in certain regions, e.g. BUM was more associated with the Inter American Seas province. Temperate tuna species, ALB and BFT, appeared to be highly associated with the Mediterranean region, as well as the North Atlantic Transitional provinces, while ALB also showed strong presence in the southern provinces like the South Central Atlantic Gyre and Subtropical Convergence provinces. In conclusion, the Spalding PPOW has a higher potential alignment with the spatial distributions of tuna and billfish communities at the Atlantic scale.

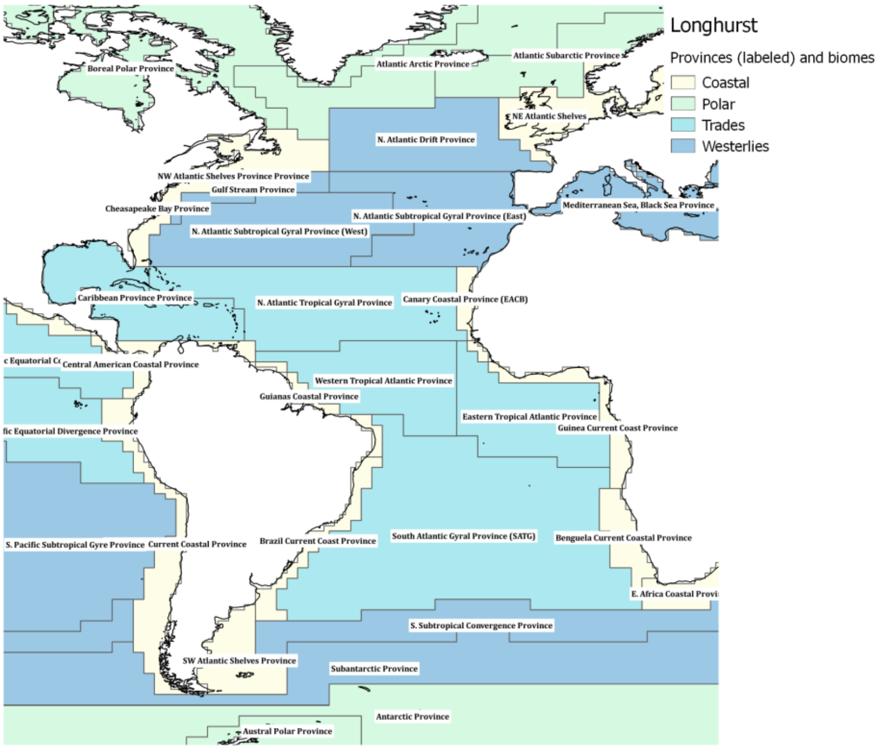


Figure 4.10 Longhurst biogeographic provinces in the Atlantic Ocean.

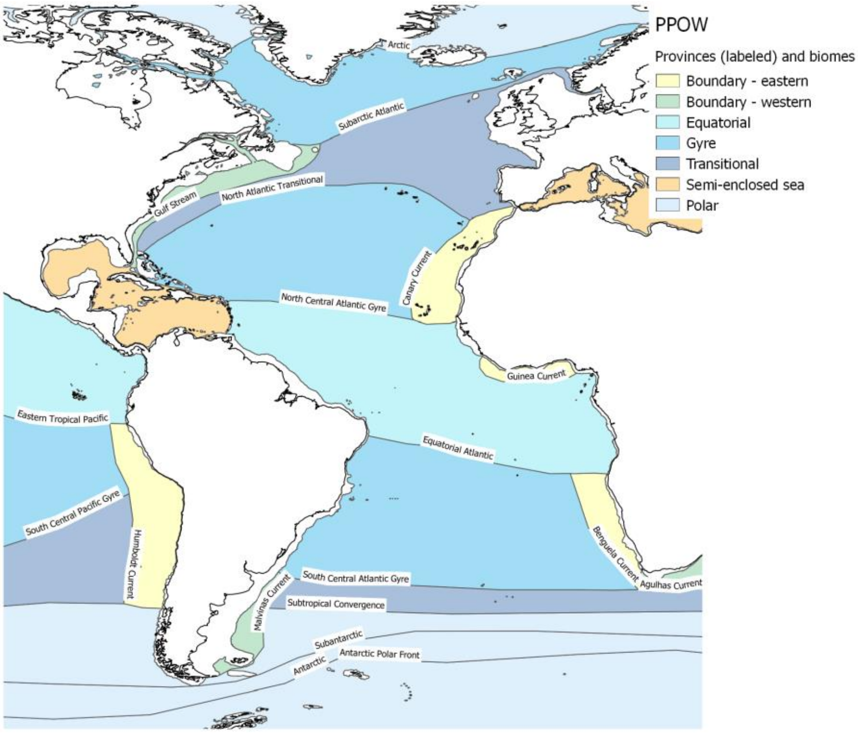


Figure 4.11 Spalding pelagic provinces of the worlds in the Atlantic Ocean.

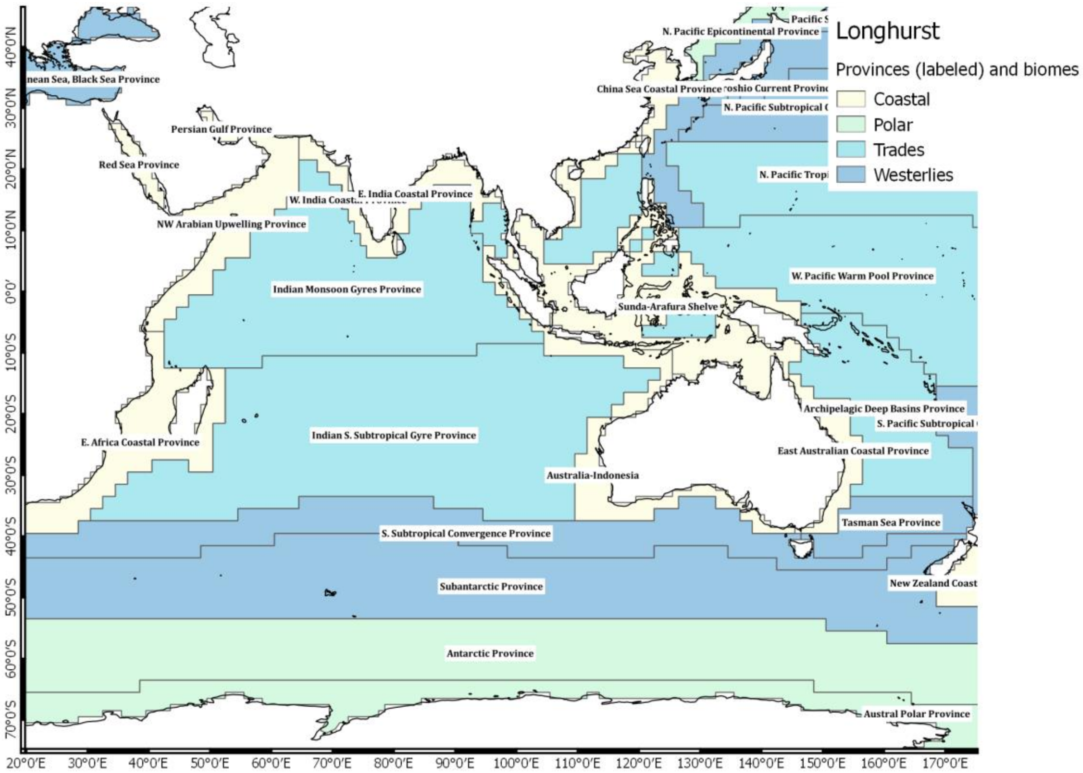


Figure 4.12 Longhurst biogeographic provinces in the Indian Ocean.

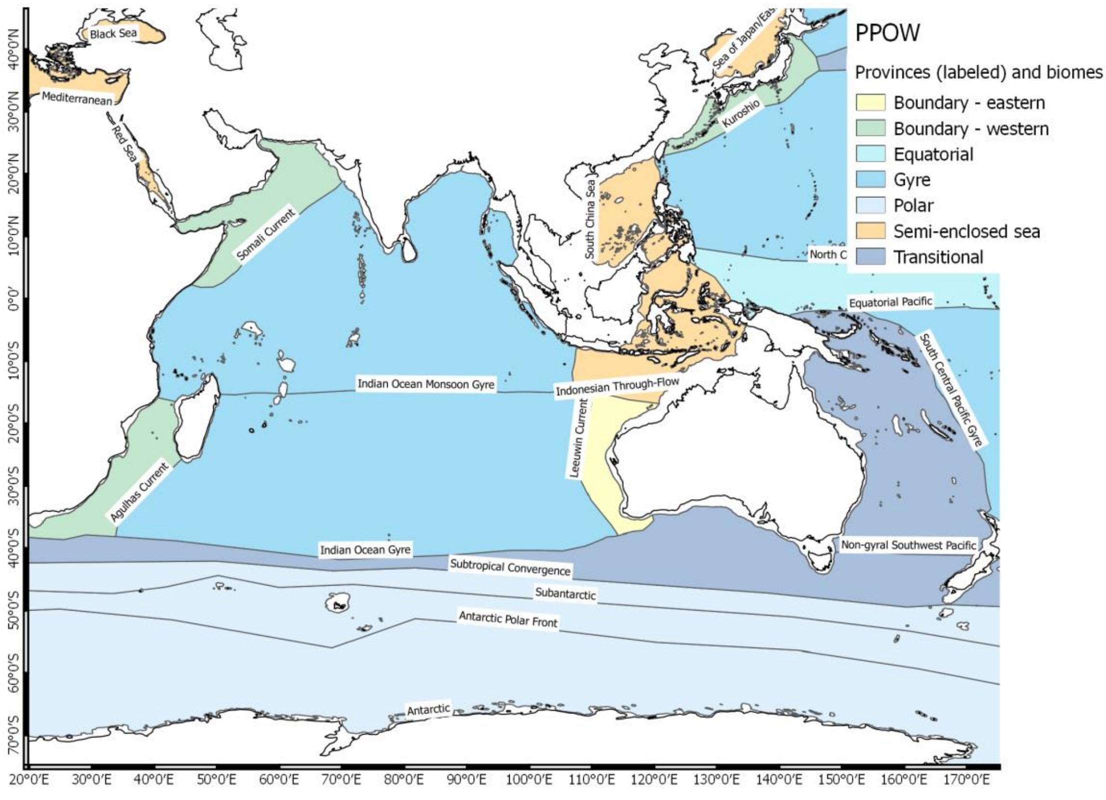


Figure 4.13 Spalding pelagic provinces of the worlds in the Atlantic Ocean.

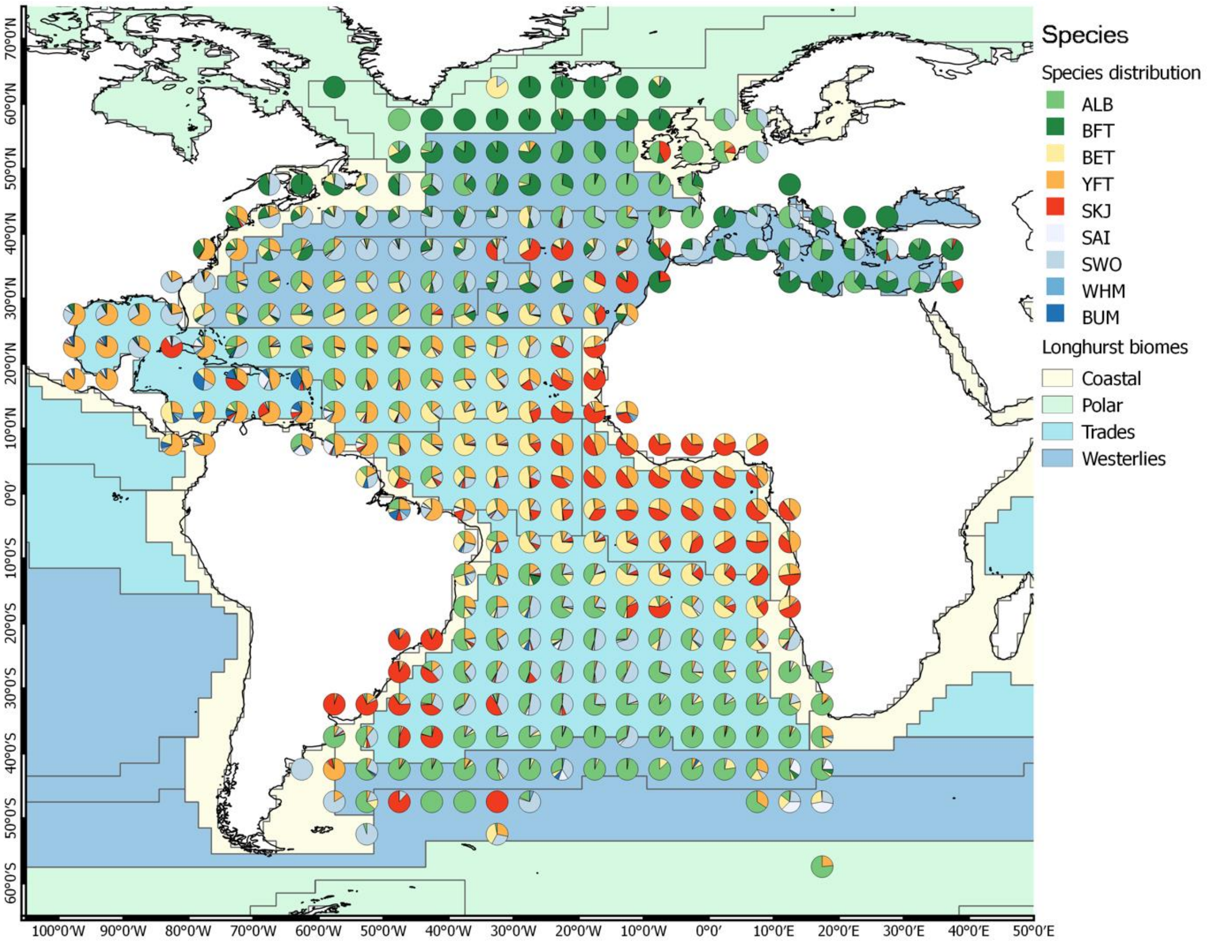


Figure 4.14 Spatial patterns of species catches overlaid on top of Longhurst BGCPs. The Longhurst provinces are represented by the black line divisions, and Longhurst biomes are represented by colours. See figure 4.7 caption for a description of the data illustrated in the pies.

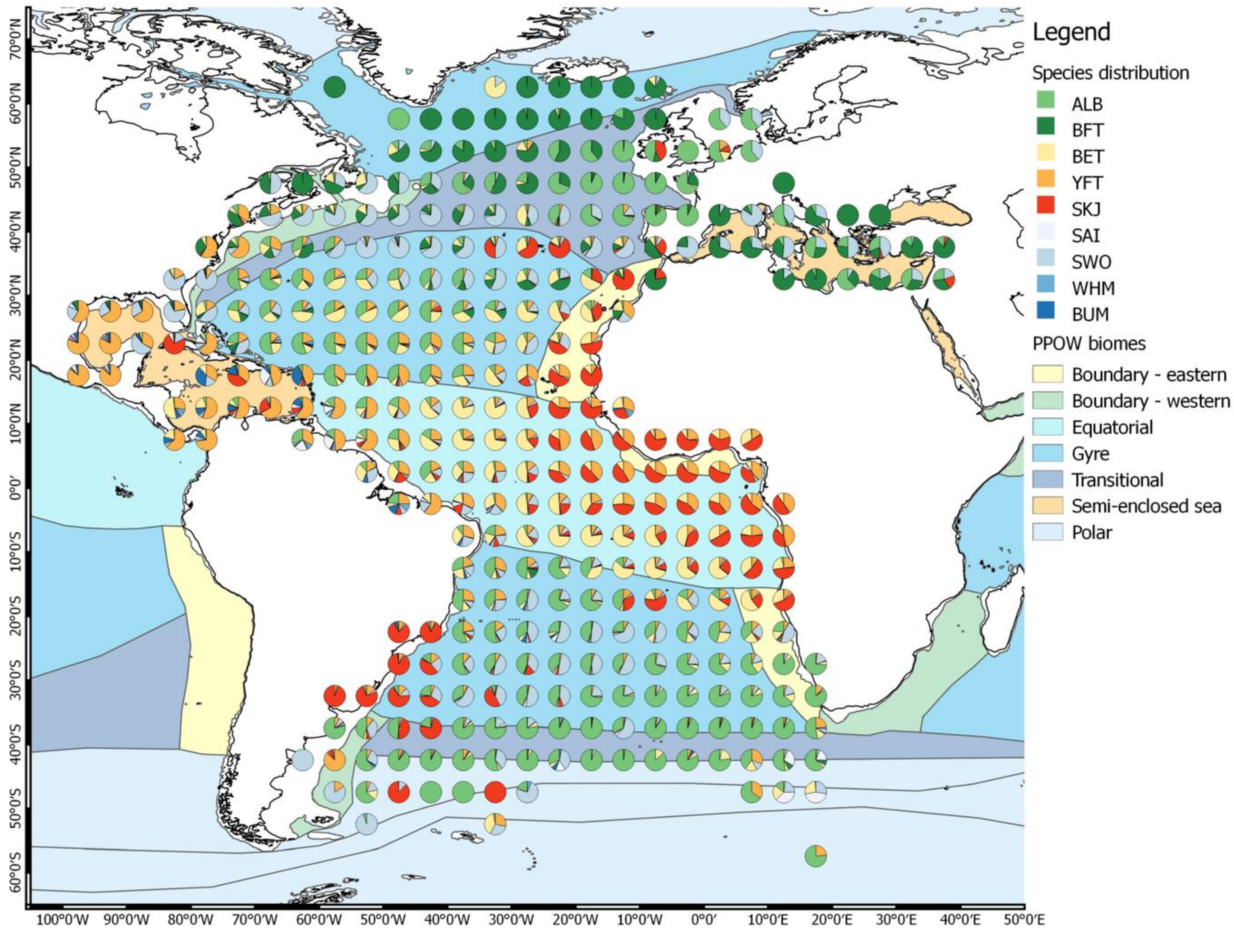


Figure 4.15 Spatial patterns of species catches overlaid on top of Spalding PPOW biomes and provinces. The PPOW provinces are represented by the black line divisions, and PPOW biomes are represented by colours. See figure 4.7 caption for a description of the data illustrated in the pies.

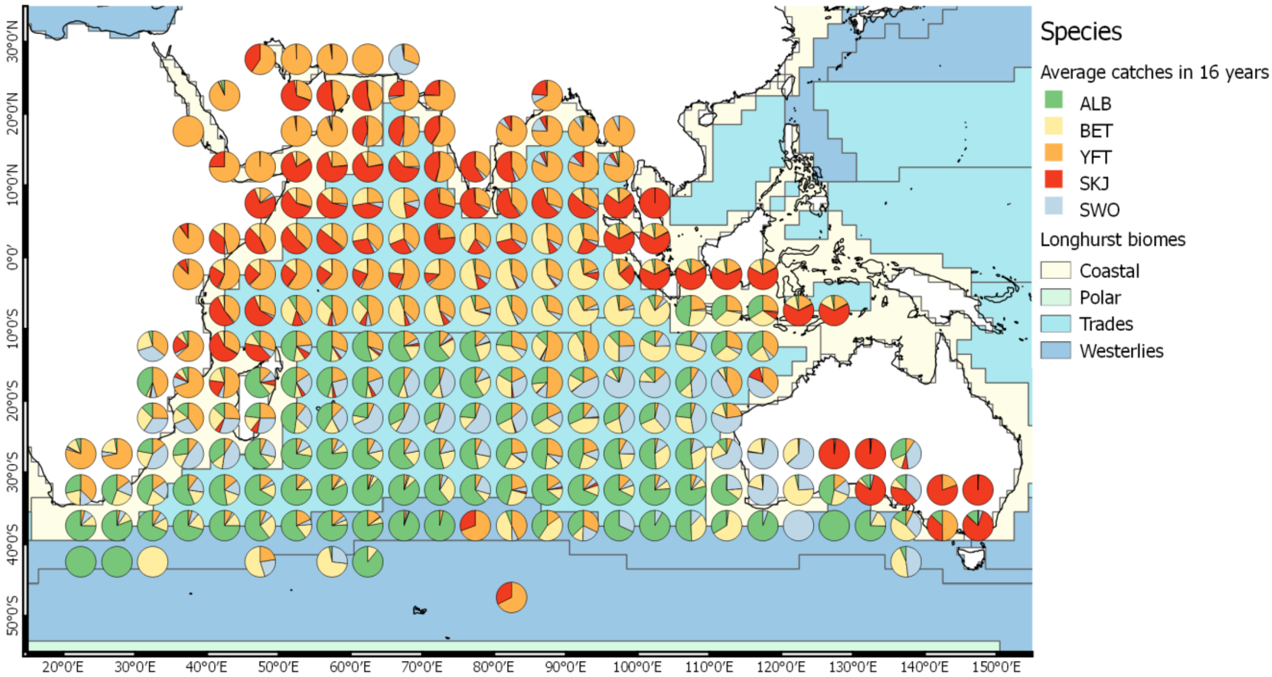


Figure 4.16 Spatial patterns of species catches overlaid on top of Longhurst BGCPs. The Longhurst provinces are represented by the black line divisions, and Longhurst biomes are represented by colours. See figure 4.7 caption for a description of the data illustrated in the pies.

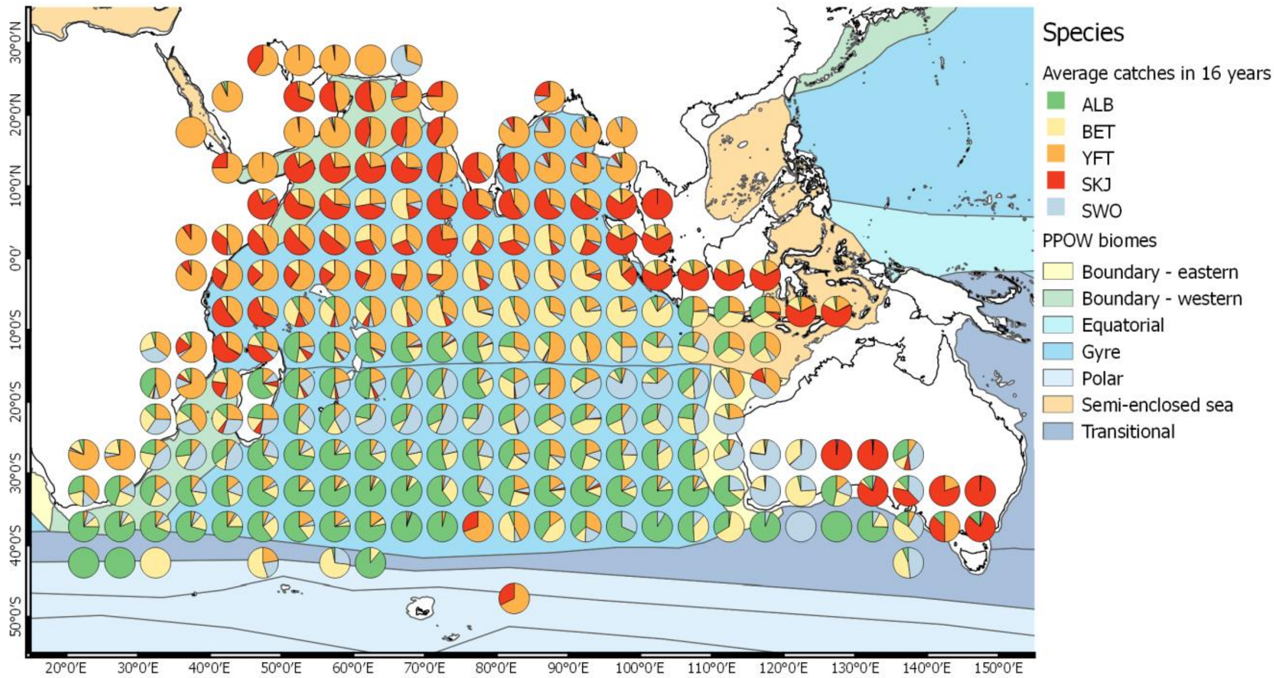


Figure 4.17 Spatial patterns of species catches overlaid on top of Spalding PPOW biomes and provinces. The PPOW provinces are represented by the black line divisions, and PPOW biomes are represented by colours. See figure 4.7 caption for a description of the data illustrated in the pies.

The Longhurst and Spalding biogeographic classifications of the Indian Ocean were quite similar, dividing the ocean into very similar number of provinces (Figure 4.12-13). Both classification divide most of the oceanic waters into three large regions, the Indian Ocean Monsoon gyre in the more northern waters (North around of 10^{o}S), the Indian Ocean Subtropical Gyre in oceanic waters between around 10^{o}S and 35-40^{o}S, and the most southern waters of the Indian Ocean including the most Subartic and Artic waters. Both classifications also have a number of coastal provinces either associated to the upwelling region off the Somalia coast, or the Indo-Pacific coastal areas. However, while the Spalding combines some of the coastal areas into the oceanic provinces, the Longhurst classifies all the coastal areas into coastal provinces. Nevertheless, given their similar classifications of the oceanic waters, it is not a surprise that both classifications aligned quite well with the spatial patterns of catches of tuna and billfishes over the Indian Ocean (Figure 4.16-17). At large, the distributions of tropical tuna species (skipjack tuna, yellowfin tuna and bigeye tuna) are largely associated with the most tropical provinces including the Indian Ocean Monsoon Gyre provinces as well as coastal provinces off Somalia and the Arabic Peninsula, while the most subtropical tuna and billfish species, swordfish and albacore tuna, are mostly associated with the Indian Subtropical Gyre province and the Agulhas Current/Eastern African Coastal provinces.

Since the Spalding PPOW had a better alignment with the spatial distributions of tuna and billfish communities in the Atlantic Ocean, as well as a good alignment in the Indian Ocean, an indicator-based analysis was performed to further explore the association between tuna and billfish communities and the PPOW classification. A set of indicators were estimated (indicators of species specificity and fidelity to each province) to identify indicator species or communities that characterize each of the biogeographic regions. Following the work of Dufrene and Legendre (1997) and Reygondeau *et al.* (2012), the following indicators were calculated:

The Specificity ($A_{i,j}$) of a species (i) for a province (j) was calculated as the ratio of the mean abundance (N) of the specie in each province ($N_{i,j}$) to the sum of the mean abundance of the species in all the provinces (N_i):

$$A_{i,j} = {N_{i,j}}/{N_i}$$

The Fidelity ($B_{i,j}$) of species (i) in each province (j) was calculated as the ratio of the number ($S_{i,j}$) of geographical cells in one province where the species is present to the total number (S_j) of geographical cells present in the province:

$$B_{i,j} = {S_{i,j}}/{S_j}$$

The Overall Indicator value ($V_{i,j}$) is calculated by multiplying the specificity and fidelity indicators, and further multiplying them by 100:

$$V_{i,j} = A_{i,j} * B_{i,j} * 100$$

In the indicator analysis the species catch data was used as a proxy of species' abundance. While the catch per unit effort (CPUE) of species is also a common, and often preferred, proxy of fish abundance, the catch data were used instead because i) the use of CPUE data as a proxy of abundance for tropical tuna species caught by purse seiner is controversial (Kaplan *et al.*, 2014), and ii) it is challenging to estimate a combined CPUE for species that incorporates information across all gears (such as longline and purse seine gears). However, to explore whether the choice of the proxy for abundance (catch or CPUE proxies) had an impact on the results of the indicator analysis, the indicator analysis was repeated using the CPUE series for species caught by longline fisheries (therein, longline CPUE) only in the Atlantic Ocean. Catch data (by longliners) were combined with a longline effort dataset (number of estimated hooks) provided by ICCAT to calculate the longline CPUE index. The ICCAT effort dataset (EFFDISS) longline dataset was used which provides spatio-temporal estimates of overall Atlantic fishing effort for longliners. Only catches and fleet effort data (estimated as number of hooks) from the Japanese fleet were used in the analysis as this fleet has a long history of fishing and has historically fished over a wider area in comparison to other fleets from other countries. To estimate the CPUE index, we took the sum of the reported effort per year and averaged across the last 15 years. Then, the average catch data for each species (just caught by Japanese longliners) was divided by the average effort data in 5-degree strata.

In the Atlantic Ocean the specificity catch-based indicator for tuna and billfish species, which illustrates the dominance of one species in one region relative to the other regions, shows the highest values of specificity for tropical tunas and subtropical billfishes in the equatorial provinces (Figure 4.18 and Figure 4.19). The tropical tunas (skipjack tuna, yellowfin tuna and bigeye tuna) were the dominant species in the Guinea Current, Canary Current and Equatorial Atlantic provinces, followed by some of the subtropical billfishes (Blue marlin, white marlin and sailfish). The specificity indicator was also relatively high for Atlantic bluefin tuna and albacore tuna in the most northern temperate provinces. The Atlantic bluefin tuna and albacore tuna species dominated the Gulf Stream, North Atlantic Transitional and Mediterranean provinces in the northern temperate region of the Atlantic Ocean. Albacore tuna had also a relatively high specificity value for the Benguela Current, South Central Atlantic Gyre and the Subtropical Convergence provinces in the more southern subtropical region of the Atlantic Ocean. The medium-low values of specificity of albacore tuna, in comparison to Atlantic bluefin tuna values, indicate that this species is distributed across a larger number of provinces and climates than Atlantic bluefin tuna (Figure 4.18 and 4.19). Similarly, the subtropical billfishes of blue marlin, white marling and sailfish also showed between low and intermediate values of specificity since they are distributed across a large number of provinces.

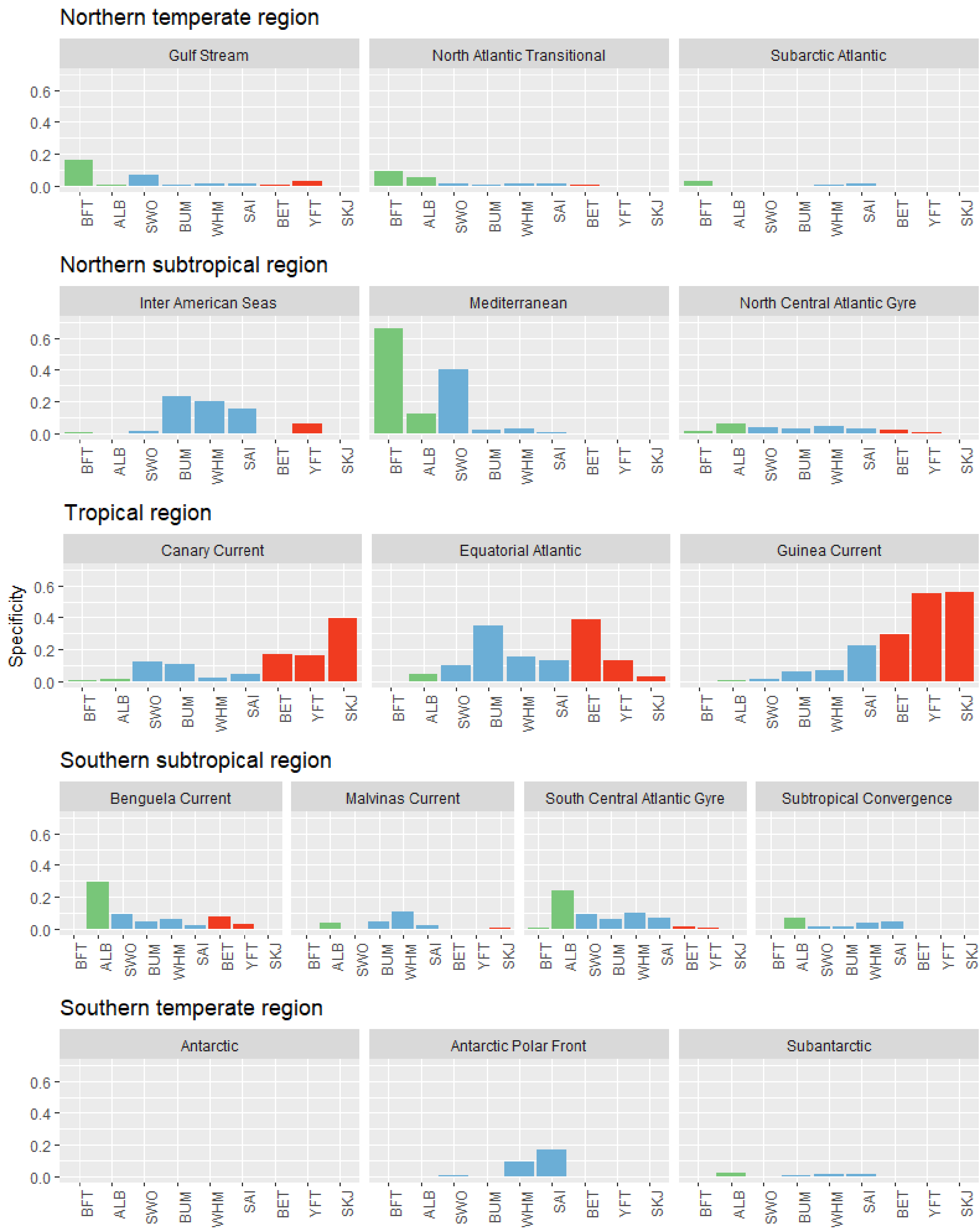


Figure 4.18 Specificity Indicator based on catch data for each tuna and billfish species and Spalding´s PPOW. The indicator values can go from 0 to 1, 1 meaning maximum specificity of a species for a given province. The provinces have been ordered by major climatic regions (temperate, subtropical and equatorial regions) to facilitate visualisation. Tropical tuna species coloured in red, temperate tunas coloured in green, subtropical billfishes coloured in blue.

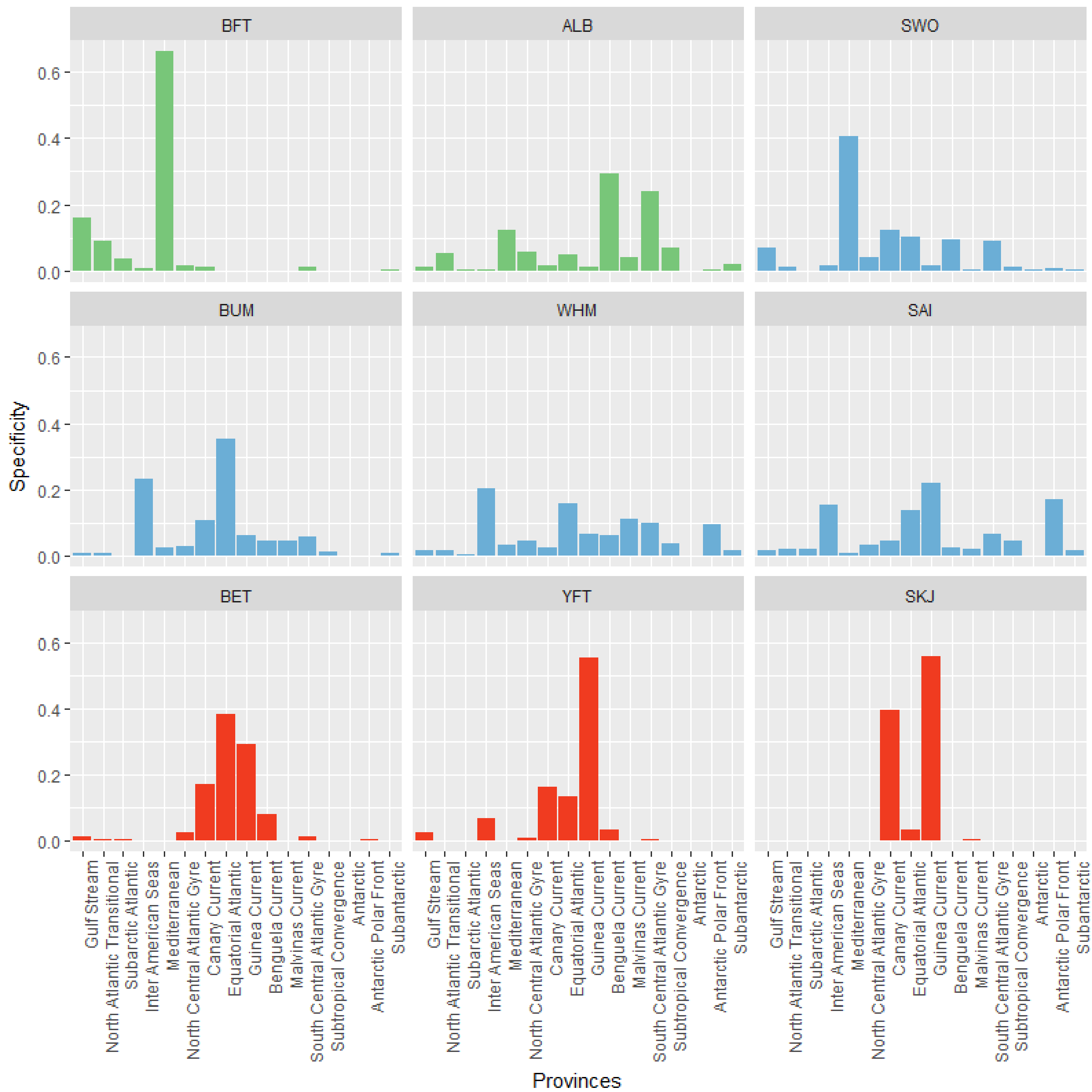


Figure 4.19 Specificity indicator based on catch data for each tuna and billfish species and Spalding and colleagues' PPOW. The indicator values can go from 0 to 1, 1 meaning maximum specificity of a species for a given province. Provinces have been ordered by major climatic regions (temperate, subtropical and equatorial regions, from north to south), and species from temperate to subtropical and tropical, to facilitate visualisation. Tropical tuna species coloured in red, temperate tunas coloured in green, subtropical billfishes coloured in blue.

In the Atlantic Ocean, the fidelity catch-based indicator for tuna and billfish species, which allows us to account for the degree of presence of a species in a particular province, was very high for all the species in all the provinces, with very little exceptions. The high values observed is due to the widespread distributions of all tunas and billfishes across the Atlantic Ocean (Figure 4.20). The low values of the indicator show what species are absent from specific regions. For example, the blue marlin, white marlin, sailfish and bigeye tuna are rarely found in the Mediterranean Sea or in the most northern and southern temperate provinces, being the Subarctic Atlantic, Antarctic, Antarctic Polar Front provinces. Due to the high values of the fidelity indicators across all provinces and species, the overall species indicator value, which combines both measures of specificity and fidelity, showed very similar results and patterns as the specificity indicator and is not shown here. Overall, the biogeographical provinces found in the more tropical regions were characterised by few but dominant species, provinces in the subtropical regions were characterised by a more diverse group of species with not clear doming species, while the provinces found in the more temperate regions in the north and southern Atlantic Ocean were characterised by single species dominance (Figure 4.18 and 4.19).

The CPUE-based indicator analysis based on the Japanese longline data was largely in agreement with the catch-based indicator analysis (Figure 4.21), yet some differences were observed. The tropical tuna species and subtropical billfishes have lower fidelity values in the Subarctic Atlantic and North Atlantic Transitional provinces found in the northern temperate region such, as well as in the Antarctic Polar Front and Subantarctic provinces found in the southern temperate region, where the subtropical billfish species like blue marlin and sailfish are not even caught (Figure 4.21). The CPUE-based species indicator for tuna and billfishes also differed from the catch-based indicator in the most tropical provinces (the Guinea Current, Canary Current, Equatorial Atlantic provinces) (Figure 3.21). This is not surprising since longline fisheries do not target skipjack or juveniles of yellowfin and bigeye tuna in the tropics as the purse seine fisheries do.

Figure 4.20 Fidelity indicator based on catch data for each tuna and billfish species and Spalding´s PPOW. The indicator values can go from 0 to 1, 1 meaning maximum fidelity of a species for a given province. The provinces have been ordered by major climatic regions (temperate, subtropical and equatorial regions) to facilitate visualisation. Tropical tuna species coloured in red, temperate tunas coloured in green, subtropical billfishes coloured in blue.

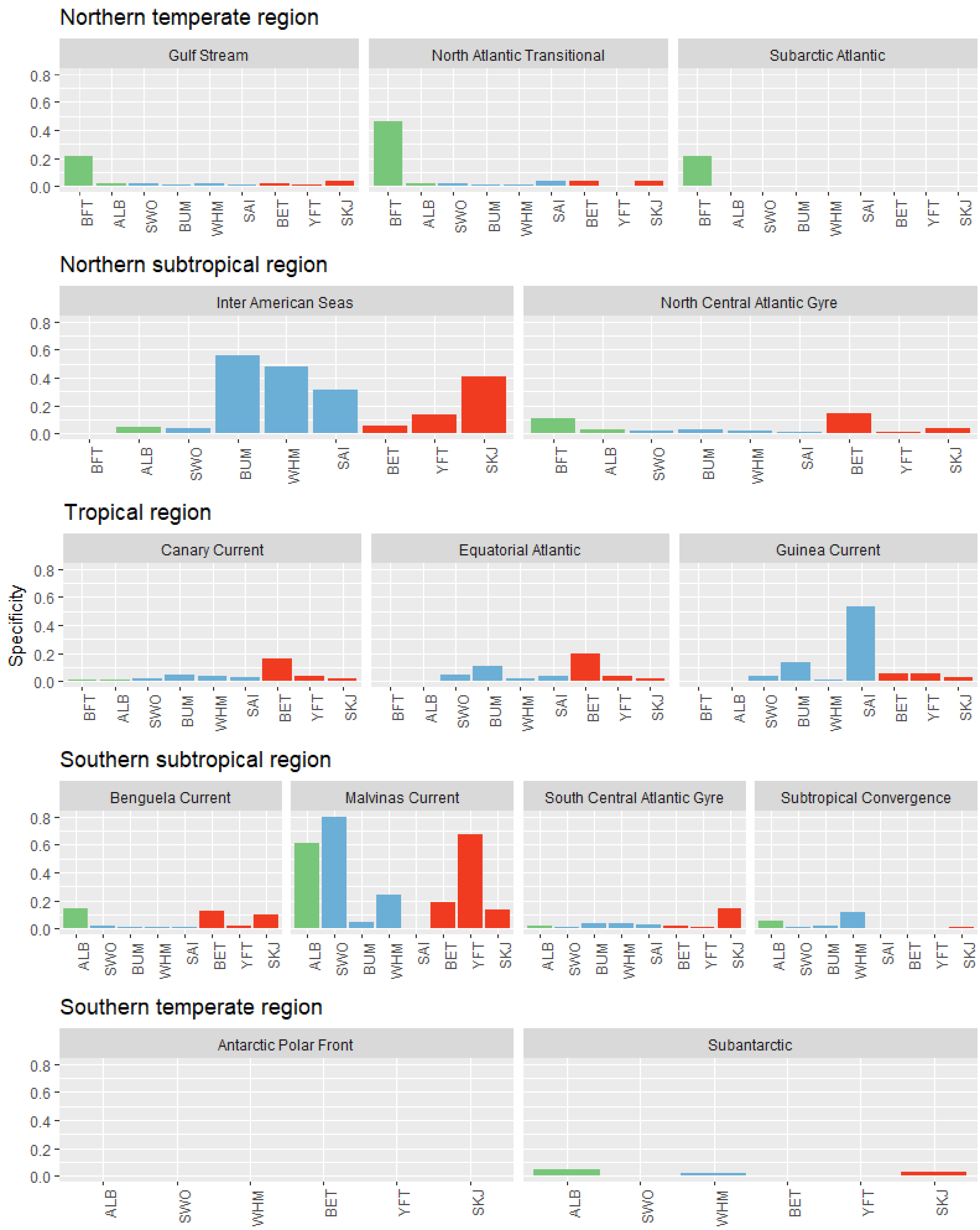


Figure 4.21 CPUE-based specificity indicator based for each tuna and billfish species and Spalding PPOW classification. The indicator values can go from 0 to 1, 1 meaning maximum specificity of a species for a given province. The provinces have been ordered by major climatic regions (temperate, subtropical and equatorial regions) to facilitate visualisation. Tropical tuna species coloured in red, temperate tunas coloured in green, subtropical billfishes coloured in blue.

In the Indian Ocean, the specificity catch-based indicator for tuna and billfish species, which illustrates the dominance of one species in one region relative to the other regions, showed the highest values of specificity for tropical tunas in the most equatorial provinces (Figure 4.22). The tropical tunas (skipjack tuna, yellowfin tuna and bigeye tunas) were the dominant species in the Indian Ocean Monsoon Gyre and the Somali current provinces. Skipjack tuna was also the dominant species in the Indonesian Through-Flow province. The specificity indicator was also relatively high for albacore tuna in the most southern subtropical provinces. Albacore tuna dominated the Agulhas current and Indian Ocean Gyre provinces. Last the subtropical swordfish had intermediate values across all provinces suggesting it has the widest distributions and preferences of all species.

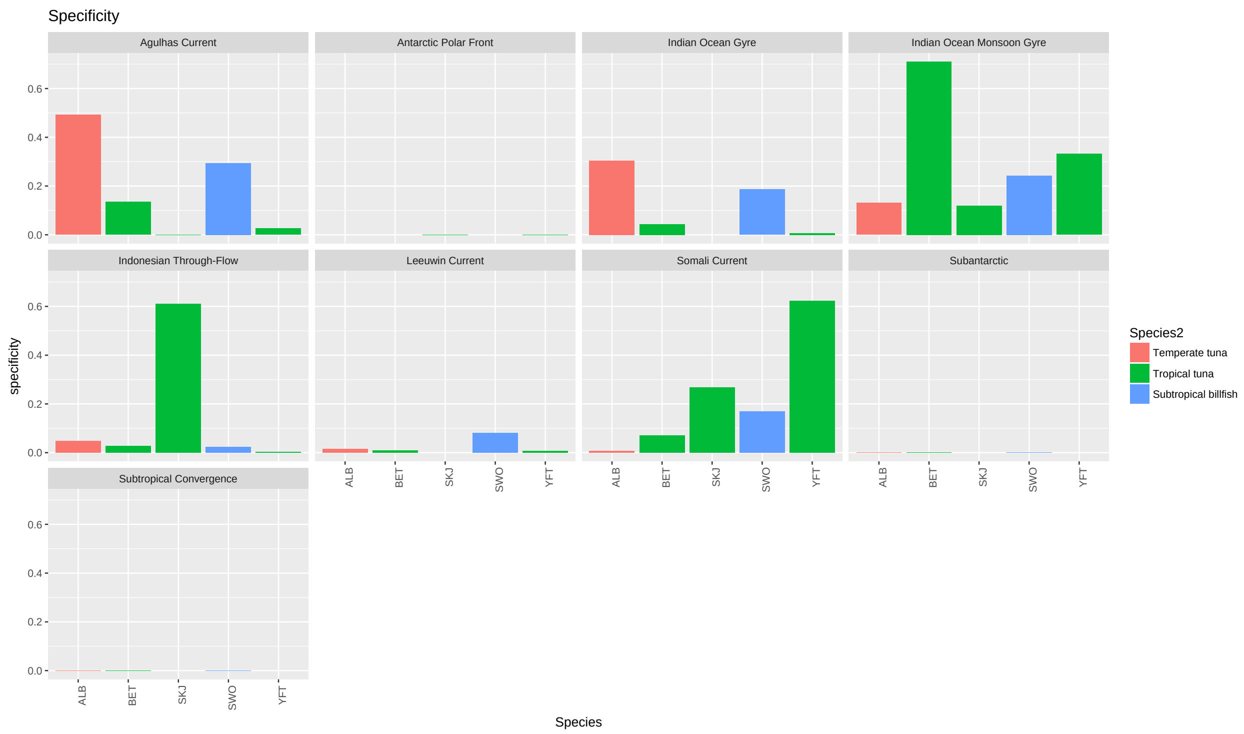


Figure 4.22 Specificity indicator based on catch data for each tuna and billfish species and Spalding PPOW classification in the Indian Ocean. The indicator values can go from 0 to 1, 1 meaning maximum specificity of a species for a given province.

The spatial distributions of major fleets targeting tuna and tuna-like species can also be used to inform the boundaries of potential ecoregions. Tunas and billfishes are predominantly caught by two different gears in the Atlantic – longlines and purse seines. Therefore, the spatial patterns of catches made by these major gears were also examined and overlaid over the Spalding PPOW classification in the Atlantic (Figure 4.23 and 4.25) and Indian (Figure 4.24 and 4.26) Oceans. Industrial purse seine fisheries setting on relatively surface waters (with a typical seine maximum depth range between 150 and 180 m) target surface schools of tropical tuna species (skipjack, yellowfin and bigeye tunas) in the tropical eastern Atlantic Ocean (Figure 4.24). The purse seine catches further corroborate that the three species of tropical tuna (skipjack, yellowfin and bigeye tuna) co-occur in space and interact and form a distinct multi-species assemblage associated with the tropical environment. Most of the purse seine catches are caught in the following biogeographic provinces, the Canary current, the Guinea current and the tropical Equatorial provinces. In the Indian Ocean, industrial purse seine fisheries also target surface schools of tropical tuna species (skipjack, yellowfin and bigeye tunas) in the most tropical provinces, the Indian Ocean Monsoon Gyre and the Somali current provinces (Figure 4.26). In contrast, industrial longline fleets catch a wider range of tuna and billfish species all over the Atlantic and Indian Oceans (Figure 4.25 and 4.26). The longline fisheries have also different mode of operations to target different species (not shown in Figure 4.25 and 4.26 due to data availability). The two distinct fishing modes depend on the species being targeted: (i) longliners setting deep (typical hook depth ranging from 100-250+) target tropical tuna species mostly in tropical waters and (ii) longliners setting shallow (typical hook depth 0-50+) target temperate tunas and swordfish. These different modes of operations set a clear spatial differentiation of longline fleets across the Atlantic and Indian Oceans.

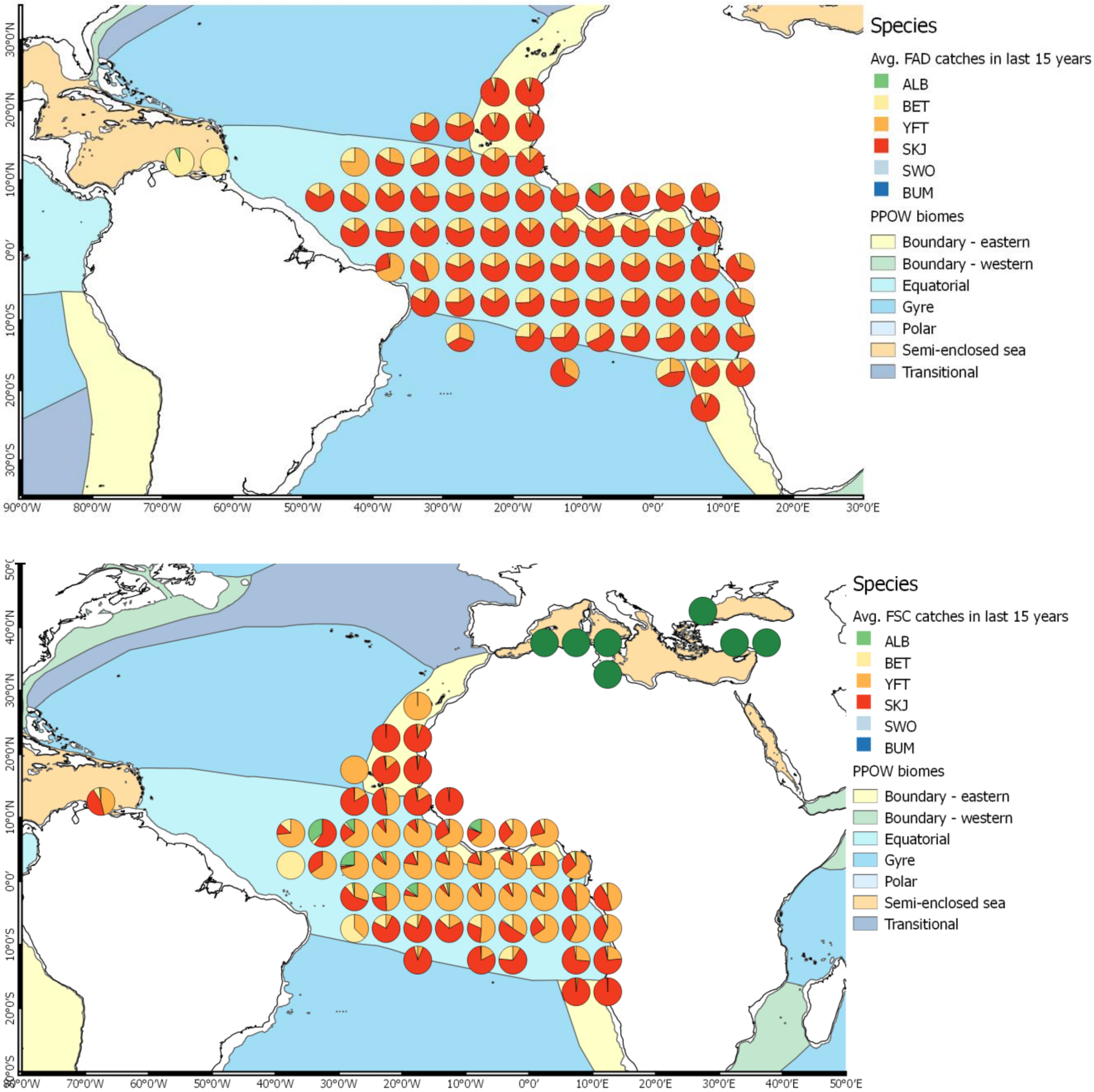


Figure 4.23 Spatial patterns of purse seine catches in the Atlantic Ocean within the last 15 years overlaid on the PPOW classification, associated with (a) fish aggregating devices and (b) free schools of tunas. The area of each circle has been scaled to unity, and the size of each wedge represents the fraction of catch of each species. Values are averages for each 5° X 5° grid cell over the period 2000-2014. The colour coding of the species show temperate tuna species (ALB, BFT) in shades of green, tropical tuna species (BET, YFT, SKJ) in shades of yellow to red, and subtropical billfishes species (SAI, SWO, WHM, BUM) in shades of blue.

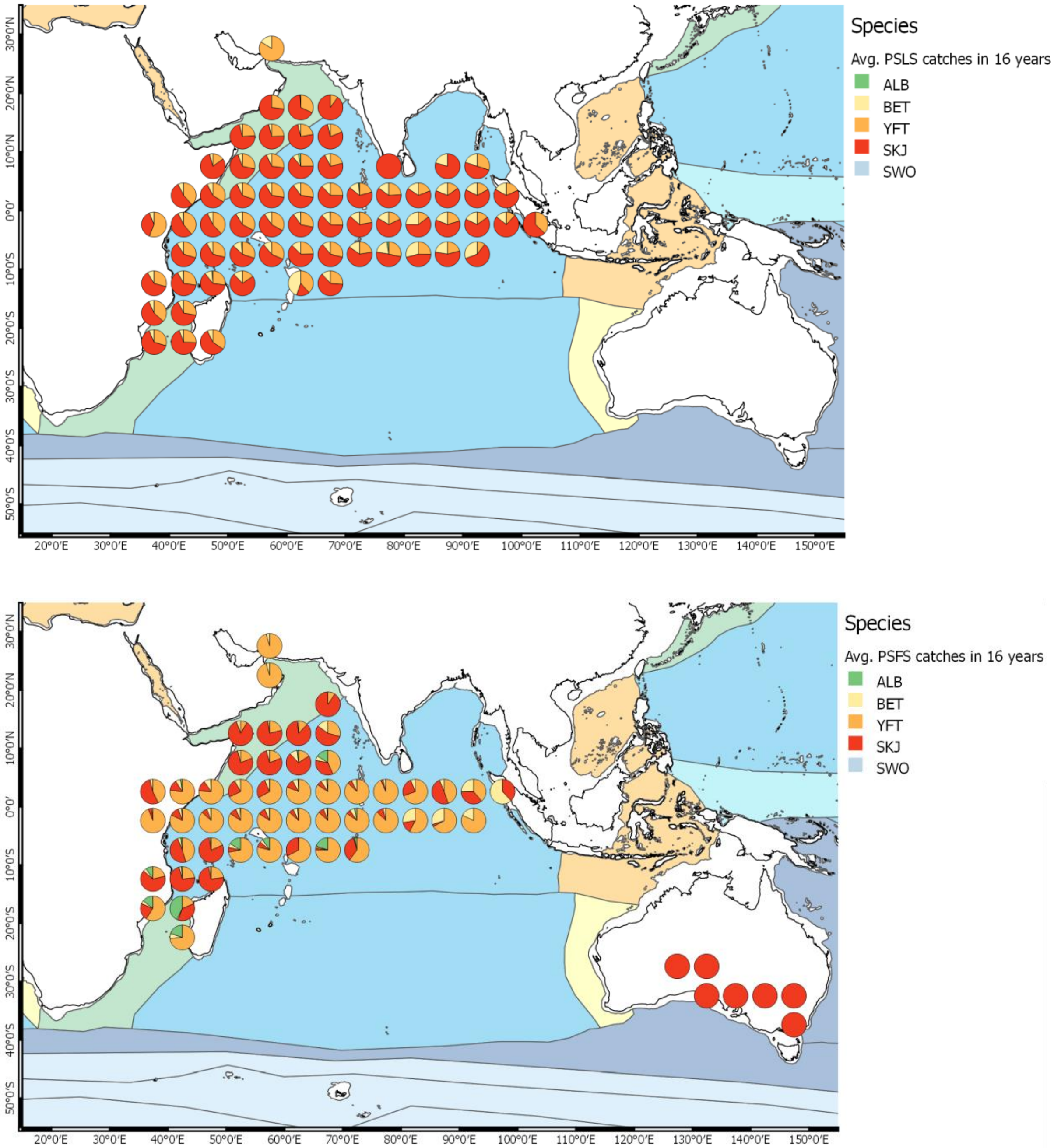


Figure 4.24 Spatial patterns of purse seine catches in the Indian Ocean within the last 15 years overlaid on the PPOW classification, associated with (a) fish aggregating devices (PSLS refers to purse seine log schools) and (b) free schools of tunas (PSFS refers to purse seine free schools). The area of each circle has been scaled to unity, and the size of each wedge represents the fraction of catch of each species. Values are averages for each 5° X 5° grid cell over the period 2000-2014. The colour coding of the species show temperate tuna species (ALB, BFT) in shades of green, tropical tuna species (BET, YFT, SKJ) in shades of yellow to red, and subtropical billfishes species (SAI, SWO, WHM, BUM) in shades of blue.

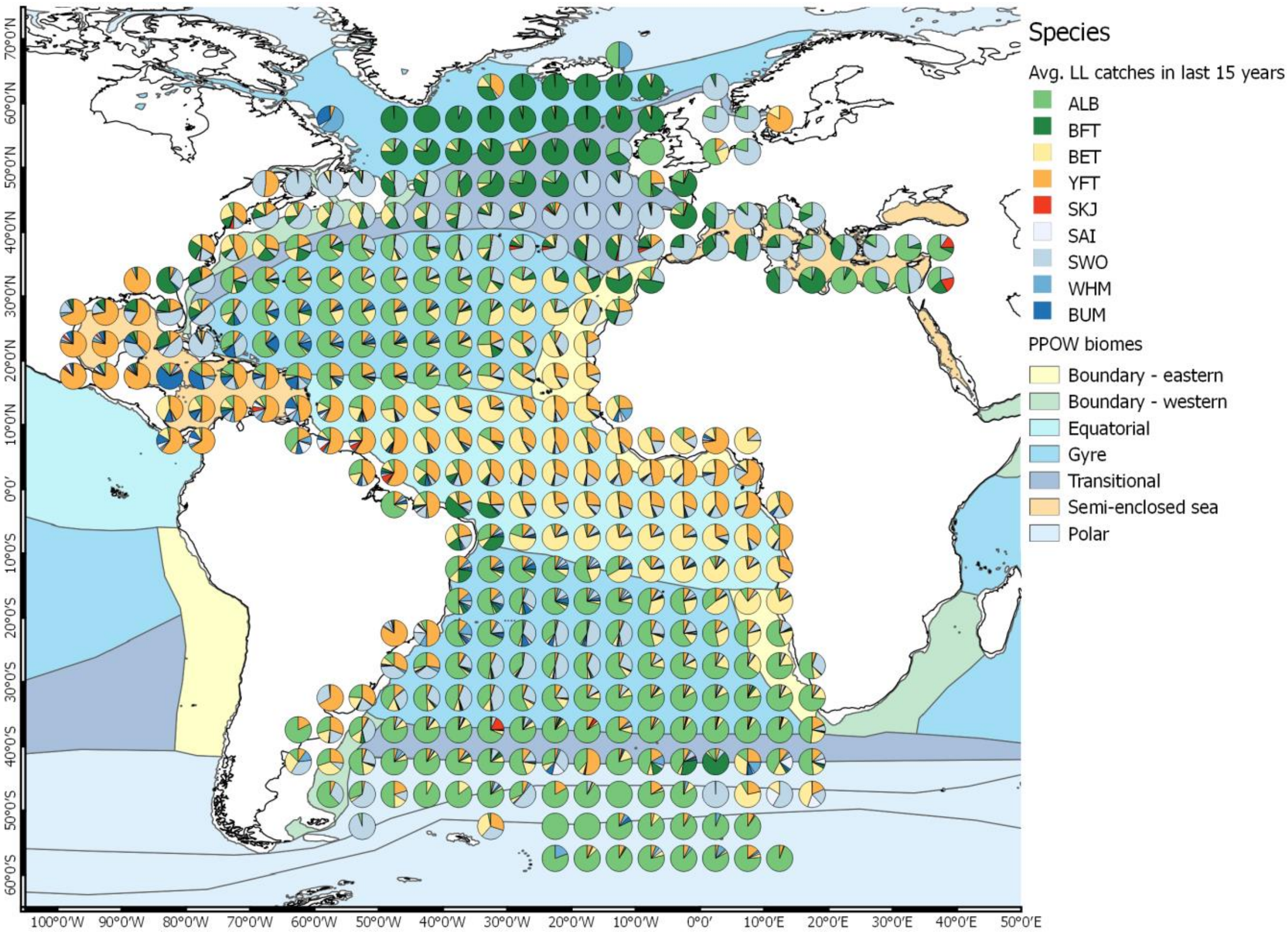


Figure 4.25 Spatial patterns of longline catches within the last 15 years overlaid on the PPOW classification in the Atlantic Ocean. The area of each circle has been scaled to unity, and the size of each wedge represents the fraction of catch of each species. Values are averages for each 5° X 5° grid cell over the period 2000-2014. The colour coding of the species show temperate tuna species (ALB, BFT) in shades of green, tropical tuna species (BET, YFT, SKJ) in shades of yellow to red, and subtropical billfishes species (SAI, SWO, WHM, BUM) in shades of blue.

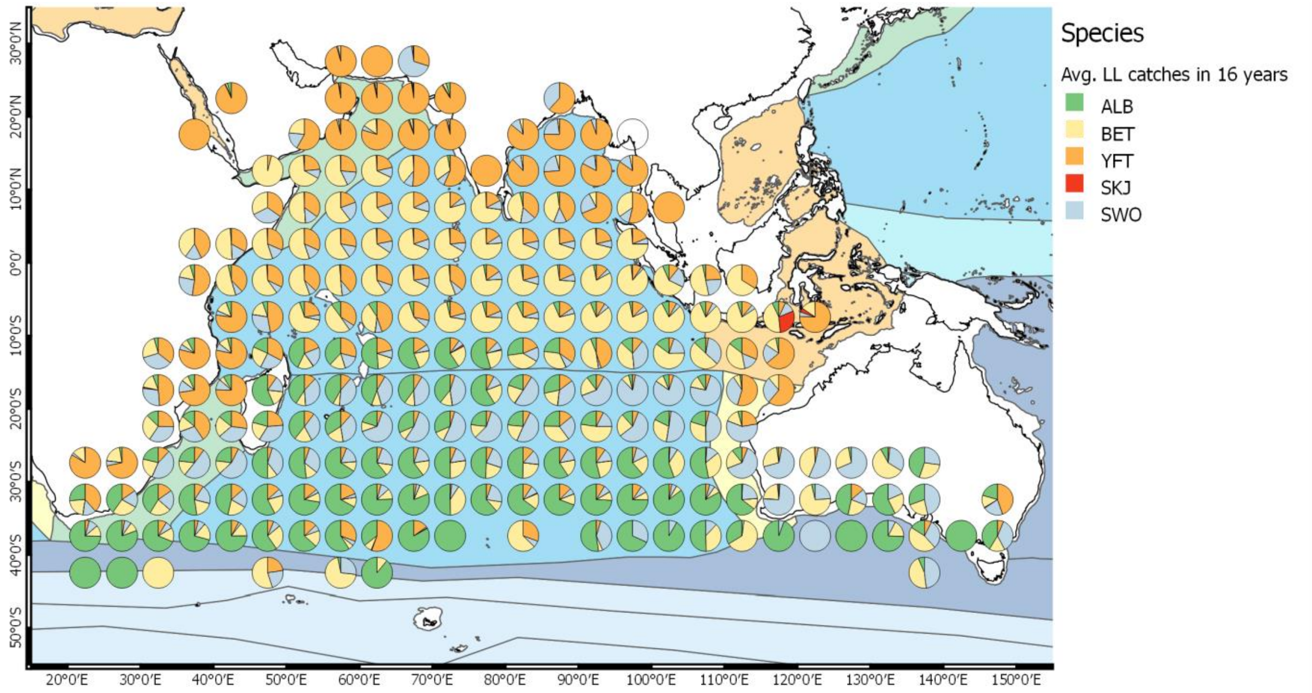


Figure 4.26 Spatial patterns of longline catches within the last 15 years overlaid on the PPOW classification in Indian Ocean. The area of each circle has been scaled to unity, and the size of each wedge represents the fraction of catch of each species. Values are averages for each 5° X 5° grid cell over the period 2000-2014. The colour coding of the species show temperate tuna species (ALB, BFT) in shades of green, tropical tuna species (BET, YFT, SKJ) in shades of yellow to red, and subtropical billfishes species (SWO) in shades of blue.

4.4. Sub-task 3.3- Definition of criteria to identify "High Sea" ecological regions and proposal of candidate ecoregions

Subtask 3.3 outlines criteria and synthesises the main results of task 3.1 and 3.2 to inform the choice of potential ecoregions that could be used as area-based fisheries assessment units to implement an EAFM in ICCAT and IOTC. In doing so, first the main lessons and good practices learnt from the reviewed biogeographic classifications are synthesised. These lessons and good practices are expected to inform discussions in ICCAT and IOTC in choosing candidate ecoregions to support the operationalisation of EAFM for tuna and billfishes in the Atlantic and Indian Ocean. Second, potential ecoregions are proposed within the ICCAT and IOTC convention areas based on three pillars of information: (1) the Spalding biogeographic classifications of the pelagic environment, (2) the spatial distribution of tuna and tuna-like species and communities, and their overlap with the Spalding biogeographic classification, and (3) the spatial distributions of the main fishing fleets targeting tuna and billfishes and their overlap with the Spalding biogeographic classification.

4.4.1. Synthesis of main lessons and good practices learnt from the revised biogeographic classifications

The wide range of approaches used and processes leading to the biogeographic classifications reviewed, allowed us to extract best practices and lessons to inform our choice and proposal of ecoregions to support the EAFM for tuna and tuna-like species in the Atlantic and Indian Oceans.

Best practices and lessons can be summarized as follows:

1. **Be prepared for a long consultative process:** The classification of useful ecoregions that are both ecologically meaningful and practical is the result of a long interactive process where expert knowledge and feedback from fisheries managers and conservation practitioners is needed;
2. **Start the process with the resources at hand:** It is important to start the process, make informed decisions based on the best science available following the precautionary approach, then further improvements and additions can be included over time as new information and experience is accumulated;
3. **Hierarchical classifications facilitate fisheries management at different spatial scales:** A nested or hierarchical classification (e.g. having biomes and provinces within biomes) is more advantageous, since the different spatial levels and subdivisions could be used for different management purposes;
4. **Static boundaries are more practical for fisheries management:** While ecoregion boundaries that are dynamic might portray a more realistic and accurate picture of the spatial dynamics of marine ecosystems, it is imperative that static boundaries are identified and used for practical purposes;
5. **Larger regions allow transboundary management for HMS:** While a larger number of smaller ecoregions might also portray a more realistic and accurate picture of the spatial dynamics of marine ecosystem, having a smaller number of larger ecoregions at the expense of simplifying the dynamics of marine ecosystems, can lead to higher possibilities of trans-boundary management for HMS such as tuna and tuna-like species;
6. **Classifications should be informed by physical and biological attributes of the marine system:** Accounting for the spatial, physical, and biological

attributes of marine ecosystems can lead to more realistic and accurate biogeographic classifications;

7. **If possible use fisheries independent data:** The use of fisheries independent data is recommended over the use of fisheries dependent data to infer ecological processes which can be used to inform the classification systems. This is because fisheries dependent data can be biased by the changing fishing behaviour of the fleets. However, in the case of HMS fishery dependent data have a better spatial coverage than any costly fishery independent survey aimed at HMS. In fact, few, if any, fishery independent surveys are available for HMS spanning their entire distribution. Therefore, the use of fishery dependent data is a compromise to be made to improve our knowledge of pelagic biological diversity and patterns of species distributions and to inform biogeographic classifications in the open ocean.

4.4.2. Proposal of potential ecoregions within the ICCAT and IOTC convention areas

Despite tunas and billfishes having a very broad tolerance for a wide range of environmental conditions, the indicator-based analysis suggested that for the majority of the species, their core distributions are associated with specific biogeographic provinces with specific environmental conditions. The overlap of the spatial catch composition of tunas and billfishes with the Longhurst BGCPs and Spalding PPOW biogeographic classifications showed that the spatial scales and number of the Spalding PPOW in the Atlantic Ocean aligned better with the spatial distribution of tuna and billfishes catches. The Spalding PPOW in the Indian Ocean also had a good alignment with the spatial distribution of tuna and billfishes catches. The large number and spatial scale of the Longhurst BGCPs and the low level of alignment with the spatial patterns of catches of tunas and billfishes made this biogeographic classification potentially less suitable to inform potential ecoregions in the Atlantic and Indian Ocean. In the Atlantic Ocean, the Spalding provinces in the more temperate regions were characterised mostly by a single or double species dominance; in the subtropical regions by a diversified community of species with not clear dominance, though with different communities in the northern and southern hemisphere; and the provinces found in the tropical region were characterised by multispecies dominance. In the Indian Ocean, the provinces found in the tropical region were also dominated by a tropical tuna complex and the most subtropical and temperate regions were characterised by a single or double species dominance. Finally, the spatial patterns of the major fisheries analysed have also shown a clear spatial partitioning, with specific fishing fleets exploiting a common pool of fish species with a strong spatial overlap, which also can be used to inform potential delineation of ecoregions. For example, deep setting longliners and the two modes of purse seiner fleets have a strong spatial overlap in the tropical Atlantic area and exploit a common set of fish species, principally bigeye tuna, yellowfin tuna and skipjack tuna.

Based on the spatial overlap between the major fleets, the core distributions of the species and their association to the biogeographic provinces we suggest grouping several Spalding biogeographic provinces into larger spatial units, referred here as the ecoregions (see below proposal). The proposed groupings of biogeographic provinces into ecoregions aims to respect natural oceanographic boundaries occurring in the ocean, that exhibit relatively distinct environmental conditions, communities of tunas and billfishes and fleets targeting them. In other words, each of the ecoregions proposed bellow are characterised by greater similarity in biogeographic and oceanographic characteristics, in fish communities, and types of fleets operating in the area. Therefore, the ecoregion can be seen as a region with relatively homogenous oceanographic characteristics where a set of fishing fleets exploits a common fish community over their most suitable environment (ICES, 2004; Uriarte *et al.*, 2014).

In the ICCAT Convention Area, five potential ecoregions are proposed within the Atlantic Ocean and two ecoregions covering the two adjacent seas of the Atlantic Ocean (Figure 4.27).

1) **Northern Temperate Ecoregion** – It groups the Subarctic Atlantic, Gulf Stream and North Atlantic Transitional provinces. In this region, the Gulf stream has an important role in the poleward transfer of warm, tropical waters, which warm up the European subcontinent. Furthermore, a counter-clockwise circulation system forms around the Icelandic low-pressure system, which brings up the nutrient rich, deep, cold waters and increases productivity in this area. This ecoregion features a community characterised primarily by albacore and bluefin tunas, and secondarily by swordfish, bigeye and yellowfin tunas in the Gulf stream province. The large majority of catches of these species are mainly taken by surface setting longline fleets.

2) **Northern Subtropical Ecoregion** – It includes the North Central Atlantic Gyre province. This region is characterised by a large gyral system with the Sargasso Sea located in its centre. This area is known for its large accumulations of holopelagic Sargassum seaweed and its known to be an important migratory route and spawning ground for many species. This ecoregion has a very

diversified community of tuna and billfish species including swordfish, bigeye tuna, yellowfin tuna, albacore, and bluefin tuna, yet it does not represent the core distribution for any of the species. Instead, it represents a transitional area between the more temperate and tropical waters explaining the weaker association of the species with this region. The large majority of catches of these species are mainly taken by surface setting longliners.

3) **Tropical Ecoregion** – It includes the Guinea Current, Canary Current and Equatorial Atlantic provinces. This region is characterised by several areas of coastal upwelling along the African coast, with increased biological productivity, and rich fishing grounds. It also features the seasonal equatorial upwelling (July – September) which creates environmental conditions quite different compared to adjacent gyres. The pelagic ecosystem is taxonomically diverse and features a community dominated by tropical tuna species – skipjack, yellowfin, and bigeye tunas, and secondarily swordfish, and other billfish species. The large majority of catches of these species are mainly taken by purse seine fisheries, followed by deep setting and shallow setting longliners.

4) **Southern Subtropical Ecoregion** – It includes the Malvinas Current, South Central Atlantic Gyre, the Benguela Current and Subtropical convergence provinces. This region includes some coastal areas that are amongst the most productive ecosystems in the world, supporting a large biomass of fish and other species. It also comprises the South Atlantic Central Gyre which is one of the least well-researched regions. This ecoregion features a species community characterized primarily by albacore and swordfish, and secondarily by billfishes as well as bigeye and yellowfin tunas at the northern edge of the Benguela Current and South Central Atlantic Gyre provinces. These species are caught primarily by surface longline gears.

5) **Southern Temperate Ecoregion** – It includes the Subantarctic, the Antarctic Polar Front and Antarctic provinces. The conditions in the poleward waters change as they extend across all three major ocean basins and mix with low salinity, nutrient rich, cold waters from the Antarctic. In this region species diversity is very low, some marine mammal species are present, and the biomass is dominated by phytoplankton and krill. Southern bluefin tuna occupies the most southern waters of the Atlantic Ocean, but its management is under the purview of other tuna RFMOs, the CCSBT. Therefore, there is no strong presence of any of

the species under purview of ICCAT in this region and it is characterized bylow presence and low intensity of fishing by ICCAT fisheries with catches disappearing in the lower latitudes (around 55 degrees latitude south).

6) **Mediterranean Ecoregion** – It includes the Mediterranean province. In this region, water movement is driven by the pressure gradient of the cool Atlantic water entering the warm and salty Mediterranean waters, which later sinks and returns to the Atlantic as Mediterranean Intermediate Water. It somewhat resembles the subtropical Antarctic with the seasonal cycle of primary production and consumption. This area, nonetheless, has a distinctly different environment from the Atlantic Ocean and is therefore viewed as a separate ecoregion in which the Mediterranean albacore and swordfish stocks and the eastern Atlantic bluefin tuna stock are the main targeted species with billfishes species taken as bycatch. The large majority of catches of these species are taken by longliners followed by purse seine fisheries.

7) **Wider Caribbean Ecoregion** – It includes the Inter American Seas province. This area, just like the Mediterranean Sea, is almost completely enclosed by various landmasses. The cool, oxygenated waters enter the area influenced by the easterly Trade winds and form a clockwise loop around the Gulf of Mexico. Productivity of the region is complex as it features two phytoplankton blooms, in winter and summer. This is influenced by nutrient enhancement present in the region, and it is the reason for high concentration of highest trophic level species. This ecoregion features a community dominated by tropical tuna species – skipjack, yellowfin, and bigeye tunas, and secondarily, swordfish, and other billfish species. The large majority of catches of these species are taken by longline fisheries.

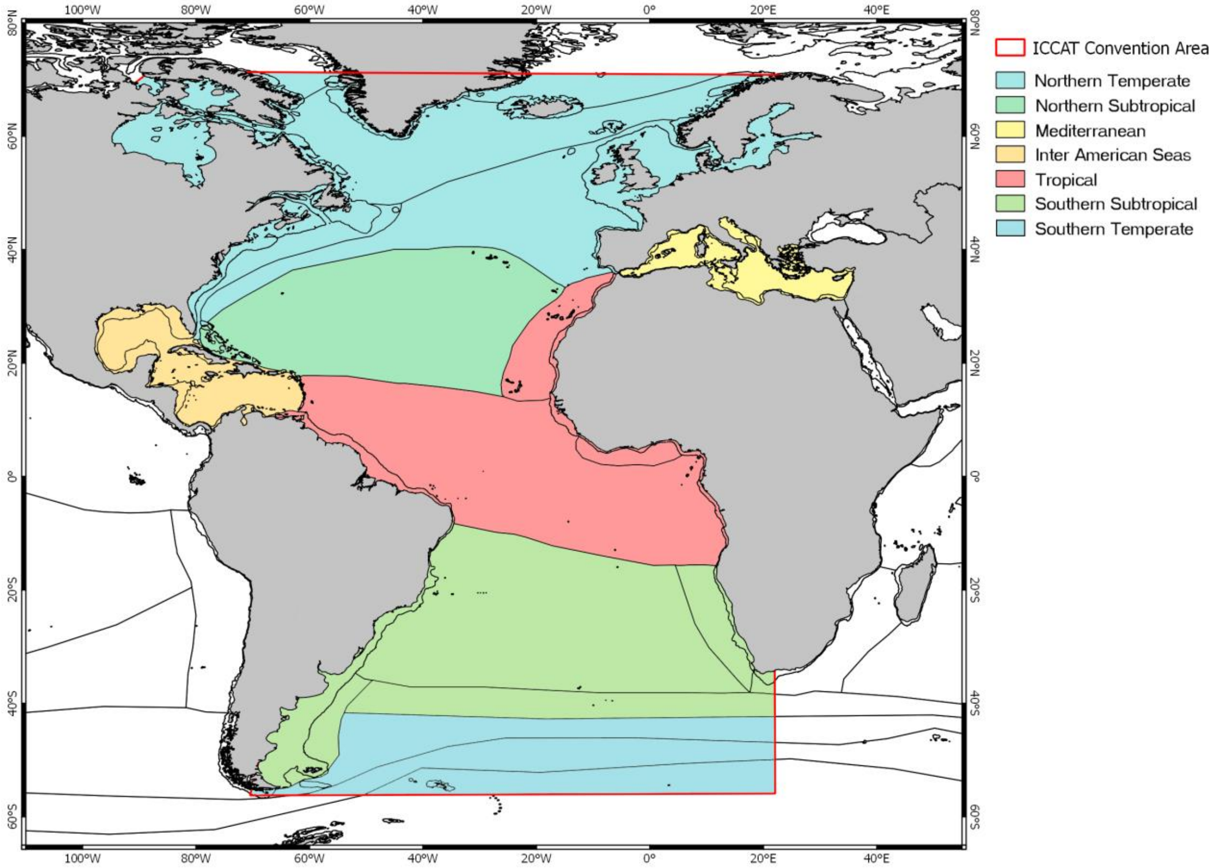


Figure 4.27 Seven potential ecoregions have been identified in the Atlantic Ocean by grouping several of the Spalding PPOW.

In the IOTC Convention Area, two potential ecoregions are proposed within the Indian Ocean (Figure 4.28).

1) **Tropical Ecoregion** – It includes the Somali Current, the Indian Ocean Monsoon Gyre and Indonesian Through-Flow Provinces. This region is characterised by the monsoon. The currents in the northern Indian Ocean are mainly controlled by monsoon winds and are dominated by a large circular clockwise current. The summer monsoon winds produce localised upwelling along the Somali and Omani coasts. During the winter monsoon, these circulation processes are reversed. The pelagic ecosystem is taxonomically diverse and features a community dominated by tropical tuna species – skipjack, yellowfin, and bigeye tunas, and secondarily swordfish. The large majority of catches of these species are taken by purse seine fisheries, followed by deep setting longliners.

2) **Subtropical and Temperate Ecoregion** – It includes the Indian Ocean Gyre, Agulhas current, and Leeuwin Current provinces as well as some areas of the

subtropical Convergence, Subarctic and Antarctic Polar Front provinces. The southern Indian Ocean is dominated by a large circular anticlockwise current. It represents a transitional area between the more tropical waters in the north and temperate waters in the south explaining the weaker association of the species with this region. This ecoregion features a species community characterised primarily by albacore and swordfish. These species are caught primarily by surface longline gears. Southern bluefin tuna also occupies the most southern waters of the Indian Ocean, but its management is under the purview of another tuna RFMOs, the CCSBT.

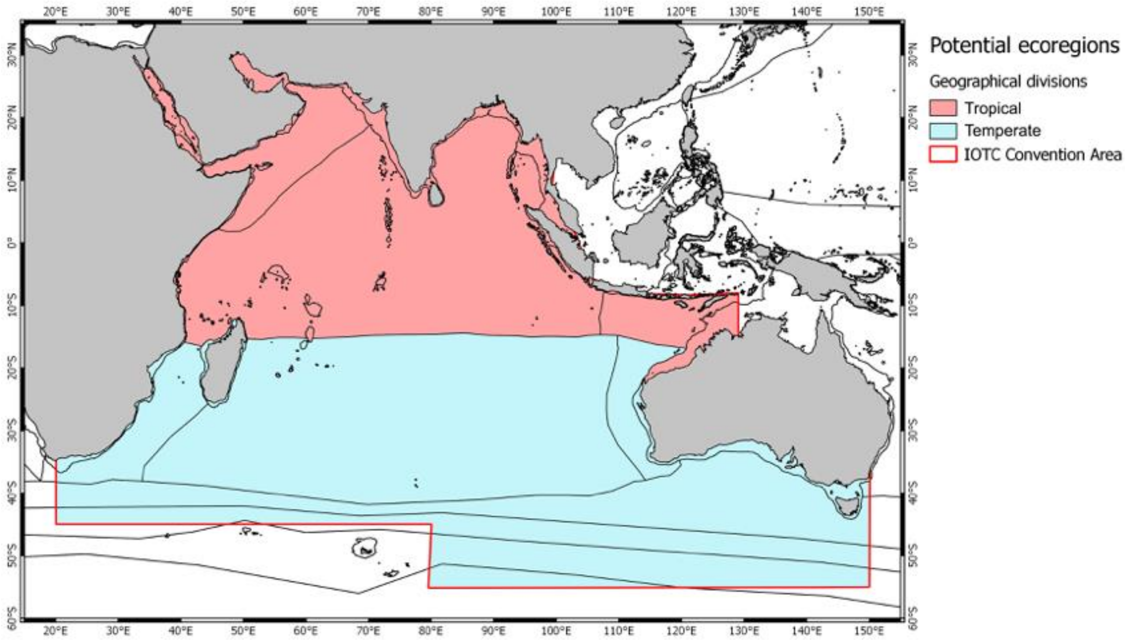


Figure 4.28 Two potential ecoregions have been identified in the Indian Ocean by grouping several of the Spalding's PPOW.

To finalise our proposal of ecoregions, the existing geopolitical limits of ICCAT and IOTC, mainly their convention area geographical limits, also needed to be accounted for. Therefore, the boundaries of the ecoregions proposed above were extended to their adjacent coastlines and extended to the ICCAT and IOTC northern and southern geopolitical limits to ensure the entire ICCAT and IOTC convention area are covered. Note the PPOW is a biogeographic classification of the surface epipelagic and oceanic waters of the world's oceans. It excludes the worlds coastal and continental shelf waters as these areas have been classified under the Marine Ecoregion of the World (Spalding *et al.*, 2007). The MEOW classification complements the PPOW and, together, they cover the world epipelagic waters. This final step of extending the ecoregions to include all the coastal and shelf waters, even if they are not considered oceanic waters by the PPOW classification, is important since ICCAT and IOTC fisheries operate also within the exclusive economic zones of many countries and the ICCAT and IOTC convention areas includes the extended economic zone of all countries bordering the Atlantic and Indian Ocean.

These ecoregions have been proposed to support the implementation of an EAFM in the ICCAT and IOTC convection area. This proposal is a response to increased efforts in ICCAT and IOTC towards operationalising an EAFM and supporting the development of ecosystem plans and assessments which makes the delineation of ecoregions necessary. It represents a solid starting point to support ecosystem planning, for developing ecosystem assessments and management measures to provide more holistic and integrative ecosystem advice to ensure sustainable fisheries and resilient ecosystems on which they depend (ICES, 2004; Rice *et al.*, 2011). For example, if ICCAT decided to develop ecosystem assessments for each ecoregion, these ecoregions have the potential to provide a framework for monitoring climate and fishing impacts on the state of the different components of the ecosystem including fishes, seabirds, sea turtles, marine mammals and the food web. This would facilitate measuring the success of specific fisheries management actions by region and prioritizing fisheries conservation actions on less resilient regions and species. By working and focusing on specific regions, the CPCs with active fisheries in the region and other relevant stakeholders could also be effectively engaged. The regionalisation of the ecosystem approach, it also allows us to identify and address information gaps relevant to the region and focus on priority research specific to each region. Although there are not many worldwide examples of attempts to define ecoregions to support the operationalisation of an EAFM in oceanic waters or the high seas, efforts have already been made or are underway in other RFMOs such as NAFO and CCMLR (Constable *et al.*, 2000; Nilsson *et al.*, 2016; NAFO, 2017). The majority of areas that have adopted well defined geographic areas defined by ecological criteria to support the regionalisation an EAFM are coastal nations such as the USA, Australia and the European Union (Levin *et al.*, 2013; Heiskanen *et al.*, 2016; Zador *et al.*, 2016; Smith *et al.*, 2017).

The boundaries between ecoregions should be seen and treated with flexibility, recognising that marine ecosystems are dynamic. The borders of the proposed ecoregions could also be adjusted to account for additional policy objectives, and if the end users, here ICCAT and IOTC, deem it important. As is common in most management approaches, the delineation of ecoregions (the number of them as well as their boundaries) should be seen as an iterative and consultative process. The proposed ecoregions aim to start a debate in ICCAT and IOTC to inform decisions based on the best science. The proposed ecoregions are also open to further improvements as new information and experience is accumulated (ICES, 2004; Rice *et al.*, 2011). A total of seven potential ecoregions were proposed within the ICCAT Convention Area and two were proposed within the IOTC Convention Area. A smaller number of larger ecoregions is preferred over a larger number of smaller ecoregions at the expense of simplifying the dynamics of marine ecosystems since it can lead to higher possibilities of trans-boundary management for highly migratory species such as tunas and billfishes. This poses the question, should ICCAT and IOTC prepare an ecosystem plan and assessment for each of the proposed ecoregions? It is neither our intention nor our responsibility to answer this question, which we prefer to leave open to initiate an iterative and consultative process within ICCAT and IOTC. However, the development of pilot ecosystem plans for two case studies, one in the Atlantic Ocean and one in the Indian Ocean, under Task 6, will test its usefulness as an assessment unit to drive ecosystem science, management, and advice.

It is concluded that it is possible to identify potential ecoregions for managing tuna and billfish species in the ICCAT and IOTC convention area as required by the ecosystem approach to fisheries management. An ecoregion aims to guide management advice that encompasses multiple species and stocks which inhabit a common and geographically defined area. It is hoped that the proposed ecoregions will hopefully encourage discussions and debates about the need of ecoregion classification to facilitate the identification of appropriate management units for the application of the EAFM in ICCAT and IOTC.

4.5. Research recommendations for future work

Some potential limitations in the current datasets and analysis are highlighted below and suggestions are presented for future analysis. Three major potential limitations were encountered in the spatial analyses of catches of tuna and billfishes conducted under sub-task 3.2: (1) lack of spatial distribution of catch and effort for some fleets and species, (2) the complete absence of spatial data for bycatch species of major tuna and billfish fisheries such as small tunas, sharks, turtles, seabirds, marine mammals, and (3) the challenge of using and combining CPUE data from multiple fishing gear types.

The spatial distribution of catch data from ICCAT and IOTC is missing for many commercially important tuna and billfish species as well as commercial sharks, which could not be included in the analysis. Bycatch data spatially distributed for species such as sharks, turtles, seabirds and marine mammals are not available in the ICCAT or IOTC Secretariats. This makes this study incomplete and the ecoregions identified biased towards the commercially important tuna and billfish species. This limits any attempt to investigate the full diversity of pelagic communities to produce more accurate biogeographic classifications in the open ocean. Finally, It is challenging to combine the CPUE data that standardises effort data across different gear types. Tuna and billfish species are caught by multiple fishing gears, therefore, any fish community analysis would need to be based on data collected from multiple gear types. Consequently, these community analyses are sensitive to the differences in the relative scale of indices and measures of abundance produced by the different sampling methods of the different gear types, prompting the need for methods to combine disparate CPUE indices from different fishing gears (Gibson-Reinemer *et al.*, 2017). It is encouraged to further investigate methods that could combine CPUE data across multiple gear types such as CPUE from longliners and purse seiners tuna fisheries to inform future biogeography studies in pelagic oceanic ecosystems.

5. TASK 4 – CHOOSING REFERENCE POINTS AND FRAMEWORKS TO FACILITATE THE LINK BETWEEN THE ECOSYSTEM INDICATORS AND MANAGEMENT OPTIONS

Key message

- The high variability in data quality precludes having a standardized methodology to estimate reference points, which in conjunction with the absence of proper communication tools to synthesize complex ecosystem information is hindering the use of indicators for an ecosystem approach to managing HMS.
- A general framework based on a rule-based decision tree is prepared to guide on how reference points can be set and used for diverse types of ecosystem indicators, so they can be better used in management decisions.
- The framework describes three broad approaches to define reference points (based on functional relationship, time series analysis and spatial comparisons) depending on the data quality/quantity and the knowledge of ecosystem functioning. Strengths and weaknesses of each method are described.
- Different visualization strategies to integrate ecosystem information used by the North Pacific Fisheries Council and the Convention for the Conservation of Antarctic Marine Living Resources as well as the ocean health index and DEVOTES tools are reviewed to inform potential ecosystem communication strategies to be implemented in tuna RFMOs

5.1. Objectives

Although tuna RFMOs are attempting to fully implement an ecosystem approach to managing HMS, there are a number of impediments that must be tackled. A particular issue concerns the lack of a clear methodology to estimate reference points (indicator value that can represent a limit or a target management point) for ecological indicators and a simple guideline that states how this information can be used effectively to support fisheries management decisions and advice. To address this issue, we (the Consortium) provide guidance on how reference points can be set and used in association with the selected indicators. We also explore potential frameworks to integrate information from ecosystem indicators and fisheries stock assessments so they can be better used in management decisions.

To accomplish this, Task 4 is divided into the following sub-tasks:

- Subtask 4.1. Guidance on how to set reference points for ecosystem indicator.
- Subtask 4.2. Exploration of frameworks to better integrate ecosystem information with management advice.

5.2. Sub-task 4.1 – Guidance on how to set reference points for ecosystem indicators

In general terms, reference points can be estimated in different ways depending on the type of indicator and data. In this subtask, first several existing guidelines are reviewed for establishing reference points (their type, their utility, and their limitations) and are adapted to inform the selected indicators in Task 2. The following developed guidelines to set reference points were reviewed: by EU DEVOTES project (Rossberg *et al.*, 2017), the Ocean Health Index programme (Halpern *et al.*, 2012) and three relevant published studies (Probst *et al.*, 2013; Probst & Stelzenmüller, 2015; Shephard *et al.*, 2015). Second, a general framework is designed to define reference points based on knowledge acquired through the aforementioned review.

5.2.1. Review of scientific literature

Determining reference points to compare the state of ecosystem indicators is a complex task for a variety of reasons, mainly the lack of data and long time series, as well as poor knowledge of the ecosystem response (and hence, the ecosystem state indicators) to environmental and human pressures. This difficulty is reflected on the shortage of work that has addressed the problem of determining reference points for use in resource management. However, in recent years, due to the need for setting such reference points to support the operationalisation of the ecosystem approach, different projects and specific papers have been developed. Next, a brief summary is provided of the main literature reviewed. For a more detail description see Appendix 4.1.

The Ocean Health Index project (Halpern *et al.*, 2012)

The Ocean Health Index is a tool for the ongoing assessment of ocean health intended to be applicable for ecosystem index-based management worldwide (Halpern *et al.*, 2012). As part of this project, a protocol to estimate reference points for a very wide range of ecological indicators was developed (Samhouri *et al.*, 2012).

The framework designed to set reference points for a wide range of ecological indicators is compatible with different levels of scientific understanding and data availability and provides a practical approach to combine a diverse range of information and type of indicators and data. This framework contains a decision tree, which provides guidance for choosing and setting three broad types of reference points (or levels) to use in the assessments of the current ecosystem state. The three broad types of reference points are:

(1) Based on functional relationships, and derived models to find them.

(2) Based on time-series approaches where analysis of indicator values over time are used to determine the best guess for a reference point.

(3) Based on spatial comparisons, where comparison of indicator values in different areas subjected at different levels of human pressure are used to estimate a common reference point.

The DEVOTES project (Rossberg *et al.*, 2017)

The EU project DEVOTES focused on the development of tools to assess the impact of human activities and climate change on biodiversity and the socio-economic consequences of achieving a Good Environmental Status in the European Seas. The proposal of the DEVOTES project for estimating reference points is based on the idea that sustainable development is one that meets the needs of society in the present but does not compromise the capacity of the ecosystem to fulfil the needs of future generations (Rossberg *et al.*, 2017). This is what the paper calls "strongly sustainable use". Acceptable values of the ecological indicator are those that fall within a target range the shall be one which determines the upper limit in the level of exploitation so that if the human pressure disappears the status of the indicator will recover within the time R to a level within 95% of the natural distribution of that indicator.

There are difficulties in estimating the target ranges for the different indicators and in estimating the variation of the state indicator with respect to the pressure indicator. This requires knowledge of the functional relationships between changes in pressure and state indicators. Modelling makes possible to determine the number of years it will take to recover the ecological indicator to levels within 95% of its range of natural variation. Despite the best option being an ecosystem model, a partial model may be sufficient to estimate reference points. The range of variation of an ecological indicator under natural conditions can be determined through modelling, but also through prior knowledge for which time series of historical data are very useful.

Reference indicators informed by simple time series-analysis (Probst *et al.*, 2013)

This study performs an indicator-based assessment of North Sea fish and shellfish species as required by the MSFD (Probst *et al.*, 2013). Since many reference values (targets or limits) were lacking in the indicator assessment, a simple time-series analysis was used to set the reference values. In this analysis, the last three-year-mean (LYM3) of each time series for each indicator was compared to reference values for the indicator. The LYM3 was compared to the 33%-percentile (in the case of the state indicator) or 66%-percentile (for the pressure indicator) of the remaining time-series. These percentiles were selected based on the fact that they allow a 16% deviation of LYM3 from the long-term median.

Reference points informed by more complex time series-analysis (Probst & Stelzenmüller, 2015)

This study combined two time-series analysis methods (breakpoint analysis and linear regression) in a time-series-based benchmarking and assessment framework (Probst & Stelzenmüller, 2015). The breakpoint analysis identifies periods of relative stability that are used to define reference points while the linear regression is applied to the last 5 years to assess the state of the indicator in comparison with the reference point. Depending on the chosen assessment rationale, i.e. prevent further decline (PFD) or improve leading to recovery (IMP), these reference points could be referred to as the best period or the average of the reference period.

Reference points for surveillance indicators (Shephard *et al.*, 2015)

Surveillance indicators are those for which there is no clear knowledge about the relationship between human pressure and the state of the biological-ecological aspect that is intended to be preserved and of which the indicator is directly representative (Shephard *et al.*, 2015). Surveillance indicators are helpful elements to modulate management measures when the values of these surveillance indicators are outside safe limits. Therefore, for these surveillance indicators there are no reference points but bounds, a range of high and low limit values that must be determined from time series analysis. The purpose of surveillance indicators is not to monitor everything that can be monitored, but to acquire a supplementary class of indicators that have a valuable and specific role to play in the way that operational indicators are used to support ecosystem assessments and operationalisation of an EAFM.

5.2.2. Proposal of guidelines to set reference points for HMS

Based on the literature reviewed, we propose a new adapted framework to guide the setting of reference points for the type of ecosystem indicators proposed under Task 2. We have developed a rule-based decision tree (Figure 5.1) that steps through the various options to set reference points for ecosystem indicators. The framework presented by Samhouri *et al.* (2012) was taken as the basis to create a general decision tree that incorporates the methods proposed by Rossberg *et al.* (2017), Probst *et al.* (2013), Probst and Stelzenmüller (2015) and Shephard *et al.* (2015).

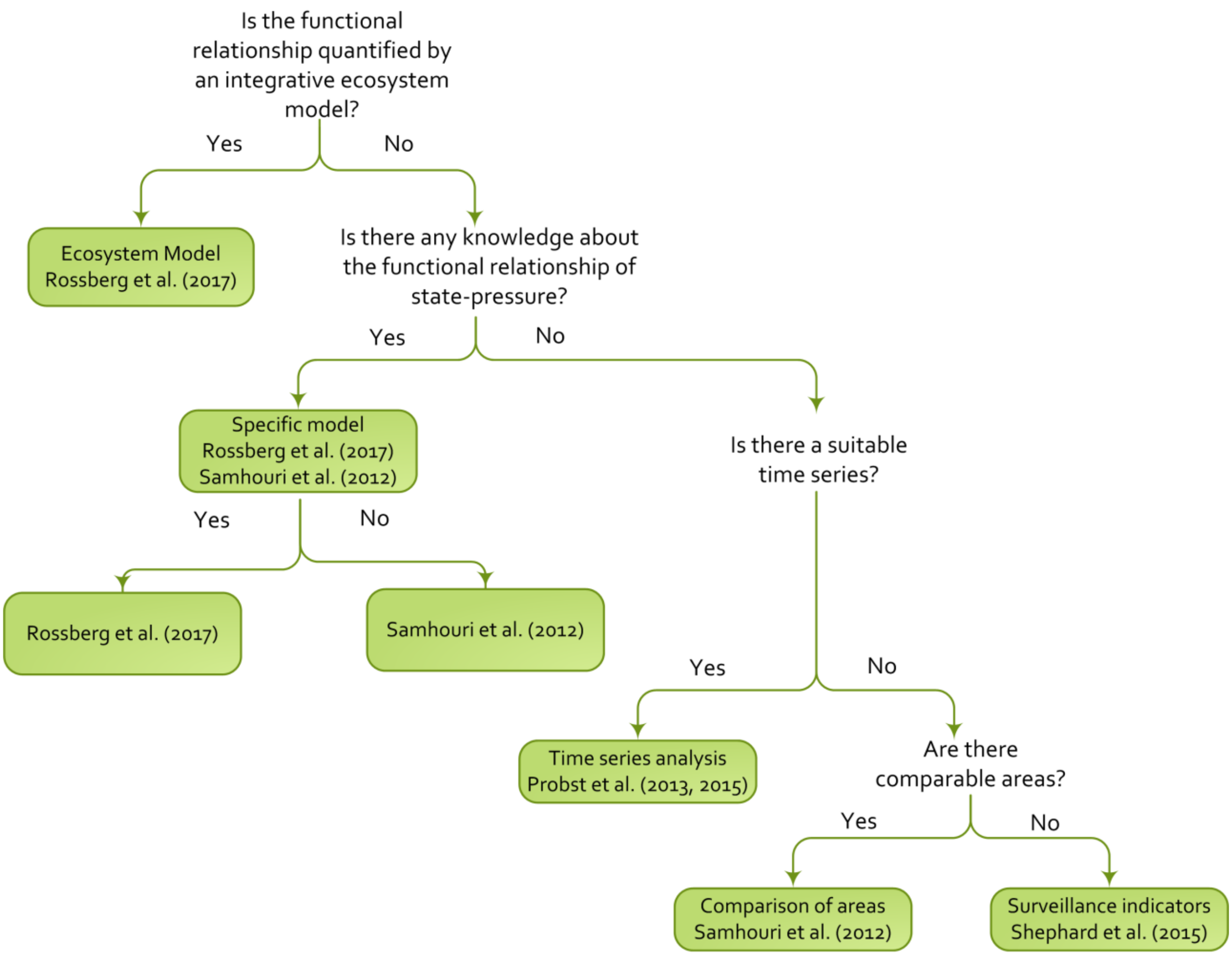


Figure 5.1 Guidance to estimate reference points for ecosystem indicators.

This guideline is designed with the intention of providing an approach that is not necessarily ranking the different options from a better-to-worse situation, but should be considered as a framework to organize the different options available depending on the model reliability, data availability, quality of time series, etc. The three broad approaches (functional relationship, time series, and spatial comparison) to define reference points are potentially equally useful, and they have to be critically evaluated before considering which of the three is selected. Having an ecosystem model does not necessarily mean that it should be used to estimate reference points for a given ecosystem indicator if the outputs are thought to be highly uncertain. Furthermore, having an ecosystem model (even if it is known to produce reliable results) does not preclude the use of time series analyses if they are available for estimating reference points. The same applies to the spatial comparison approach. Indeed, the best option would be to use each of the methods to determine reference points and compare the findings.

Below, each of the steps of the rule-based decision tree to set reference points are described (Figure 5.1). The strengths and weaknesses of each approach are also discussed.

a. Reference points based on a functional relationship

Reference points can be based on functional relationships and be informed by existing ecosystem models (e.g. ecopath-ecosim models), or if those ecosystem models are not available, they can be informed by simpler and more specific models available (e.g. a statistical model relating a pressure and a state indicator).

When an ecosystem model is available, we propose to follow the approach presented by Rossberg *et al.* (2017). In this approach, the ecosystem model is used first as a tool to select those ecosystem indicators that are most strongly connected to the human pressure. These indicators would be the ideal candidates to assess the effect of a given management strategy. After the ecosystem indicators are selected, reference points can be set under the management objective of "Strongly sustainable use", according to the following two steps. First, the natural range of variability for the ecosystem indicator (2.5% and 97.5% quantiles, I_{low} and I_{high} respectively) needs to be estimated. This range can be estimated using the ecosystem model or some other kind of inferential approach (Rossberg *et al.*, 2017). Second, the target range (reference point) for the indicator can be estimated using the ecosystem model as the range of values of the ecosystem indicator that, when all human pressures are removed, would allow a recovery to the natural range in a time frame that is not larger than the acceptable mean recovery time (R), which is a generation time and in this study is considered to be 30 years.

Rossberg *et al.* (2017) presents an example of how to estimate a reference point under this approach using the Large Fish Indicator. The natural range of variability of the Large Fish Indicator (LFI) is not known, but simulation studies predict that indicator values of 0.5 or more could be reached if pressures where lower (Fung *et al.*, 2013). Without any fishing simulations by Fung et al. (2013, Fig. S5a) predicted indicator values close to 0.8. This is assuming a coefficient of variation for LFI of 0.05 in its natural distribution, so that the 2.5% quantile corresponds to about 90% of the mean undisturbed value. Simulations by Fung *et al.* (2013) (in Fig. 7) predicted that recovery from LFI ≈ 0.5 would take around 30 years and recovery from LFI ≈ 0.25 around 35–40 years. This suggests that LFI ≥ 0.3 is a reasonable reference point for a mean recovery time (R) on the order of 30 years.

It is important to highlight that the modelling approach has a notable requirement in order to be correctly applied. In a real management process, the ecosystem indicators will be estimated from data collected in specific surveys. Since the survey does not provide a perfect perception of the sampled system but a partial overview, the range of variability of the ecosystem indicator and the reference point estimated directly by an ecosystem model are not necessarily applicable to the survey data, since the model is working with the "real ecosystem". It is then necessary to include a sub-model simulating the collection of data by the survey in the modelling framework. The two-step process described above would then being applied to this simulated survey data to estimate the range of natural variability and reference point for the ecosystem indicator that would be used to provide scientific advice for management decisions.

When an ecosystem model has not been developed for the study area, but simpler and more specific models are available, the "Strongly sustainable use" concept can still be applied for setting reference points. Under this scenario, information from various sources will need to be compiled to determine the 95% natural variability range for the ecosystem indicator. Historic data or previous studies will be necessary at this point (see examples in Rossberg *et al.* (2017)). The number of years needed for the ecosystem indicator to be back within the acceptable range of variability can then be estimated using the specific model.

Rossberg *et al.* (2017) presents an example of how to estimate a reference point under this approach for the grey seal population abundance in the Baltic Sea. Due to seal haunting, the population declined from a size of 80,000-100,000 individuals in the early 1900s to 20,000 in 1940, and a further decline to 2,000 individuals by the late 1970s. The population growth rate has been >10% yearly between the early 1990s and mid-2000s but slowed down to about 6% in the 2010s. Hence, based on previous knowledge, a population size of 80,000–100,000 individuals can be used as an estimate of the natural range for the Baltic Sea grey seal. Assuming a constant 10% yearly population growth rate, a population size of 5050 individuals would be enough to rebuild the population to 80,000 individuals in R=30 years; and an annual growth rate of 6% would require 15,800 individuals or more. Assuming, more realistically, logistic growth with a carrying capacity of 100,000 individuals, the limit of the strongly sustainable population target range is more conservative, 40,000 individuals.

The framework designed to set reference points under the Ocean Health Index project (Samhouri *et al.*, 2012) presented a different approach, which is not based on the "Strongly Sustainable Use" concept but on what Rossberg *et al.* (2017) call "Weakly Sustainable Use" (see Table 1 of that paper). The weakly sustainable use usually targets the value of an indicator of state corresponding to the optimal long-term use or state. When there is no capacity to assess the recovery time of a given indicator if human activities are removed, the weakly sustainable use is still a very convenient approach. The framework of Samhouri *et al.* (2012) also presents a protocol to estimate reference points using several types of functional relationships. In a nonlinear functional relationship with an optimum, the optimum is used to set the reference point. In the case of a nonlinear functional relationship with a threshold, the threshold occurs where there is a pronounced change in the slope of the relationship between ocean conditions related to a management goal and a pressure. With linear functional relationships, a target (represented by the point on the line) can be set based on existing legal regulations or documented social norms. Analysis of time series or spatial comparisons may be of help at this point.

Strengths:

- Functional relationships (whether coming from ecosystem modelling or specific models) provide direct insight into how pressures can be adjusted to achieve management goals and do not rely on relative comparisons using other places or previous conditions.

Weaknesses:

- Developing an ecosystem model is time consuming and needs a very large amount of data and previous work, as well as a very important resource investment.
- Reference points based on functional relationships require a mechanistic and quantitative understanding, involve site-specific knowledge of how pressures influence the state of marine ecosystems, and cannot be developed in many places where data are limited. In practice, it is likely that the other types of targets (time series based or spatial comparisons) will be used with greater frequency.

- It is possible that estimating the reference point implies going beyond the limits of the observed data used to parameterise the model. This implies extrapolation, which has to be considered very carefully.
- The knowledge of survey uncertainty would be necessary to estimate the "observed indicator value" instead of the "real value".

b. Reference points based on time series analysis

Reference points can also be estimated based on time series analysis. Ecosystem models and other models of functional relationships are very suitable tools but not necessarily better than the analysis of time series or spatial comparisons when setting reference points. Model assumptions are sometimes too strong, while a long and consistent time series may provide a simple but very trustable way to set reference points. However, when time series analysis is used, it is not possible to set reference points using the weakly sustainable use approach (Samhouri *et al.*, 2012; Rossberg *et al.*, 2017). While the longer the time series the better it will be the estimate of the reference points, it is not absolutely necessary to have a long time series, but to have a time period when sustainable values were observed. The most important factors that determine the usefulness of a time series are consistency in the sampling protocol and effort over time that ensures continuity in the time series.

If time series are long enough to contain a period of pristine conditions or a period of sustainable exploitation then the time-series approach proposed by Samhouri *et al.* (2012) can be followed. This approach focuses on a stationary time period and relays on information about what was previously possible in a particular location. It is especially useful for goals for which the desired state occurred at a fixed time in the past. However, it is important to highlight that the reference point at which we aim might not be the one in a pristine state (since this is not achievable anymore under human pressure), but one that reflects the level of the indicator observed in a period when human pressure was considered sustainable. The method described by Probst and Stelzenmüller (2015) can be used to estimate a reference point from this absolute approach. It is based in the analysis of time series and current state of the ecosystem indicator. Two time-series analysis methods are combined, a breakpoint analysis and linear regression. The breakpoint analysis identifies periods of relative stability within a time series, and the reference point of the ecosystem indicator is estimated from the stable periods. Depending on the management goals, whether preventing a further decline of the status of the ecosystem component or improving and recovering it to a good status, the reference point will be estimated as the level of the indicator that in the breakpoint analysis was estimated using the best period or the average value of all those periods, respectively. Once the reference point is defined, the trend over the last 5 years of the indicator time series can be analysed by fitting a linear regression. This allows assessing whether the indicator is increasing, decreasing or stable in the recent years. The value of the ecosystem indicator in the present and the estimated trend is used to assess the estate of the indicator in relation to the management goals.

If the time series is not long enough and does not contain a pristine or sustainable exploitation period, a simpler approach described in Probst *et al.* (2013) can be used to set the reference point. Based on that approach, the reference point for the state indicator is set at the 33 percentile of the observed values in the time series. The 66 percentile is used for the pressure indicator. The mean for the last 3 years is estimated and compared to the reference values to determine the state of the indicator. The 33% and 66%-percentiles were chosen by Probst *et al.* (2013) to allow for some random deviation from the median. However, alternative quantiles could be chosen as indicator metric limits, depending on the ambition of the responsible authority.

<u>Strengths</u>: A target based on a time series has the advantage that it creates an internal standard against which ocean conditions in a location of interest are measured, i.e. it controls for all variables that are specific to a particular location.

<u>Weaknesses</u>: The need for site- or region-specific time series data, the subjectivity involved in choosing an appropriate reference time period, and need for knowledge about longer-period cycles that can influence possible reference values.

<u>c. Reference points based on spatial comparisons:</u>

If there are not time series of data available, or those available do not include a range of values that are representative of the historical high and/or low values of the indicators, they have serious problems of consistency, or there are concerns about some other important aspects for the reliability of the time series, then the spatial comparison should be explored as an alternative approach. The spatial comparison approach to set reference points presented by Samhouri *et al.* (2012) can be used if information about the same ecosystem indicator in comparable areas is available. Reference points derived from spatial comparisons gauge the current ocean conditions in a particular location relative to the current ocean conditions in a reference area(s).

To estimate a reference point using spatial comparison, one starts by cataloguing the current state of the indicator under study in each location within a study region. Then, the maximum observed value is defined as the target, and finally, the status of the indicator in each location within the region is assessed relative to that target value.

Strengths: Targets based on spatial comparisons can be advantageous because they require data only from the current time period and allow direct, straightforward comparisons among locations. In addition, they are grounded in the reality of what is possible given current productivity regimes, human population densities, levels of development, legal and social norms, and financial resources.

Weaknesses: A spatial comparison creates an external standard against which ocean condition in a location of interest is measured. Thus, it assumes that what is possible in one place is possible in others, which may not be true for either ecological/biophysical or human/social reasons. Another weakness of the spatial comparison approach is that it assumes that the regional potential maximum state at any time and the regional maximum state today are one and the same. As a result, a target based on the spatial comparison approach may underrepresent the potential of a location (e.g. if its reference values are close to the regional maximum value) and may be too ambitious for other locations in the region.

The choice between using a time series approach or spatial comparison to set a target can be made based on an assessment of the strengths and weaknesses of each approach, the needs of the application, and constraints of available data.

d. Reference points for surveillance indicators:

Surveillance indicators are those for which a functional relationship is not known and for which a reference point cannot be estimated. Hence, these indicators cannot be used to provide a direct input for management decisions. However, as argued by Shephard *et al.* (2015), these indicators can be very informative and may be incorporated into the management procedure as "warning indicators". Since reference points cannot be estimated for these indicators, expert judgement will be the basis on which to make decision when the level of a surveillance indicator is pointing to potential danger or problems in the ecosystem.

5.3. Sub-task 4.2 – Exploration of frameworks to better integrate ecosystem information with management advice

In this subtask, different frameworks and tools to integrate and visualise multiple indicators in a succinct way were examined with the aim of establishing the ecosystem context within which management decisions can take place. Specifically, the potential use of indicator-based ecosystem report cards was examined (Zador *et al.*, 2016). An ecosystem report card is a tool which is used to synthesise and summarise multiple and complex ecosystem information from different sources into smaller and simpler number of dimensions. The NPFMC in the USA (approach 1) uses this tool to synthesize and communicate the overall state of the different components of the ecosystem in a region. The approach followed by CCAMLR (approach 2) to synthesize and communicate ecosystem information was also explored to find elements of interest for this project. Additionally, the Ocean Health Index (approach 3) developed by Halpern *et al.* (2012) and the NEAT tool (Nested Environmental status Assessment Tool) (approach 4) designed within the project DEVOTES (Berg *et al.*, 2017; Rossberg *et al.*, 2017) were also explored to identify different ways to integrate and synthesize ecological information.

5.3.1. Review of existing approaches

In this section the main elements and achievements of the four approaches mentioned above are presented in a summarised way. For a more detailed description see Appendix 4.2.

Approach 1: The North Pacific Fisheries Management Council (NPFMC).

The NPFMC manages groundfish fisheries in four large marine ecosystems in the Alaska exclusive economic zone. Over the last 10-15 years, the NPFMC has been actively engaged in implementing the ecosystem approach to manage its fisheries. Accordingly, it has designed and developed over time a process and a series of products that aim to support its implementation, in order to better link ecosystem information and science into its management advice and decisions. The main steps and elements developed by the NPFMC are:

- Strong development of an ecosystem-based management policy with long-term planning initiatives, fishery management actions, and science planning to support ecosystem-based fishery management.
- The creation of an Ecosystem Committee to provide ecosystem based fisheries management advice in the context of the NPFMC
- The development of Fishery Ecosystem Plans (FEP)
- The development of an annual Ecosystem Considerations Report including Ecosystem Assessments and ecosystem Report Cards

The objective of a FEP, which the NPFMC has developed for each ecoregion within its exclusive economic zone, is to formalise and strengthen the delivery of ecosystem information to the Council, to provide a transparent tool for evaluating emergent trade-offs between conflicting management objectives (e.g. conservation and fisheries harvest), and refine fisheries advice under changing climatic conditions (NPFMC, 2007b).

The FEPs usually include an initial ecosystem overview of the region which describes and integrates existing research and information about the main physical, ecological, and socio-economic components of the ecosystem and their interactions. It also can include a conceptual model of the ecosystem and an ecosystem risk assessment, which helps identify key ecosystem interactions that describe the ecological and economic impacts of the different commercial activities on the regions. These ecosystem products provide general guidance to the Council on priority areas and issues for management attention and further research and analysis (NPFMC, 2007a).

An Ecosystem Consideration Report is also prepared annually as part of annual harvest specifications which include an ecosystem assessment for each ecoregion. Currently, the Ecosystem Consideration Report includes four main sections (1) Report Cards for each ecoregion, (2) Executive Summary, (3) Ecosystem Assessment, (4) Ecosystem Status and Management Indicators (Zador, 2015).

The Ecosystem Report Cards (see example in Figure 5.2) are used to summarise the status of top indicators that best describe the ecosystem and provide a synthesised ecosystem-based view to the Council in order to inform fisheries management decisions every year (Zador, 2015). Ecosystem report cards are developed for each ecoregion. The indicators contained in the Report Cards are monitored and updated annually to ensure they are taken into consideration in fisheries management decisions.

The Executive Summary section is used to provide a written concise summary of the status of marine ecosystem in Alaska for a wide range of stakeholders including fishery managers, stock assessment scientist and the public (Zador, 2015).

The Ecosystem Assessment section, which supplement the Ecosystem Report Cards and the Executive Summary section, aims to synthesise historical climate and fishing effects in each ecoregion using information from the fourth section (Ecosystem Status and Management Indicators) and the existing single species stock assessment reports. The Ecosystem Assessment also discusses a list of hot topics relevant for the management year. In the future, this section aims to use a blend of data analysis and modelling to communicate not only the current status of the ecosystem but also possible future directions and scenarios (Zador, 2015).

The Ecosystem Status and Management Indicator section provides detailed information and updates on the status and trends of all the indicators that are used to monitor the different ecosystem components (physical, ecological, social relevant ecosystem components) of each ecoregion. Each indicator comes with a detailed description including how it is calculated, data sources and data requirements, a description and interpretation of its trends and current state capturing the uncertainty of the indicators, factors causing the observed trends and a final section with its implications and link to fisheries management. These are used to provide early signals of direct human effects on the ecosystem components or monitor the efficacy of previous management action on those ecosystem components (Zador, 2015).

Different approaches, tools and strategies are used to present and communicate efficiently to the Commission on the ecosystem science reviewed and produced by the Ecosystem Committee, these include:.

- Strong involvement of stakeholders to provide inputs and review the data and analytic methods in the science.
- The ecosystem science is fitted within the management advice cycle presenting the ecosystem considerations report during the Annual Council Meeting. The Council is also involved in the preparation of the report since there is frequent communication between scientists and the Council.
- An effective communication and timely strategy to communicate ecosystem science to fisheries managers. Prepare and adapt the ecosystem information to fit the management cycles and needs.
- The creation of highly visual communicative products: The indicator-based Ecosystem Report Card (Figure 5.2) presented annually in the Ecosystem Consideration Report is the result of a long adaptive process and many years of consultations which have resulted in a evolved product that now serves the management needs of the Council.
- The creation of educational and outreach products to engage different stakeholders like highly visual and communicative brochures.

Eastern Bering Sea 2014 Report Card

- The North Pacific atmosphere-ocean system during 2013-2014 featured the development of strongly positive SST anomalies south of Alaska. This warming was caused by unusually quiet weather conditions during the winter of 2013-14 in association with a weak Aleutian low (positive NPI), and abnormally high SLP off the coast of the Pacific Northwest.
- The eastern Bering Sea experienced warmer air temperatures and less sea ice that were related to the broader North Pacific conditions. Dates of sea ice retreat, summer surface and bottom temperatures, and the extent of the cold pool were similar to those of the warm years of 2003-2005.
- The summer acoustically-determined time series of euphausiids continues to decrease from its peak in 2009. This suggests that prey availability for planktivorous fish, seabirds, and mammals was low in 2014.
- Survey biomass of motile epifauna has been above its long-term mean since 2010, although the trend has stabilized. However, the trend of the last 30 years shows a decrease in crustaceans (especially commercial crabs) and a long-term increase in echinoderms, including brittle stars, sea stars, and sea urchins. It is not know the extent to which this reflects changes in survey methodology rather than actual trends.
- Survey biomass of benthic foragers has remained stable since 1982, with interannual variability driven by short-term fluctuations in yellowfin and rock sole abundance.
- Survey biomass of pelagic foragers has increased steadily since 2009 and is currently above its 30-year mean. While this is primarily driven by the increase in walleye pollock from its historical low in the survey in 2009, it is also a result of increases in capelin from 2009-2013, perhaps due to cold conditions prevalent in recent years.
- Fish apex predator survey biomass is currently above its 30-year mean, although the increasing trend seen in recent years has leveled off. The increase since 2009 back towards the mean is driven primarily by the increase in Pacific cod from low levels in the early 2000s. Arrowtooth flounder, while still above its long-term mean, has declined nearly 50% in the survey from early 2000s highs, although this may be due to a distributional shift in response to colder water over the last few years, rather than a population decline.
- The multivariate seabird breeding index is above the long term mean, indicating that seabirds bred earlier and more successfully in 2014. This suggests that foraging conditions were favorable for piscivorous seabirds.
- Northern fur seal pup production for St. Paul Island remained low in 2014, with fewer pups produced than the last survey in 2012.

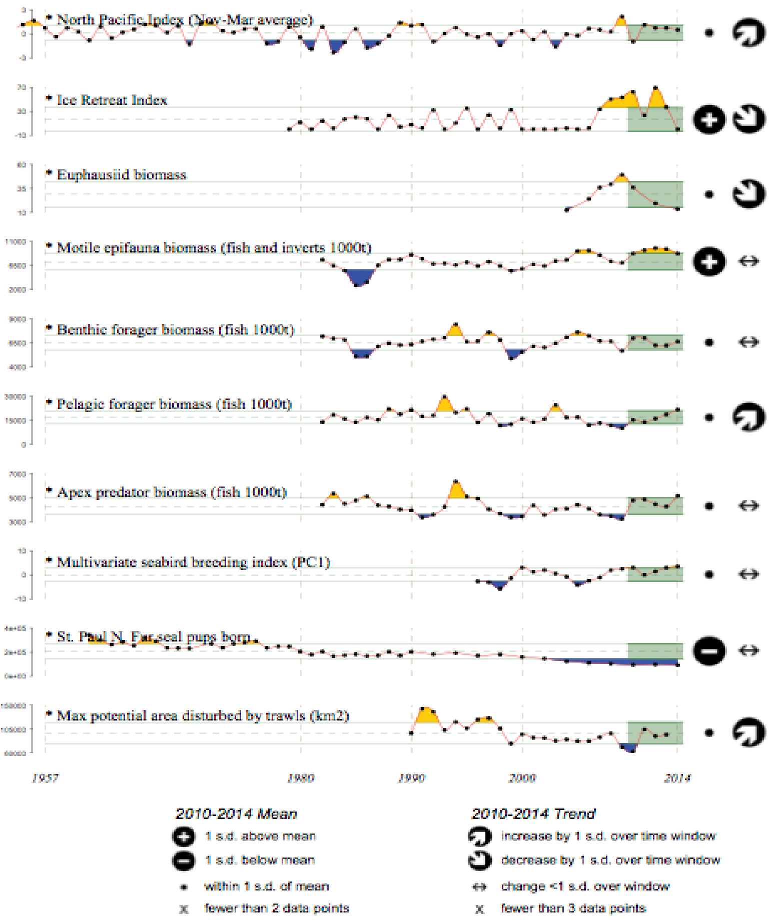


Figure 5.2 Example of an indicator-based Ecosystem Report Card generated by the NPFMC. Eastern Bering Sea Ecosystem Report Card with a set of ecosystem assessment indicators. See bullet point text for descriptions, an * indicates time series updated annually.

Approach 2: Commission for the Conservation of Antarctic Marine Living Resources (CCMLAR)

The CCAMLR convention recognises the need to account for ecosystem conservation, and therefore the management of its fisheries is based on 3 principles that need to be balanced: 1) the existence of the fishery; 2) the krill stock status; and 3) the status of krill predators, that are used as indicators of the health of the whole ecosystem.

CCAMLR has tried to reflect those principles in its management from early on, and to do so, it has adopted precautionary rules in defining catches of krill. Simulation modelling is used to incorporate uncertainty in forecasting, and the rules require that long term krill biomass remains at 75% of its pre- exploitation levels to account for the needs of predators. This process offers a way to capture ecosystem considerations into management and allowed CCAMLR to adopt a more ecosystem focused approach to fisheries management despite limitations in knowledge about ecosystem processes and their links/response to fishing pressure.

The CCAMLR Ecosystem Monitoring Program (CEMP) was set up in 1989 to provide information about the effects of fishing on dependent species including:

- Detect and record significant changes in critical components of the marine ecosystem within the Convention Area.
- Distinguish between changes due to harvesting of commercial species and changes due to environmental variability.
- Currently the focus of the CEMP is primarily on 'krill-dependent species' like penguins (Adélie penguin (*Pygoscelis adeliae*), Chinstrap penguin (*P. antarctica*) and other species), black-browed albatross (*Thallasarche melanophrys*), or the Antarctic fur seal (*Arctocephalus gazella*). The parameters monitored relate to the reproductive capacity, growth, condition, feeding ecology, abundance and spatial distribution of the krill-dependent species (CCAMLR, 2016).

In order to ensure comparability between sites and over time, CCAMLR has agreed a set of CCAMLR Ecosystem Monitoring Program Standard Methods that include details of how data should be collected, formats for submission of the data to the CCAMLR Secretariat, and procedures for data analysis.

For the integration of ecological information and assessment, the Working Group on Ecosystem Monitoring and Management (WGEMM) standardises the CEMP indices (Figure 5.3) and provides advice to the Scientific Council as well as on Vulnerable Marine Ecosystems and Illegal, Unreported and Unregulated fishing.

The Working Group on Incidental Mortality Arising from Fishing (WGIMAF) is another important element in the ecosystem approach in CCAMLR framework. Their advice focuses on bycatch species, mitigation measures, and precautionary limits to reduce the chance of over-exploitation of populations.

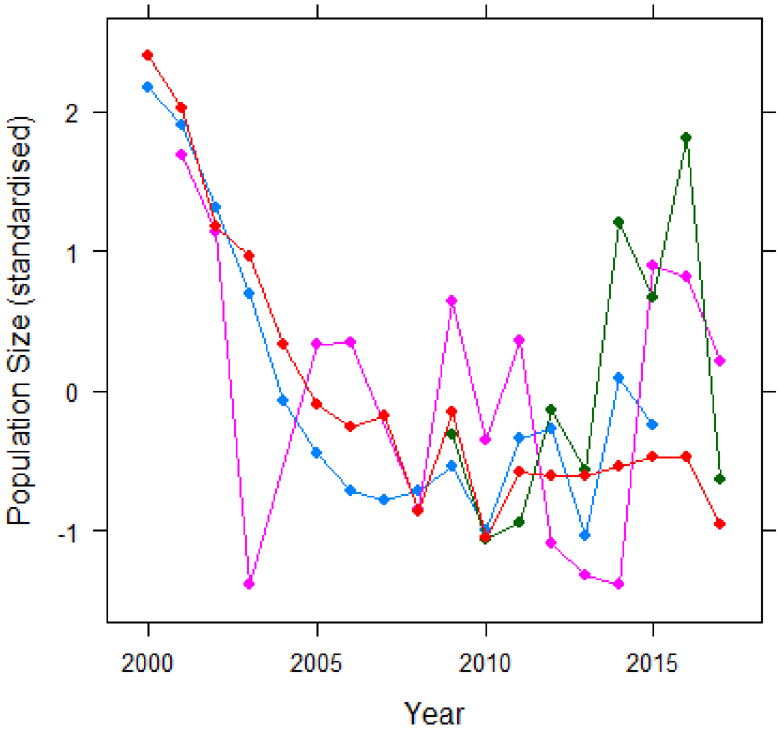


Figure 5.3 Standardised population size for Adélie penguin. Each line represents a different area where monitoring takes place (WGEMM-17/17).

Communication with stakeholders is undertaken by different Groups (above mentioned WGEEM and WGIMAF). Communication of science to the Commission is through advice developed as follows:

- Analysis of CEMP data that are summarised in working documents discussed during the annual WGEMM and WGIMAF meetings.
- Recommendations made by WGEMM are discussed and reviewed/agreed during the annual Scientific Committee (SC) meeting.
- Recommendations made by the SC are discussed and reviewed by the Commission in the annual meeting held after the SC meeting.

Ecosystem considerations are part of the CCAMLR fisheries reports, which offer a quick summary of the main information relevant to each fishery. This provides a way to mainstream such issues and increase the number of people (and managers) that are aware of them.

Approach 3: Ocean Health Index project

The Ocean Health Index (http://www.oceanhealthindex.org/) is a tool for the assessment of ocean health which tries to balance multiple competing and potentially conflicting public goals and connect human development with the ocean's capacity to sustain progress (Halpern *et al.*, 2012). This integrative approach is applied through the so-called Ocean Health Index, that integrates the assessment of changes in goals like fish stocks, extinction risks, coastal jobs, water quality and habitat restoration.

Each goal (or sub-goal) is assessed in relation to four dimensions: Status, Trend, Pressures and Resilience. These four dimensions are aspects of a goal that contribute to its current status or the likelihood of being able to sustainably deliver that goal in the future. For each goal, each of these four dimensions is assessed based on various components, which in turn are defined by data layers that support the estimation of ecological or socio-economic indicators (see Figure 5.4). A complete list of combinations of goals, sub-goals, dimensions, components and layers is provided in tables S22 and S23 in supplementary material of Halpern *et al.* (2012).

The method has a strong focus on sustainability and coupled human-natural systems, providing a score for each of the ten goals. Sustainability requires that both the current status and likely direction of change in status influence the score. Scenarios that maximise value today with no concern for future conditions are strongly penalised by the index. However, the main focus in the Ocean Health Index is on the near future (around 5 years) rather than longer term because near-term time frames are most relevant to policy makers and long-term future states are difficult to predict.

The objective (utility function) of the Index is to maximize its value (I), where I is determined as a linear weighted sum of the scores for each of the public goal indices (I1, I2, . . . , I10) and the appropriate weights for each of the goals (α1, α2, . . , α10), such that:

$$I = \propto_1 I_1 + \propto_2 I_2 + \cdots + \propto_{10} I_{10} = \sum_{i=1}^{N} \propto_i I_i$$

where $\sum_{i=1}^{N} \propto_i = 1$. The weights applied to each goal can be set based on previous knowledge, giving more importance to the final index score of one or another goal depending on the priorities, the reliability of the data, etc.

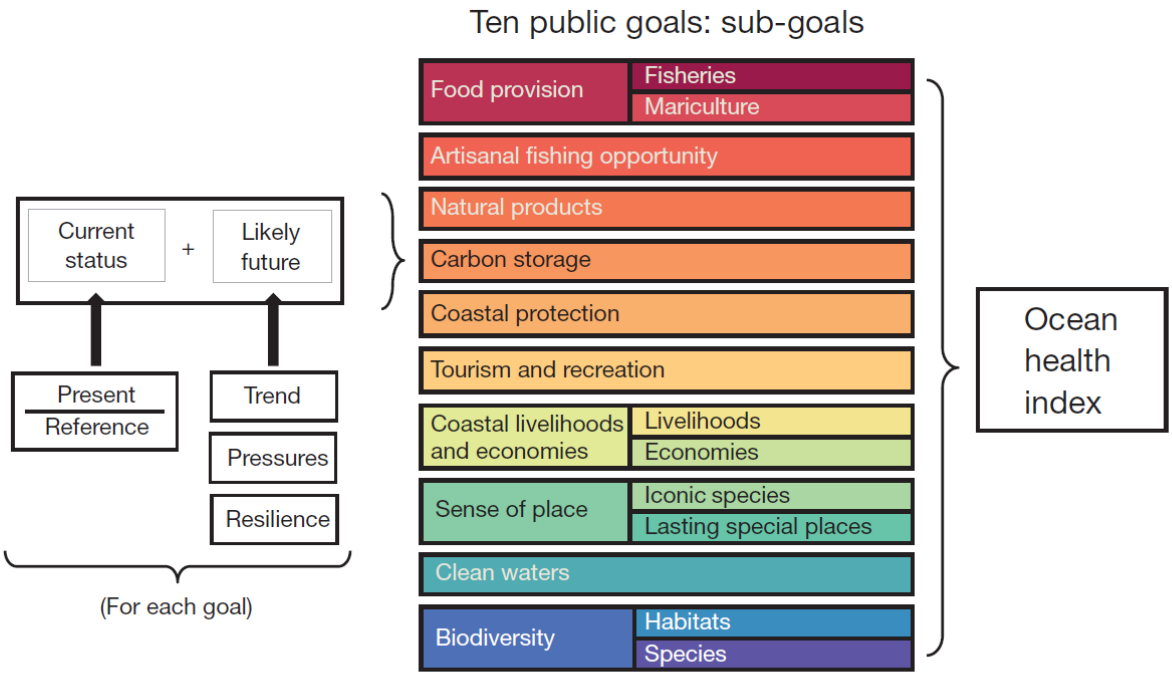


Figure 5.4 Conceptual framework for calculating the ocean health index from Halpern *et al.* (2012). Each dimension (status, trend, pressures and resilience) is derived from a wide range of data. Dimensions are combined to indicate the current status and likely future condition for each of ten goals (see more details in Appendix 4.2).

The resulting Ocean Health Index is presented in a graphic and colourful way (Figure 5.5). This visual way of presenting the index is a very intuitive and easy approach to show the score obtained for the global Ocean Health Index for all the ten goals together, but also to present the score obtained for each of the goals separately. This provides to managers easily with an idea about the global state, but also about the areas (goals) identify the most problematic areas. In addition, the scores obtained for each of the data layers, components and dimensions, can also be presented in separate tables if required by managers to identify specifically the dimensions (if current versus short-term status) and components that need more attention from a management perspective.

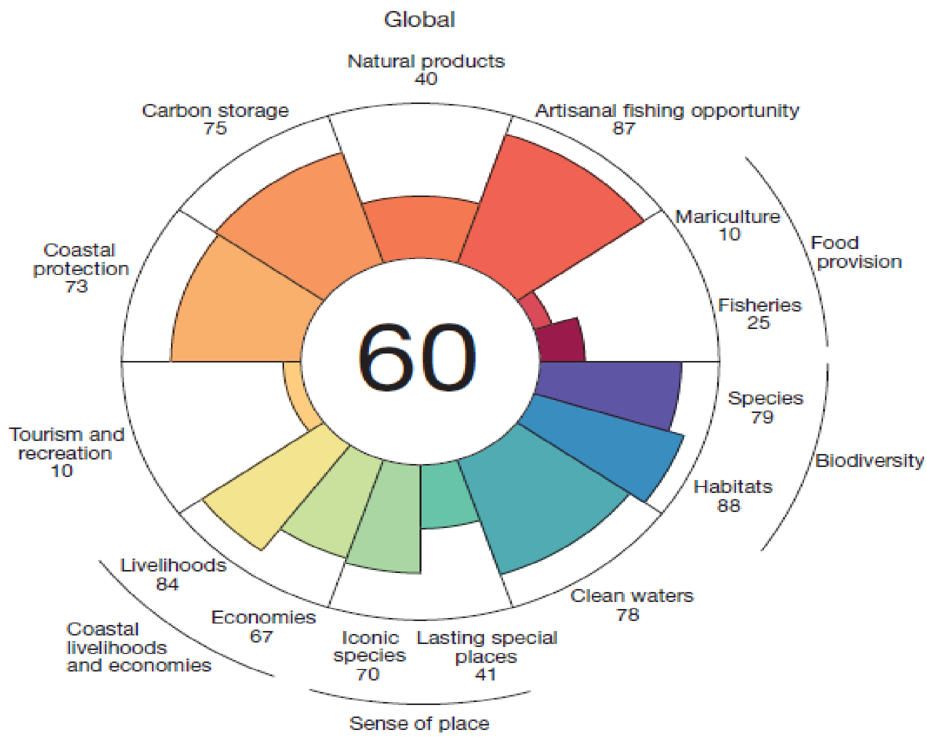


Figure 5.5 Ocean health index overall score (inside circle) and individual goal scores (coloured petals) for the global area-weighted average. The higher the score in the centre the better the global state of the system. The outer ring is the maximum possible score for each goal, and a goal's score and weight (relative contribution) are represented by the petal's length and width, respectively (Modified from Halpern *et al.* (2012)).

Approach 4: Nested Environmental status Assessment Tool (NEAT v.1.3)

NEAT is a flexible and user-friendly desktop application developed with the aim to support European CPCs and Regional Sea Conventions in their commitment to assessing the environmental status of marine waters, so they can inform managers on where management measures are needed (Berg *et al.*, 2017; Rossberg *et al.*, 2017). This software has been developed in the context of the DEVOTES project (www.devotes-project.eu).

The main principles of NEAT are:

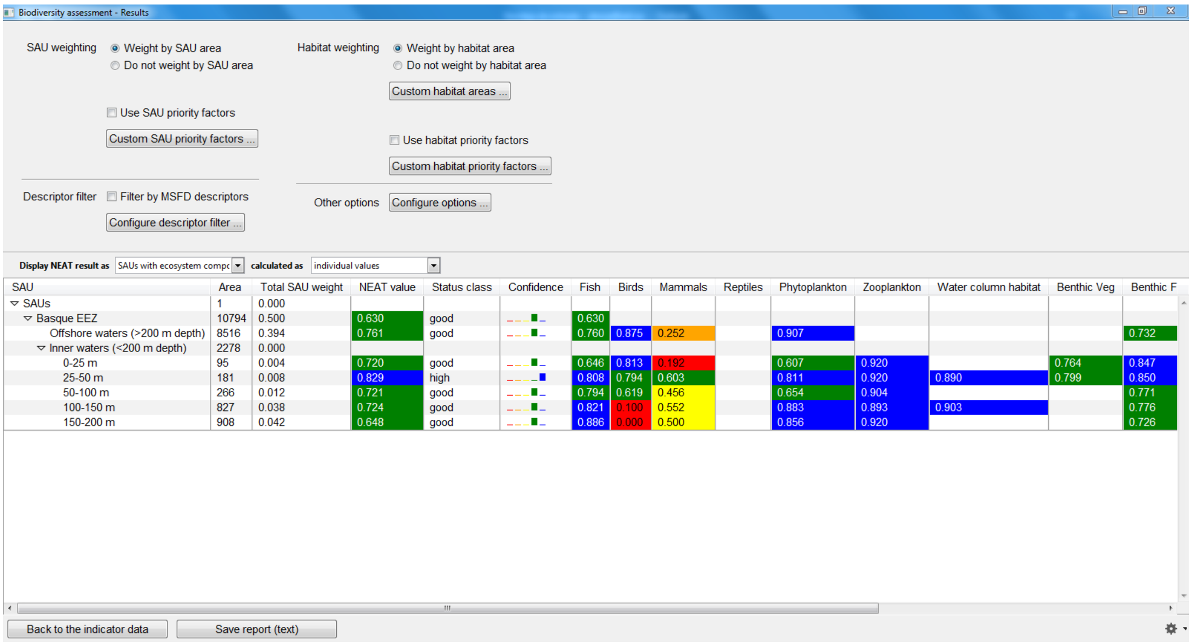
- **Indicators:** The assessment is based on indicators. The current version of NEAT integrates an indicator catalogue (Teixeira *et al.*, 2016)for predefined indicators for the biodiversity assessment. However, the tool is not limited to those indicators; it allows adding as many indicators as needed (not only biodiversity but indicators any kind of– specific to the assessment to be made).

- **Weighting and hierarchies:** the central principle in the NEAT method is a hierarchical, nested structure of Spatial Assessment Units (SAU) and habitats. The contribution of the indicator is weighted by the area to which the indicator contributes.
- **Aggregation:** in order to aggregate indicators, they are all normalised into a scale of 0 to 1. By default, aggregation is done across all indicators belonging to a SAU. However, NEAT is designed to do aggregations for multiple group entities. For example, the method can be used to aggregate all indicators of a SAU and show the status divided among the different ecosystem components of the SAU.
- **NEAT value:** the outcomes of the aggregation are visualised into a number (the NEAT value) and a colour, which corresponds to the status (Figure 5.6). This NEAT value is obtained for the whole assessed area, although it can be visualized by ecosystem components.
- **Uncertainty:** Each NEAT value is accompanied by its quantitative estimate of uncertainty. This estimate is performed using the standard error (entered at the same time as the indicator value), and performance of Monte Carlo simulations as means to understand how this error propagates throughout the assessment.

Although the driver for the development of NEAT was the biodiversity status assessment in European seas, NEAT capacity is much broader than that. The assessment principles used in NEAT are universal and can easily be adapted to other assessment types such as pressure assessments, impact assessments, ecosystem service assessment, etc. Further details on the assessment method behind NEAT can be found in (Andersen *et al.*, 2017).

The NEAT outcomes are presented in an easy to interpret table with meaningful colours (Figure 5.6). On the one hand, it is possible to visualise the different NEAT scores, and perform different visualisations of the outcomes. In addition to visualising NEAT values of the different SAU (if existing), it is possible to see how different ecosystem components (e.g. fish, mammals) contribute to the NEAT value at each SAU and to the overall assessment. Similarly, it is also possible to visualize how the different habitats contribute to the assessment. Furthermore, descriptors can be filtered, so only indicators that correspond to the descriptor of interest are considered in the assessment. In addition to the NEAT values, the background of each number is set so it provides five possible colours, each colour corresponding to 5 different types of assessment quality (i.e. bad, poor, moderate, good, high).

Finally, uncertainty is also visualised using a bar graph, which reflects the certainty of the assessment being in any of the five "quality" assessment categories.



SAU	Area	Total SAU weight	NEAT value	Status class	Confidence	Fish	Birds	Mammals	Reptiles	Phytoplankton	Zooplankton	Water column habitat	Benthic Veg	Benthic F
SAUs	1	0.000												
Basque EEZ	10794	0.500	0.630	good		0.630								
Offshore waters (>200 m depth)	8516	0.394	0.761	good		0.760	0.875	0.252		0.907				0.732
Inner waters (<200 m depth)	2278	0.000												
0-25 m	95	0.004	0.720	good		0.646	0.813	0.192		0.607	0.920		0.764	0.847
25-50 m	181	0.008	0.829	high		0.808	0.794	0.603		0.811	0.920	0.890	0.799	0.850
50-100 m	266	0.012	0.721	good		0.794	0.619	0.456		0.654	0.904			0.771
100-150 m	827	0.038	0.724	good		0.821	0.100	0.552		0.883	0.893	0.903		0.776
150-200 m	908	0.042	0.648	good		0.886	0.000	0.500		0.856	0.920			0.726

Figure 5.6 NEAT assessment outputs presented for the overall spatial scale (and its hierarchy) and visualized by ecosystem components. Colours are associated to different status levels. Bar figures present the confidence of the different assessment values.

Synthesis of strengths and weaknesses of each case study.

In this section the strengths and weaknesses (or difficulties) of each of the approaches presented in the previous four sections are summarised and ordered in a systematic way.

<u>a. Ocean Health index</u>

The Ocean Health Index project has developed a tool that focuses on synthesising in a very structured way all the ecological information available and presenting it in a clear and accessible way to managers.

<u>Strengths:</u>

- The Ocean Health Index project has developed a hierarchical and very integrative approach that incorporates, for a number of different goals, the information from ecological and socio-economic indicators assessing at once the status and the trend, with considerations about the human-environmental pressures and resilience.
- Communication with managers and stakeholders is facilitated through the use of graphical depictions, with different colours and labels that help communicate information in an easy way. Supplementary tables with detailed calculations and

results at different levels provide the necessary information to understand the bases of the results shown in these general figures.

Weaknesses:

- There is not a software tool that can be used to estimate the Ocean Health Index. Instead, the whole calculation framework has to be produced.
- Need to make decisions for several processes defined by specific parameters for which there is no information at hand, or intense research would be needed. Accordingly, it is expected that the application of the Ocean Health Index framework would require considerable time and resources.

b. North Pacific Fisheries Management Council

The NPFMC provides a clear example of how management institutions, organisational regulations, planning mechanisms, data collection, and scientific analysis should work to achieve an ecosystem assessment that can be useful for decision-making. The section devoted to the NPFMC describes the main elements that enable and facilitate the use of ecological knowledge for the management of exploited ecosystems. This section can be taken, to a large extent, as a guide for the development and implementation of the ecosystem approach in tuna RFMOs. In particular, two ecosystem products or elements developed by the NPFMC, the development of an ecosystem report card and an ecosystem assessment document, are found relevant to the ongoing work in tuna RFMOs and therefore have the potential to be developed in the tuna RFMOs.

Strengths:

- The NPFMC ecosystem report card is a simple but very practical approach.
  - It includes a very brief but thoroughly selected number of ecological and pressure (both human and environmental) indicators.
  - The status of all these indicators is determined by comparing the current state of the indicator to estimated reference points (can be high and low).
  - The trend in the indicator is established based on the pattern observed in the last 5 years.
- Presentation to managers and stakeholder is done by depicting the time series of the different indicators, the reference points, in different colours to highlight the period when the trend is assessed. This figure also includes a system of arrows that provide extra information in an easy manner. This representation is not as integrative and visual as the OHI approach, but due to the low number of indicators by NPFMC it

seems still a powerful way to communicate and synthesise the ecosystem information in an integrated way.

- An ecosystem assessment document is presented providing all the details about all the ecosystem indicators estimated and assessed by the scientific community.

Weaknesses:

- All the information on all indicators assessed is not integrated into one product. The most integrated product is the ecosystem report card which communicates a selection of ten ecosystem indicators, but still, they are presented in isolation to each other.
- The evaluation of environmental and human pressure while presented it is not analysed in conjunction with the assessment of the status of the ecological indicators (social and ecological trade-offs are not made apparent).

c. Commission for the Conservation of Antarctic Marine Living Resources

The approach followed in CCMLAR shows a relatively high segmented development of an ecosystem approach. Therefore, it cannot be said that they have developed it yet, but rather that they have used isolated elements of the ecosystem approach for direct management purposes.

Strengths:

- Positive aspects of the CCAMLR approach mainly relate to procedures used to make use of data within the organisation, standardisation standards applied, and commitment of all CPCs to collect and provide the required information in an appropriate way.
- There is a pragmatic vision in the use of indicators with a well-defined objective:
  - Use of indicators of abundance of predators (penguins and marine mammals) to estimate the amount of krill that should remain in the system to support such a community of predators.
  - Use of pressure information (fishing footprint) to estimate the potential impact on VMEs.

Weaknesses:

- Although many datasets of ecological information are available, they are not combined or integrated into one ecosystem assessments. Instead, these are isolated elements within the ecosystem approach. It can be said that the EAFM is under construction in CCAMLR.

- In addition, information to managers is not prepared and communicated presented in an easy way, but it is reflected in a scientific annual report more designed for scientists.

d. DEVOTES-NEAT

Strengths:

- The NEAT is freely available.
- There are existing manuals for users as well as webinars available that allow any potential user to become familiar with the software in very short time.
- The way the tool is presented is very simple so, despite complex algorithms being behind the calculations, it is user-friendly.
- Once data on the ecosystem indicators are introduced in the tool, the assessment is very fast, and performed within seconds.
- It presents the outcomes in a visual and user-friendly manner, providing all NEAT values, uncertainty and colours.
- It is possible to perform sensitivity analysis of the results.
- The NEAT has now been tested in different regions, showing that it is possible to adapt the tool to the different use needs. It is a very flexible tool and all settings can be customised and made fit for purpose.
- Several workshops have been carried out to present NEAT, including a "fisheries" experts fora, which have enable to improve and adapt latest NEAT versions to such needs.
- Further versions of NEAT are expected, as it is regularly updated with the feedback that is received from end users.

Weaknesses:

- Although there are pre-defined settings, it is clear that for the purpose of this project, it requires new settings (e.g. define the area for which the assessment will be performed, and any possible hierarchy of ecosystems components), prior to starting the assessment.
- It requires some extra indicator information (values, standard error, targets) in order to carry the assessments, which may not be easily accessible for all the indicators considered, and this would need extra work and resource investment.
- In the current version, information needs to be manually imported.
- If temporal trends are to be explored, although it can be easily and quickly done, it requires one assessment per time-lap.

- It does not integrate information on pressure indicators to be linked to the estimates of the ecosystem status. Instead, as with the status indicators, NEAT evaluates pressure indicators in the same way that it does for the ecosystem status indicators.

Conclusions

Each of the four approaches analysed provide elements of interest but has its drawbacks, difficulties or limitations. Therefore, it is clear that the most balanced and optimal framework can arise from integrating the most positive elements of these four approaches and minimising the weaknesses of each of them. This section proposes two possible alternative frameworks resulting from combining different elements from these four approaches. Each framework includes the development of three different products which differ in how the ecosystem information is synthesized and communicated to the different end users including managers to scientists (Figure 5.7).

<u>Option 1. Framework integrating elements from the ocean health index and the NPFMC approaches</u>

This framework (Figure 5.7) uses the integrated tool developed in ocean health index to identify goals relevant to the HMS (like retained and non-retained fish species, bycatch and threatened species, trophic relationships and habitats) and evaluate the state of different components (represented by one or more indicators) in relation to their respective reference points (see Figure 5.4). The assessment of the state would be the result of the combined analysis of trends in the time series, along with the human-environmental pressure and resilience of that component. The score of all the components would provide the score of a given goal. The weighted sum of the different goals would result in the total score for the state of the HMS system. While not necessarily the same, the graphic representation that would be presented to the managers would take the form of that presented by the ocean health index (see Figure 5.5).

Moreover, two additional elements would be incorporated into this assessment framework from the NPFMC approach. In the first place, an ecosystem report card would be created including a graphical representation of the time series of the most relevant ecosystem and pressure indicators (human and environmental) against their respective reference points. This ecosystem report card would also incorporate information about trends in the last years of the time series (see Figure 5.2). Finally, an ecosystem assessment report would also be elaborated and presented to the managers. This report will present a detailed description of each of the indicators evaluated, the development of time series, and other aspects of interest from the ecosystem approach's perspective.

A detailed analysis of the ocean health index calculations, figures and so forth, would also be developed.

Difficulties with this framework would relate mainly to the complexity of the integrated tool developed by the ocean health index, the weighting of the different goals and components, as well as the determination of parameters related to pressure and resilience.

Option 2.- Framework integrating elements of NEAT and NPFMC approaches

This framework (Figure 5.7) uses the integrated tool developed in NEAT to structure and synthesise the ecological information relevant to the HMS. Unlike option 1, in this case, the assessment and synthesis would be focused exclusively on the state of both ecosystem and pressure indicators, and not on an analysis of trends and resilience. The different indicators would be organised in their respective ecosystem components that would be nested by areas within a given ecoregion, following the protocol of NEAT.

Similarly, to option 1, the ecosystem report cards and ecosystem assessment reports would be key components of this framework. Since trends are not evaluated in the integrated assessment of NEAT, the ecosystem report card plays a more important role. Time series of the most relevant and informative ecosystem indicators would be presented in the ecosystem report card and the trend in the last years evaluated. Alternatively, annual assessments can be performed with NEAT to track changes and trends over time in ecosystem status. As indicated already in option 1, the ecosystem assessment report would also be a key element providing detailed information of the calculations of the indicators, their interpretations and links to fisheries management.

Therefore, in both options the proposed frameworks would contain three main elements (Figure 5.7):

1. A synthesis component to summarize the information of all the indicators or groups of indicators in a single or few numerical values:

   a. Structuring and synthesis based on the method developed in the ocean health index, which integrates state, trend, pressure and resilience at the cost of a high complexity and potentially important assumptions. In addition, there is no developed software to perform the analysis of the ocean health index.

   b. Structuring and synthesis based on the NEAT tool, where the synthesis is carried out only in terms of status, and pressure is evaluated in the same way as the state indicators. The software NEAT would be used to perform the analysis.

2. An ecosystem report card where top ecosystem indicators are presented in highly visual manner, for which the time series would be displayed as well as their values with respect to reference points. The ecosystem report card would be of special relevance in the case of using NEAT as a synthesising tool since NEAT does not perform analysis of trends.

3. An ecosystem assessment which provides detailed information on all the indicators used to monitor the pressures and the state of the different ecosystem components. Each indicator would come with a detailed description including how it is calculated, data sources and data requirements, a description and interpretation of its trends and current state capturing the uncertainty of the indicators, factors causing the observed trends and a final section with its implications and link to fisheries management.

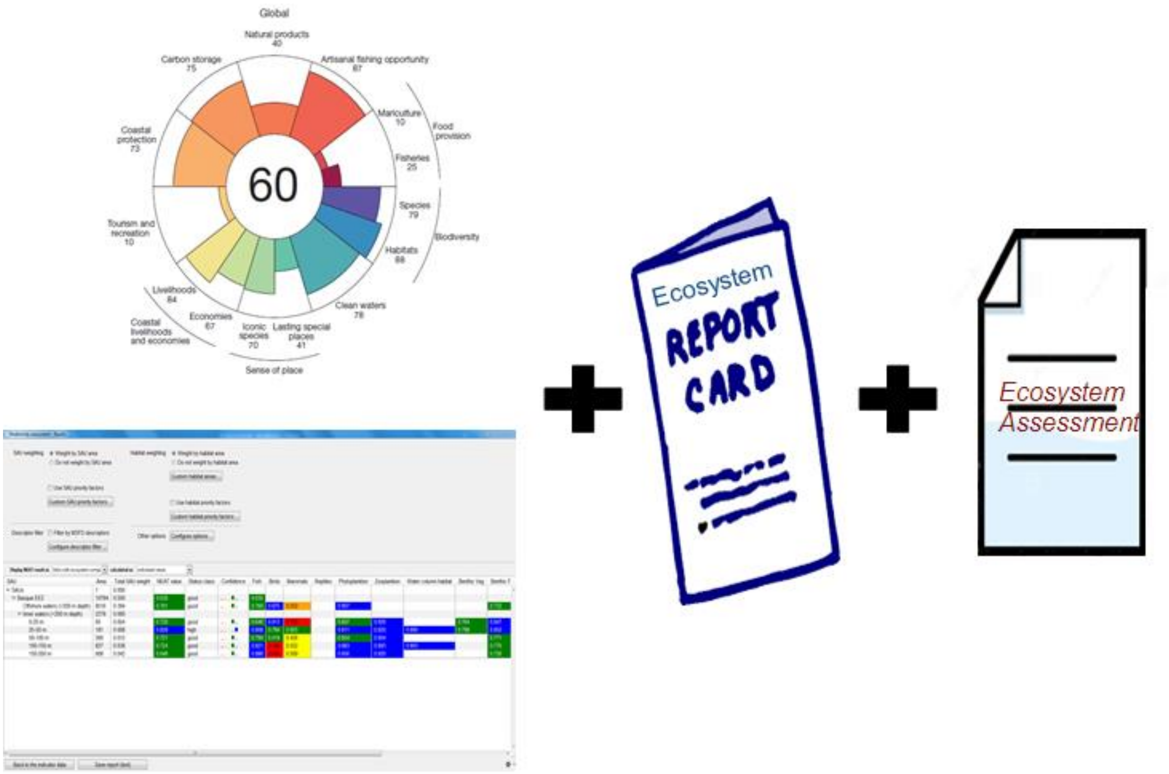


Figure 5.7 The proposed framework contains three elements, with the intention of having a transition from: 1) the more integrated and visual approach of the ocean health index and NEAT tools (left); 2) an intermediate level of disaggregation of information but still an integrated approach consisting of the ecosystem report cards; 3) to a very detailed and descriptive ecosystem assessment, analysing all the ecosystem indicators and element of interest from an ecosystem approach perspective.

5.4. Research recommendations for future work

Defining reference points for ecosystem indicators has been a pending task for many years. While the number and variety of ecosystem indicators has been increasing in the last decades, the estimation of target or limit values that can be used to assess the state of the ecosystem has been rarely addressed. Only in the last years, different studies, like those analysed in subtask 4.1, have faced this complex task and have come up with practical protocols to use the available data and functional relationships in place to define reference points.

The use of ecosystem indicators as supporting information for marine ecosystems management is also a relatively new field of work that has only been implemented in a few management areas and projects in the world, like those analysed in subtask 4.2.

Hence, the use of ecosystem indicators to assess the state of marine ecosystems and its communication to policymakers for management purposes remains a challenging task. Due to the novelty of the methodologies and frameworks described and designed within this task and complexity of the goals addressed, it is expected that the proposed frameworks designed in subtasks 4.1 and 4.2 will need some adjustments when applied to specific case studies. Nevertheless, it is considered that the proposed frameworks and procedures designed in this task 4 are in line with the current needs and have taken the most avant-garde ideas in these areas of research.

6. TASK 5 – ORGANIZE A WORKSHOP BETWEEN DG MARE, EASME AND SCIENTISTS OF THE CONSORTIUM

6.1. Objectives

Task 5 consisted of organizing a workshop between DG MARE, EASME and scientists of the Consortium to analyse outcomes of Tasks 1-4, and select the two case studies or ecoregions for the development of pilot ecosystem plans under Task 6. During the workshop, one ecoregion was chosen within the ICCAT convention area (the Tropical Ecoregion of the Atlantic Ocean) and one within the IOTC convention area (the Temperate Ecoregion of the Indian Ocean). For each of them, a pilot ecosystem plan was developed under Task 6.

7. TASK 6 – DEVELOP TWO PILOT ECOSYSTEM PLANS AND INTEGRATE WORK CARRIED OUT UNDER PREVIOUS TASKS

Key message

- Effective management needs effective planning and the pilot ecosystem plans developed under this task aim to guide the operationalisation of an EAFM in ICCAT and IOTC.
- The ecosystem plans are driven by objectives centered on the ecosystem, and not on individual species or stocks.
- The ecosystem plans aim to focus fisheries management on specific regions, here the ecoregions, highlighting priority issues with the most challenging needs for the Commission.
- The pilot ecosystem plans seek to create awareness about ecosystem planning, create disscussion about what elements need to be part of a planning process and intent to be the basis for a future participatory and cosultative process in ICCAT and IOTC for the development of formal ecosytem plans.

7.1. State of the art background and main objectives of the ecosystem plans

Effective management needs effective planning. Therefore, operational ecosystem plans are needed to link higher level policies and objectives into actions (Staples *et al.*, 2014). The main purpose of the pilot ecosystem plans is to facilitate the implementation and operationalisation of the EAFM in ICCAT and IOTC. While ICCAT and IOTC have committed to operationalising the EAFM within their Convention Areas, their ecosystem-based research and activities have been implemented in an *ad hoc* way, without having a long-term vision and a formalised plan to prescribe how fisheries will be managed from an ecosystem perspective (Juan-Jordá *et al.*, 2017).

There are multiple purposes and benefits in developing an ecosystem plan that ultimately aims to guide the implementation of an EAFM in a region (NPFMC, 2007b; Staples *et al.*, 2014; Levin *et al.*, 2018), including:

(1) Creates a transparent process that may help the Commission to set ecosystem goals and management purposes;

(2) Provides a framework of strategic planning to guide and prioritise fishery and ecosystem research, modelling and monitoring needs;

(3) Facilitates the integration of information and knowledge from different fisheries operating in a region and their cumulative impact on the ecosystem;

(4) Provides a framework to document current and best practices in the region as well as short-term expectations and impediments hindering the operationalisation of EAFM in the region;

(5) Provides a framework to identify key ecosystem components in the region, their interconnectedness, and importance for specific management questions;

(6) Helps the Commission to understand the cumulative effects of fisheries and emergent trade-offs between multiple objectives;

(7) Serves as a communication tool to better link ecosystem science and policy and as a dialogue forum for managers, scientist and stakeholders;

The main objective of Task 6 is to develop two pilot ecosystem plans for two case study regions (one in the Atlantic and one in the Indian Ocean). We developed a pilot ecosystem plan for the Tropical Ecoregion of the Atlantic Ocean (Figure 7.1) and the Temperate Ecoregion of the Indian Ocean (Figure 7.2) to guide the operationalisation of an EAFM in ICCAT and IOTC. The plans are based on objectives centred on the ecosystem and not on one individual species or stock.

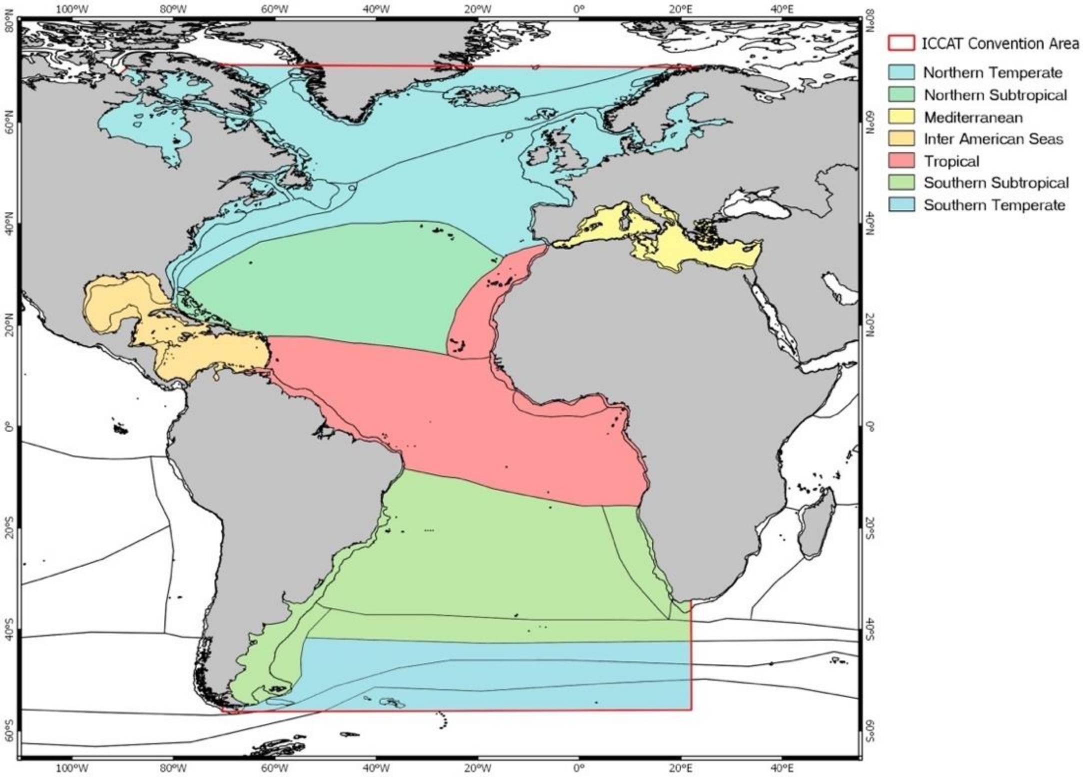


Figure 7.1 Proposal of eco-regions within the ICCAT Convention area. The Tropical Ecoregion is the core boundary of the pilot ecosystem plan in the Atlantic Ocean.

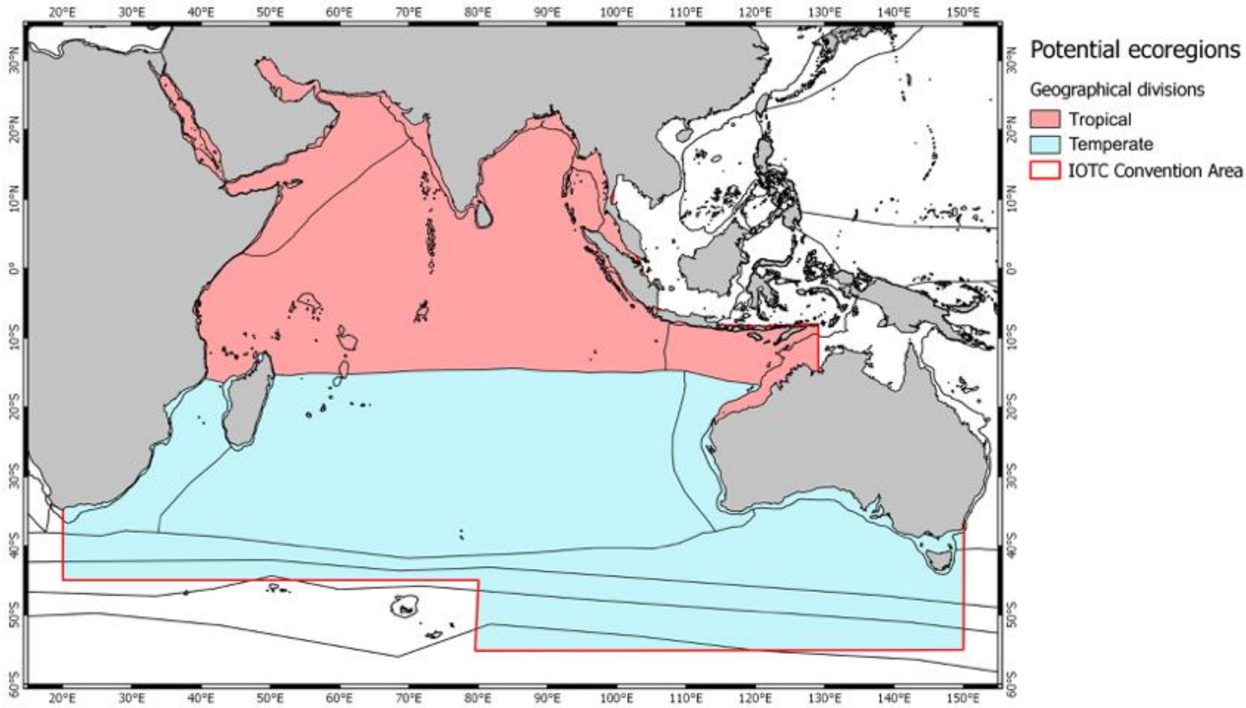


Figure 7.2 Proposal of ecoregions within the IOTC Convention area. The Temperate Ecoregion is the core boundary of the pilot ecosystem plan in the Indian Ocean.

7.2. Core elements of the pilot ecosystem plans

Development of an ecosystem plan requires the use of multiple tools and development of multiple elements and processes. Here, the pilot ecosystem plans developed for the Tropical Ecoregion of the Atlantic Ocean and the Temperate Ecoregion of the Indian Ocean include the following main core elements which will be developed individually in each of the plans (Figure 7.3).

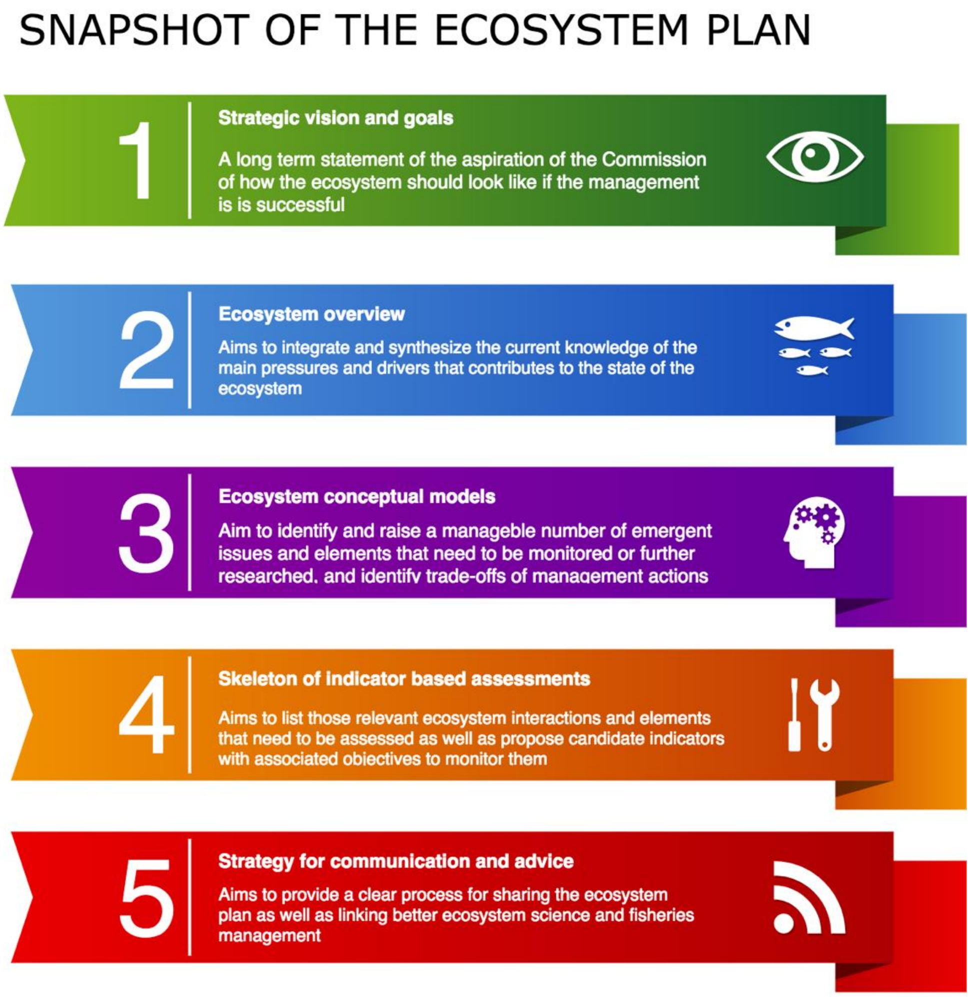


Figure 7.3 A snapshot of core elements of the pilot ecosystem plans.

Each core element is briefly presented and described below:

1. **Strategic vision and goals –** An ecosystem plan needs a vision, goals, and objectives. Ideally a strategic vision and high-level goals should be agreed by the Commission. A vision in line with the ecosystem approach to fisheries should be a long-term statement of the aspirations of the Commission of what the future would look like if management is successful (Staples *et al.*, 2014). This vision

should encapsulate key principles of the ecosystem approach such as the sustainable use of fish resources, conservation of biodiversity, and maintenance of resilient ecosystems. Until the Commission defines and adopts a strategic vision for ecosystem plans, we are basing the vision and goals of these pilot ecosystem plans on the ICCAT and IOTC aspirations reflected on their mandates and adopted recommendations and resolutions.

2. **Ecosystem overview** – The ecosystem overview aims to integrate and synthesise current knowledge of main pressures and drivers that contribute to the state, and changes in the state, of the different ecosystem components in the ecoregion covered by the plan. It also enables identification of ways in which the different ecosystem components interact and relate to each other, highlighting those emergent issues that need to be monitored. Ecosystem overviews also facilitate identifications of data and research gaps in the region. It can be used as a tool to synthesise ecosystem information for the Commission.

3. **Conceptual ecosystem models** – While the ecosystem overview facilitates integration, conceptual ecosystem models are a tool that enables visualisation of those relevant ecosystem components and their interconnection. It also helps identify and raise a manageable number of issues that may need to be researched separately or jointly and ensures that no critical components are missed. Conceptual ecosystem models can also help identify trade-offs of management actions relating to different components of the ecosystem, which may lead to more informed decision making. Conceptual ecosystem models are also used as a tool to synthesise and communicate ecosystem information to the Commission (as well as the public). Therefore, it can be used as a communication tool for ecosystem science.

4. **Skeleton of an indicator-based ecosystem assessment** –The ecosystem overview and conceptual ecosystem models developed for each ecoregion can identify those issues that need to be addressed in the ecosystem plan and issues or ecosystem elements that would require monitoring or further research. Here, a general framework is designed to list all the relevant ecosystem interactions that need to be monitored and assessed by the Commission. For each ecosystem interaction, a list of ecosystem indicators is proposed as well as potential management objectives to track the state of each relevant interaction. In the ecosystem plans, an "interaction" is defined as a component (or group of components) that has an impact on another component (or group of components). At this stage, we are only listing and defining the relevant

ecosystem interactions (for example, climate impacts on marine ecosystems); a later exercise, outside the SC02 project, will need to determine the degree of importance of each interaction to the Commission based on their probability of occurrence as well as the level of impact on the current ecosystem state (the two pillars informing an ecosystem risk assessment). Defining these interactions and their relative importance and risk to the system, provide managers with a tool to either make choices between different risks and trade-offs or take action to avoid unwanted risk through appropriate management actions.

5. **Strategy for communication and advice –** The pilot ecosystem plan needs to be shared and communicated to different audiences including the Scientific Committees and the ICCAT and IOTC Commission. A communication strategy is proposed for sharing results in a logical and strategic way. This ecosystem plan also identifies and proposes a series of products and activities that could be developed to better link ecosystem science and fisheries management advice

7.3. Pilot ecosystem plans

The pilot ecosystem plan for the Tropical Ecoregion of the Atlantic Ocean can be found in Appendix 5.1, and the pilot ecosystem plan for the Temperate Ecoregion of the Indian Ocean can be found in Appendix 5.2. Here, we briefly summarize the main findings and reflexions developing them. Concrete recommendations to foster the development, use and implementation of ecosystem plans in ICCAT and IOTC with indicative timelines can be found under Task 7 (section8 of this document).

7.4. **Main findings and** reflexions **from developing the two pilot ecosystem plans.**

- While the ecosystem plans have been developed for ecoregions with well-defined geographic boundaries, these boundaries should be relaxed when developing ecosystem analyses and assessments to allow understanding of the external pressures, impacts and ecosystem processes governing the ecoregions. However, the ecosystem-level management advice should be focused on the most pressing and challenging needs of each ecoregion.

- Ecosystem plans should be driven by objectives centered on the ecosystem, and not on individual species or stocks. ICCAT and IOTC have not developed and adopted their own ecosystem policy which should include a well-defined ecosystem vision statement, ecosystem goals and an implementation strategy to achieve them. These pilot plans include examples of ecosystem vision statements adopted by other organizations and programs and highlight their commonalities to guide the Commission on what key principles should be included when developing its own.

- The ecosystem overviews developed have facilitated the synthesis and integration of all relevant and available ecosystem information for each ecoregion, so it can be better communicated to the Commissions. It is importat to highpoint that each ecoregions is characterized by unique biogeographic and oceanographic characteristics, they are characterized by different tuna and billfish communities and different type of fishing fleets exploiting them. The bycatch species and the extent of the impacts of fisheries on bycatch species also differ by ecoregion. Next, we present the main highlights derived from the ecosystem overviews which are shared largely by both ecoregions.

    - The selective extraction of species by fishing is the primary manageable pressures by ICCAT and IOTC causing an effect on the state of the ecosystem. The ICCAT and IOTC Commission does monitor the extent of fishing pressure and effort to support the design of sound management strategies to manage principally their main targeted species (principal market tunas, billfishes and some sharks), and to a limited extent to design management strategies that minimize and avoid undesired impacts on bycatch species, foodwebs and the broader the ecosystem. Despite the Commissions effort to monitor fishing effort, there have been limited resources and capacity to map the spatio-temporal patterns of fishing activity and fishing pressure (across all the fleets and by area at relevant spatial scales), which limits the potential of defining area-based plans to minimize regional impacts of fishing on main target species, on vulnerable taxa (e.g. avoid localized depletions), and habitats of ecological significance.

    - The production and dumping of marine debris derived from fishing activities is another manageable pressure by ICCAT and IOTC which can cause an effect on the state of the ecosystem. There have also been limited resources and capacity to monitor and minimize the extent and magnitude of marine debris produced by ICCAT and IOTC fisheries.

    - Changes in the environment and climate are the main pressures non-susceptible to ICCAT and IOTC management. The ICCAT and IOTC Commissions are not monitoring or accounting for the effects of the environment and climate on ICCAT and IOTC fisheries and species, with some few exceptions.

  - The state of the principal market tunas (and few billfish, shark and neritic species), which are the main targeted and retained species in ICCAT and IOTC fisheries, are relatively well known and monitored. There remain a large number of retained fish species for which their state is unknown. Furthermore, the state of the large majority of non-retained species including sharks, marine turtles, seabirds and marine mammals are also poorly known and monitored.

  - The impacts of ICCAT and IOTC fisheries on the community structure and marine foodweb also remain poorly monitored and understood.

  - Habitat of ecological significance, which might include areas used by species for spawning grounds and migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate in a particular time, are also poorly monitored and understood in ICCAT and IOTC.

- The conceptual ecosystem models developed for each ecoregion, which identify and connect all the relevant ecosystem components, revealed those ecological interactions ICCAT and IOTC should be monitoring in order to ensure the conservation and sustainable management of all its fisheries and avoid undesired changes of ecosystem state. A total of 14 relevant ecological interactions were identified in the ICCAT Tropical Ecoregion, while 10 ecosystem interactions were identified for the Temperate Ecoregion. The broad ecosystem interactions identified were very similar in each ecoregion, however the type of fisheries operating in each ecoregion were different. The main species exploited by ICCAT and IOTC fisheries and the species impacted by those fisheries were also different in each ecoregion. The smaller number of interactions identified in the Temperate ecoregion is due to the smaller number of major fisheries operating in Temperate waters (purse seiners are not a major fishery in the temperate region).

- All the ecological interactions identified in each ecoregion are treated at this stage as equally important to monitor changes in the state of the ecosystem and avoid undesired ecosystem states. However, some interactions might be more relevant than others, either because they are more prevalent and have a higher probability to occur or because their level of impact might be relatively higher which might be imposing a high cost to the fishery or the ecosystem. We expect that the relative importance of these interactions will also differ by ecoregion. In the future, an ecosystem risk assessment should be conducted to determine the degree of importance of each interaction to the Commission, so the Commission can prioritize research, management actions and make choices between different risks at the ecoregion level. Regulatory and socio-economic interactions should also be identified in future revised ecosystem plans.

- For each of the ecological interactions identified, candidate management objectives and ecosystem indicators were proposed to monitor all the ecosystem interactions. The potential data sources and research needs for the future development of the ecosystem indicators were also discussed. Last, the risks of not monitoring each of these interactions were described, as well as how the ICCAT and IOTC Commissions are currently addressing (or could be addressing) these risks. Next, we present the main highlights derived from developing the candidate list of indicators and their potential future development which are shared largely by both ecoregions.

    - ICCAT and IOTC only routinely monitor a small number of the proposed ecosystem indicators. Many ecosystem indicators could potentially be developed in the short term using the data available in ICCAT/IOTC, using the data collected by the observer programs, and using external data sources. Ecosystem indicators, for which data are not currently and readily available for their estimation, are still included in the proposal, to guide future data collection and research efforts.

    - The future development of the ecosystem indicators has to overcome some challenges. Currently catch, effort and size data with explicit spatial information is only available for a small number of ICCAT and IOTC species, which hampers the regional development of many of the ecosystem indicators proposed.

    - Many of the proposed indicators rely on data collected by the ongoing regional and national observer programs and on the level of coverage of these programs. The data derived from these programs are currently underexploited for the development of ecosystem indicators. This is due in part because the observer data held by the ICCAT and IOTC Secretariat at their current state are of no use to develop any of the ecosystem indicators proposed in this project. These is because the spatial and temporal coverage, the aggregation levels, and quantity of the data received by the ICCAT and IOTC Secretariat is poor. Alternatively, the observer data collected by National observer programs of each CPC offer an opportunity to estimate many of the ecosystem indicators proposed. Joint-CPC projects are recommended for the development of ecosystem indicators to understand the cumulative effects of fishing and climate on marine ecosystems and to override the confidentiality rules of the data.

  - There have been limited resources and capacity in ICCAT and IOTC to conduct end-to-end ecosystem modelling to better understand the direct and indirect effects of fishing and environment on the population dynamics of tuna species and marine foodwebs. The Temperate Ecoregion in the Indian Ocean lags behind the Tropical Ecoregion in the Atlantic Ocean in terms of developing such ecosystem modelling analyses. Both ICCAT and IOTC lag behind other tuna RFMOs (WCPFC and IATTC) in terms of developing such ecosystem modelling analyses. Many of the ecosystem indicators proposed also rely on the development of ecosystem models since they are model-based. On one side, ICCAT and IOTC should promote and support studies of fish diet, feeding ecology and food habits to support the development of ecosystem models and better understand trophic interactions and foodweb dynamics in marine ecosystems. On the other side, ICCAT and IOTC should promote and support the development and use of a suite of modelling techniques (from multispecies models, size-based community models, end-to-end ecosystem models, bioenergetic models).

- The identified interactions and proposed indicators intend to be an interim step towards developing comprehensive regionalized ecosystem status assessments at the ecoregion level. Ecosystem status assessments aim to provide an integrated overview of the health and status of the ecosystem in a given region. Ecosystem status assessments can be a powerful tool to inform fisheries and marine resource decision making and advice for several reasons: (1) they can provide early signals of the impacts of pressures (fishing, climate) on ecosystem components that might warrant management interventions (2) they can spur new understanding of the connections between ecosystem components by bringing together the results from a blend of data observations, data analysis, models and indicators; (3) they can bring ecosystem indicators and research efforts that are not easily incorporated into single species stock assessments to the attention of managers, and (4) they can provide evidence on the efficacy of past management measures.

- The last core element of the ecosystem plans is a well-defined communication strategy to disseminate them. The pilot ecosystem plans need to be shared and communicated to different audiences including the ICCAT SUBECO, IOTC WPEB, the Scientific Committees and the Commissions.

- The core elements developed in each ecosystem plan should be seen as preliminary as they need to be openly discussed with the Scientific Committees and the ICCAT and IOTC Commissions. Furthermore, the elements developed should not be considered as a complete list. Future revisions of the pilot ecosystem plans could also envision to include additional elements. For example, it could include a section with management actions needed to meet each ecosystem objective, a section on skills and capabilities to support the implementation of the plan, as well as identify continuous financial support to ensure its implementation, to name a few.

- At this stage, the pilot ecosystem plans seek to create awareness about the need for ecosystem planning, iniciate discussion about what elements need to be part of a planning process, and intents to be the foundation for future participatory and consultative ecosystem plans in the ICCAT and IOTC Convention Areas.

7.5. Difficulties and future work expected

We were not able to examine and test the feasibility of NEAT (Nested Environmental Assessment Tool) in our pilot ecosystem plans because this requires having ecosystem indicators available for each ecoregion, which were not compiled or calculated as part of this project. In the future, it would be interesting to evaluate the feasibility of calculating some of the selected indicators with the objective of testing the NEAT tool to assess the ecological status in the ecoregions.

8. TASK 7 - IDENTIFY ISSUES AND GAPS OF INFORMATION, PROVIDE RECOMMENDATIONS TO FACILITATE THE IMPLEMENTATION OF THE EAFM PLANS FOR FISHERIES OF HMS AND DEFINE FUTURE ACTIVITIES

8.1. Sub-task 7.1 – Concrete recommendations to foster the development, use and implementation of ecosystem plans in ICCAT and IOTC with indicative timelines

The Consortium proposes a series of recommendations to foster the development, use, and implementation of ecosystem plans in ICCAT and IOTC, and in particular the pilot Ecosystem Plans for the Tropical Ecoregion in the Atlantic Ocean and the Temperate Ecoregion in the Indian Ocean developed under Task 6 (Table 8.1). Along each recommendation an indicative timeline and milestones are also proposed.

Table 8.1 Recommendations to foster the development, use and implementation of ecosystem plans in ICCAT and IOTC

Recommendations/action item	Timing	Milestones
The pilot Ecosystem Plans should be presented, discussed and reviewed by the ICCAT Sub-Committee on Ecosystems (SUBECO) and IOTC Working Party of Ecosystems Bycatch (WPEB) and their Scientific Committees (SC) to evaluate its usefulness and promote further steps.	Short-term	Ecosystem plan presented at the ICCAT SUBECO 2019 meeting and IOTC WPEB 2019 meeting.
The regionalisation of ecosystem plans, including its potential benefits and drawbacks, need to be further discussed and reviewed by the SUBECO and WPEB and their SC.	Short-term	Ecosystem plan and implications of regionalising the ecosystem plan presented at the ICCAT SUBECO 2019 meeting and IOTC WPEB 2019 meeting.
Future versions of an ecosystem plan should incorporate an ecosystem risk assessment, which will become a cornerstone of the plans. An ecosystem risk assessment will determine the degree of importance of each of the interactions and issues identified in the pilot ecosystem plans. It will help prioritise the main issues and research actions that need to take place to avoid unwanted risk through appropriate management actions to the Commission.	Short-term	ICCAT and IOTC request that their SCs develop formal ecosystem risk assessments to be developed as part of the pilot ecosystem plans.

The ICCAT SUBECO and IOTC WPEB should continue the development of ecosystem assessments (and ecosystem report cards). The on-going assessments in ICCAT and IOTC can benefit from the current ecosystem plan and vice versa and both efforts should be coordinated. The pilot ecosystem plan identifies and proposes candidate indicators that can inform the development of ecosystem assessments in ICCAT and IOTC.	Short-term	The ICCAT SUBECO and IOTC WPEB develops the first version of an ecosystem assessment and ecosystem report card to be presented to the Commission.
An EAFM engagement strategy and standardised EAFM road map materials for widespread use should be developed to communicate the importance of ecosystem planning and ecosystem assessments to the Commission.	Short-term	SC to develop outreach materials for Commission.
ICCAT/IOTC Commissions need to agree on an ecosystem vision, goals, and objectives for the pilot Ecosystem Plans (or any ecosystem plan). The Commission should request that the SCs develop a formalized Ecosystem Plan(s).	Medium-term*	ICCAT and IOTC Commission agree on vision, goals, and objectives for the Ecosystem Plans. ICCAT and IOTC request that their SCs develop a formal ecosystem plan.
An Ecosystem Plan Team should be created in ICCAT and IOTC to oversee the development of the ecosystem plan(s) and provide recommendations and guidance to the SC and the Commission.	Medium-term	Ecosystem Plan Team created by the SC or WPEB/SUBECO.
Future versions of an ecosystem plan should identify how the ecosystem plan interacts with other Commission processes as well as other SC activities and research programs.	Medium-term	Commission to ask the SC to develop a formal ecosystem plan.
Future version of an ecosystem plan should consider including a section on skills and capabilities to support the implementation of the plan, as well as identify continuous financial support to ensure its implementation.	Medium-term	Commission to ask the SC to develop a formal ecosystem plan.
An Ecosystem Plan Coordinator/Analyst at the ICCAT and IOTC Secretariat would facilitate the development of many of the activities proposed here.	Medium-long	Ecosystem Plan Coordinator/Analyst hired at the ICCAT and IOTC Secretariat
Future versions of an ecosystem plan should consider including socio-economic and	Long-term	Socio-economic Working Group created at ICCAT

governance aspects of fisheries in the region covered by the plan. Until the socio-economic and governance considerations are addressed properly, an ecosystem plan will only be partially guiding the operationalisation of EAFM in the covered region.		and IOTC. Short term consultancy acquired to develop a strategy to develop the socio-economic components of an ecosystem plan. Each CPC develops a National Plant report on economic and socio-economic considerations of their tuna-and tuna-like fisheries.

* A formal Ecosystem Plan should not be started by the SC until more guidance is received from Commission on vision, goals and objectives.

8.2. Sub-task 7.2 – Identification of main issues and gaps of information that are hindering the development of <u>ecosystem plans</u> including <u>ecosystem overviews</u> and <u>indicator-based ecosystem assessments in ICCAT and IOTC</u>

The Consortium identified the following main issues and gaps in information that are jeopardizing the ability to develop comprehensive ecosystem plans including ecosystem overviews and indicator-based ecosystem assessments on a regional basis.

- Data reporting (and its quality) by CPCs of basic fisheries statistics (catch, effort and size data), which forms the basis for all stock assessments conducted in ICCAT/IOTC, as well as the basis for developing many of the proposed ecosystem indicators, might hinder development of ecosystem assessments. Estimation of many of the proposed indicators rely on fisheries data that have explicit spatial information to support regional ecosystem assessments and area-based ecosystem indicators. While data quality (its temporal and spatial resolution) is relatively good for some of the ICCAT/IOTC species (for which data-rich stock assessments are available), the temporal and spatial resolution for the large majority of ICCAT/IOTC species, as well as other species interacting with ICCAT/IOTC fisheries is incomplete and poor.
- The coverage and stratification of observer data collected by National observer programs submitted to and held by the ICCAT/IOTC Secretariat is partial (low coverage and submission of aggregated data), hindering any attempts to quantify the cumulative impacts of fisheries on vulnerable taxa (sharks, seabirds, marine mammals and sea turtles). Reporting of the level of interactions and mortality rates between ICCAT/IOTC fisheries and vulnerable taxa continues to be low and very incomplete. Observer data held by the Secretariat at their current state are

of no use to develop any of the ecosystem indicators proposed in this project since the spatial and temporal coverage, the aggregation levels, and quantity of the data received is poor.

- Alternatively, the observer data collected by National observer programs of each CPC offer an opportunity to estimate many of the ecosystem indicators proposed. However, we found that these observer datasets are currently underexploited by each CPC to support the development of ecosystem indicators and ecosystem assessments. The level of observer coverage continues to be low in many fisheries, which in many cases limits the representativeness of data collected in these programs to be used for the development of ecosystem indicators and ecosystem assessments. For those cases where the level of observer coverage is large (e.g. 100 % observer coverage of the EU Purse Seine fleet), the temporal coverage with 100% observer coverage is not long.
- There have been limited resources and capacity to conduct end-to-end ecosystem modelling to better understand the direct and indirect effects of fishing and environment on the population dynamics of tuna species and marine food webs in the ICCAT/IOTC region. ICCAT/IOTC lag behind other tuna RFMOs (IATTC/WCPFC) in developing such modelling exercises.
- There have been limited resources and capacity to monitor baitboat and gillnet fisheries, the type of species and quantities interacting with baitboat and gillnet fisheries.
- There have been limited resources and capacity to estimate the potential impacts of climate change on ICCAT/IOTC species (distribution, abundance, phenology, etc.) and the implications for fisheries, fishing communities, and food security.
- There have been limited resources and capacity to identify and map habitat of ecological significance for the main ICCAT/IOTC species and vulnerable species, which are important for determining the biological and ecological features of communities of special importance and determining areas of high biological value or diversity. Knowledge of the spatial extent of fishing impacts on these habitats is also needed to inform management strategies to minimize and avoid fishing impacts on these habitats.
- There have been limited resources and capacity to map the spatio-temporal patterns of fishing activity and fishing pressure (across all the fleets and by area), which limits the potential of defining area-based plans to minimize regional impacts of fishing on main target species, on vulnerable taxa (e.g. avoid localised depletions), and habitats of ecological significance.

- There have been limited resources and capacity to monitor and minimize the extent and magnitude of marine debris produced by ICCAT/IOTC fisheries.

8.3. Sub-task 7.3 A proposal of future actions and research activities to strengthen the implementation of an EAFM in ICCAT/IOTC

The Consortium proposes a list of actions, research activities and capacity building activities that could strengthen the implementation of an EAFM in ICCAT/IOTC. These items are organised by different themes and areas that need to be strengthened in order to support the development of future ecosystem plans, indicator-based ecosystem assessments, and ultimately, create better links between ecosystem science and management.

Proposed actions and research activities to advance the understanding of ecosystem processes:

- ICCAT/IOTC should ensure compliance, and enhance the minimum requirements, in the collection of basic fisheries statistics (catch, effort and size data) which should be spatially explicit for a larger number of ICCAT/IOTC species and other species interacting with ICCAT/IOTC fisheries (whether retained and non-retained by the fisheries). Currently catch, effort and size data with explicit spatial information is only available for nine ICCAT and 5 IOTC fish species.
- ICCAT/IOTC should explore the potential of using data derived from the National observer programs to develop some of the ecosystem indicators proposed, as well as support joint collaborative analysis among CPCs to share confidential data, and thus develop ecosystem indicators and assessments to monitor the cumulative impacts of fisheries on different components of ecosystem on a regional basis.
- Many of the proposed indicators rely on data collected by the observer programs and on the level of coverage of these programs. ICCAT/IOTC should increase further and progressively the level of observer coverage in all fisheries to improve the representativeness of the data collected in these programs. While some purse seine fisheries are already achieving a 100% observer coverage on a voluntary basis, this should be made mandatory basis to all large-scale purse vessels. For longliners, while the minimum level of observer coverage is only 5%, many CPCs are not even achieving this level. The level of observer coverage in longliners should be increased further and progressively (for example in 2017 the SCRS recommended to increase the minimum to 20%) to improve the reliability of the data collected in these programs.

- ICCAT/IOTC should encourage the use of electronic monitoring systems, while complementing the human observer programmes, to increase the observer coverage and development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner.
- ICCAT/IOTC should create a revised list of fish and non-fish species (not included in the ICCAT/IOTC mandate) interacting with ICCAT/IOTC fisheries and a prioritise list for monitoring purposes.
- ICCAT, contrary to IOTC, does not require monitoring of the number of interactions between ICCAT fisheries and marine mammals anymore. ICCAT should consider making mandatory again the collection of marine mammal interactions and mortalities and be reported in the ST09forms.
- ICCAT/IOTC should monitor closely the type of species and quantities interacting with baitboat fisheries and the type of species and quantities used as baitboat in these fisheries and promote the development of observer programs in baitboat fisheries.
- ICCAT/IOTC should identify relevant gillnet fisheries and regions where these fisheries operate, monitor closely the type of species and quantities interacting with gillnet fisheries, and promote the development of observer programs in gillnet fisheries.
- ICCAT/IOTC should promote and support the development and use of a suite of modelling techniques (from multispecies models, size-based community models, end-to-end ecosystem models, bioenergetic models) to increase our existing knowledge of the impacts of fisheries and the environment on the structure and functioning of marine ecosystems, as well as for producing both tactical (short-medium term) and strategical (long-term) ecosystem advice for management.
- ICCAT/IOTC should promote and support studies of fish diet, feeding ecology and food habits to support the development of ecosystem models and better understand trophic interactions and foodweb dynamics in marine ecosystems.
- ICCAT/IOTC should make a better use of existing external databases, for example remote sensing products to monitor ecosystem productivity, or the automatic identification system (AIS) products to monitor fishing activity at finer spatio-temporal scales.
- ICCAT/IOTC should set a habitat research agenda and continue supporting habitat studies and mapping of habitats of ecological significance for ICCAT/IOTC

species and other vulnerable taxa. It should make a better use of the data derived from the National observer programs and from the ICCAT/IOTC tagging programs to identify habitat of ecological significance for ICCAT/IOTC species and other vulnerable taxa and encourage cross-taxa habitat studies. Habitat utilization and preferences are generally poorly known for most ICCAT/IOTC species and other vulnerable taxa and not used to inform fisheries management.

- ICCAT/IOTC should promote and support assessments of the impacts of climate change on ICCAT/IOTC species (impacts on distribution, abundance phenology, etc.) and evaluate the socio-economic implications of these impacts for national economies and food security in order to inform mitigation and adaptation strategies to climate change.
- ICCAT/IOTC should continue supporting post-release mortality studies on vulnerable taxa.

Proposed actions and research activities to prioritise vulnerabilities and risks of ecosystems and its components

- ICCAT/IOTC should focus on identifying and monitoring closely those fish and non-fish species most vulnerable to ICCAT/IOTC fisheries identified in the ecological risk assessments. Monitoring of priority species should be done by fisheries and by area, since the impacts of ICCAT /IOTC fisheries on species vary by fishery and region.
- While ICCAT/IOTC has conducted several ecological risk assessments for some gears and taxonomic groups, there are still missing for some gears and taxonomic groups. Ecological risk assessments are missing for (1) assessing the risk of gillnet fisheries on all major taxonomic groups, (2) assessing the risk of pole and line fisheries on all major taxonomic groups, (3) assessing the risk of fisheries on marine mammals (in the case of ICCAT), (4) assessing the risk of purse seine (in the case of ICCAT) and gillnet fisheries on shark species. It is pivotal that the ecological risk assessments are spatially explicit.
- ICCAT/IOTC should conduct a vulnerability climate risk assessment to identify those ICCAT/IOTC fish species potentially most-vulnerable to climate change
- ICCAT/IOTC should conduct habitat risk assessments to identify those areas known to serve as important ecological functions for multiple species groups
- ICCAT/IOTC should also conduct a more systematic and integrative ecosystem risk assessment to identify and prioritise those pressing issues arising from the assessments of the different ecosystem components (issues for the different

fisheries, bycatch species, climate interactions, etc.). An ecosystem risk assessment aims to quantify the risk of each ecosystem interactions (interaction between fisheries, species and climate) based on two sources of information, their probability of occurrence as well as the level of impact on the current ecosystem state. Defining these interactions and their relative importance and risk in the system, can provide both Commissions with a tool to prioritize potential issues, make choices between different risks and trade-offs or take actions to avoid unwanted risk through appropriate management actions.

Proposed actions and research activities to address trade-offs within the ecosystem and incorporate ecosystem considerations into management advice

- ICCAT/IOTC should continue supporting the development of ecosystem assessments currently being undertaken by the ICCAT Sub-Committee on Ecosystems and IOTC Working Party in Ecosystem and Bycatch. The purpose of ecosystem assessment is to monitor climate, environmental, and fishing effects on the state of the different ecosystem components and flag issues to the Commission. This EU project provides guidelines and proposes candidate indicators for the development of such ecosystem assessments and aims to contribute to ICCAT/IOTC process and efforts in this direction. It is also important to stress that these ecosystem assessments should be conducted by area, since fisheries, species, and environmental conditions differ across regions within the ICCAT/IOTC convention area, and therefore the issues emergent in each area might require different management responses.
- ICCAT/IOTC should support the development of analytical EAFM tools that enable the visualisation and assessment of trade-offs within the ecosystem. These include ecosystem modelling tools, visualisation tools (ecosystem report cards) and decision support tools.
- ICCAT/IOTC should support the development of Management Strategy Evaluation analysis for harvest strategies that assess trade-offs and explore harvest control rules that incorporate ecosystem considerations (e.g. climate impacts, bycatch impacts) to test robust ecosystem level strategies.
- ICCAT/IOTC should continue supporting further research and testing of more efficient mitigation methods to reduce bycatch on vulnerable taxa (e.g. shark deterrent measures, hook pods to minimize seabird interactions, biodegradable FADs, etc..). In addition, improve the knowledge of post-release mortality of vulnerable and non-retained species.

- ICCAT/IOTC should support the establishment of protocols for data collection and monitoring of the lost fishing gear of its fleets, promote preventive measures such as the use of technology to track gear position for their retrieval and reduce gear loss, disincentive the abandonment and discarding of fishing gear at sea, and establish port reception facilities for recycling unwanted gears.

Potential synergies with other on-going research activities outside ICCAT/IOTC

Finally, the Consortium identified synergies with other on-going activities outside ICCAT/IOTC that also seek to foster the implementation of the ecosystem approach in tuna RFMOS. The Common Oceans–Tuna Project (www.commonoceans.org), which is co-funded by the Global Environmental Fund and coordinated by FAO, is seen as an opportunity to improve global tuna fisheries governance through an effective implementation of an ecosystem approach. One of the tasks is to support development and implementation of ecosystem evaluations and plans in tuna RFMOs. There has been little progress on this task since the inception of this project as this has not been a priority in tuna RFMOs (FAO, 2017). However, the project supported a joint tuna RFMO workshop to review and discuss approaches used by each tuna RFMO to operationalise an EAFM and is planning to organize a 2nd joint t-RFMO EAFM meeting in 2019. We envisage there will be more opportunities to continue these joint discussions and coordinate efforts across tuna RFMOs to develop ecosystem plans and ecosystem assessments.

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10. APPENDIX 1.1 - DEFINITION OF ECOSYSTEM TERMINOLOGY USED IN FISHERIES MANAGEMENT

The recognition of the need to consider multiple human activities (not just fisheries) in the management and conservation of marine ecosystems has been described using different terms including Ecosystem-Based Management (EBM) and the Ecosystem Approach (EA). The importance of incorporating ecosystem considerations into fisheries management has also been increasingly recognized in recent years, and a number of terms have been used to refer to it. Commonly used terminologies include Ecosystem-Based Fisheries Management (EBFM), Ecosystem Approach to Fisheries (EAF), and Ecosystem Approach to Fisheries Management (EAFM). These terms are often used interchangeably and there is not a universally accepted definition for each of them. Several attempts have been made to develop a single definition and articulate the differences among the ecosystem related terminologies. This section provides an overview of commonly used terms and definitions including relevant initiatives and their links to the single species approach.

Ecosystem Approach and Ecosystem-Based Management:

A single definition of "Ecosystem-Based Management" is not agreed upon and the term is frequently used interchangeably with the term "Ecosystem Approach" (CBD, 2004). A number of definitions are available (see Table 1), but the main thread running through those definitions is the recognition of the links between biotic and abiotic systems and the need to consider multiple human activities and sectors present in the ecosystem.

Table 1 Example of different definitions used to describe the Ecosystem Approach and Ecosystem-based management

Convention on biological Diversity (CBD, 2004): **The ecosystem approach** is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. […] The ecosystem approach requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning.

OSPAR Commission[14] :

The ecosystem approach is defined as the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity.

U.S. Commission on Ocean Policy, 2004:

Ecosystem-based management looks at all the links among living and non-living resources, rather than considering single issues in isolation. This system of management considers human activities, their benefits, and their potential impacts within the context of the broader biological and physical environment. Instead of developing a management plan for one issue (such as a commercial fishery or an individual source of pollution), ecosystem-based management focuses on the multiple activities occurring within specific areas that are defined by ecosystem, rather than political boundaries.

Communication Partnership for Science and the Sea (McLeod *et al.*, 2005):

Ecosystem-based management *is an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors.*

[14] See Appendix I for list of acronyms used in the report. http://www.ospar.org/about/principles/ecosystem-approach, last access: 03/2017

A fisheries-focused ecosystem approach:

The need to consider the effects on the entire ecosystem for decision-making is the overarching principle underpinning efforts to include ecosystem considerations into fisheries management. In line with the broader ecosystem approach, the EBFM approach or EAFM focuses on the fisheries sector and views fisheries as systems that consist of linked biophysical and human sub-systems with interacting ecological, economic, social, and cultural components. Regardless of the terms used, both EBFM and EAFM consider humans as an integral part of the ecosystem.

That integration is also the focus of the FAO definition of EAFM, but other definitions also stress the balance that EAFM strives to achieve between ecological and human well-being. Some of the definitions used to describe the incorporation of ecosystem considerations into fisheries management are shown in Table 2.

Table 2 Definitions describing the incorporation of ecosystem considerations into fisheries management

FAO (Staples *et al.*, 2014) *EAFM is the ecosystem approach applied to the fishery sector and a way to implement sustainable development principles for the management of fisheries. With respect to fisheries, the EA has two dimensions: a vertical dimension of application of the EAF and a horizontal dimension of integration of fisheries with other sectors into a holistic management framework.*
From UNEP 2011[15]: *Ecosystem-based fisheries management or EBFM (often referred to as an "ecosystem approach to fisheries", EAF), considers the status of commercial fish stocks and ecosystem components that interact with those stocks*
From Lenfest report[16]: *EBFM is as a holistic, place-based framework that seeks to sustain fisheries and other services that humans want and need by maintaining healthy,*

[15] UNEP (2011): Taking Steps toward Marine and Coastal Ecosystem-Based Management An Introductory Guide

[16] Lenfest report, APPENDIX A: Concepts and principles for marine ecosystem based fisheries management, http://www.lenfestocean.org/~/media/assets/extranets/lenfest/building_effective_fishery_ecosystem_plans_appendix_a.pdf

productive, and resilient fishery systems.
NOAA Fisheries (2013)[17] *Ecosystem-based fishery management recognizes the physical, biological, economic and social interactions among the affected components of the ecosystem and attempts to manage fisheries to achieve a stipulated spectrum of societal goals, some of which may be in competition.*
EU Regulation (2013)[18] Ecosystem-based approach to fisheries management means an integrated approach to managing fisheries within ecologically meaningful boundaries which seeks to manage the use of natural resources, taking account of fishing and other human activities, while preserving both the biological wealth and the biological processes necessary to safeguard the composition, structure and functioning of the habitats of the ecosystem affected, by taking into account the knowledge and uncertainties regarding biotic, abiotic and human components of ecosystems.

Application of the ecosystem approach into a single sector implies narrowing in perspective and that is the case when applying ecosystem considerations into fisheries management. The UNEP (2011) has articulated that distinction highlighting the importance of ensuring that the two approaches (full EBM and ecosystem approach for a single sector) are not confused or that a sector-based approach does not slow down efforts to achieve full, cross-sectoral EBM (UNEP, 2011):

"Adopting environmentally-oriented management measures in just one sector falls short of the integrated goal-setting and management that full EBM entails, and which is needed to ensure the sustainability of a complete range of ecosystem services. As such, although EBFM may be an important component of successful EBM, it does not equal EBM in itself"

Within one sector, i.e. fisheries, the level of incorporation of ecosystem elements could vary, which has led to work looking specifically into defining the different levels of

[17] http://www.nmfs.noaa.gov/sfa/CMS_DEV/Councils/Training2013/O_Ecosystem_Based_Mgmt.pdf

[18] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32013R1380&from=EN

application of the ecosystem approach to fisheries. NOAA Fisheries[19] defines 2 levels of Ecosystem Management in the fisheries sector:

a. *Ecosystem-Based Fisheries Management (EBFM) – has facets of both strategic and tactical decisions solely within the fisheries sector*
b. *Ecosystem Approach to Fisheries (EAF) – adds ecosystem factors into fisheries stock assessments for tactical management decisions*

Similarly, Link and Browman (2014) used the range of impacts considered in systems that cover fisheries to distinguish between different levels of Ecosystem-Based Management application. Those levels covered on one end ecosystem based applications that considered impacts on fish stocks only and extended to cover application that consider impacts on the full system of fisheries and stocks and impacts on all ocean-use sectors affected by and impacting on the fisheries sector (Table 3).

[19] https://www.st.nmfs.noaa.gov/ecosystems/ebfm/ebfm-levels

Table 3 Levels of application of EBM that include the fisheries sector (adapted from Link and Browman (2014))

Feature	**Level of EBM in fisheries sector**			
	EBM	**EBFM**	**EAF**	**Classical FM**
Sectoral focus	All	Fisheries	Fisheries	Fisheries
Focus of the biological hierarchy	All	Community	Stock/population	Stock/population
Evaluation processes used	Integrated ecosystem assessments	Integrated ecosystem assessments, fisheries sector focus	Integrated stock assessments	Stock assessments
Primary objectives of the approach	Address cross-sector trade-offs	Address fishery sector and living marine resource trade-offs	Delineate status of stock/s	Delineate status of stock
	Ascertain ecosystem goods and services	Ascertain ecosystem productivity	Ascertain stock productivity	Ascertain stock productivity
	Identify best mix of services across goods and services	Identify best mix of goods across fisheries and stocks	Identify levels of optimal stock production cognizant of ecosystem factors	Identify levels of optimal stock production
	Evaluate cross-sector cumulative effects	Evaluate within-sector cumulative effects	Evaluate within-stock effects of multiple drivers	Evaluate within-stock effects of fishing

This classification highlights the increasing breath of factors and links that need to be captured in the analysis as one moves from a single species approach to a more holistic view of the impacts and interdependencies of fisheries. At the same time, the transition from a single-species to an ecosystem approach allows for the identification of cumulative benefits and synergies that will not been considered or taken advantage of otherwise.

Unlike NOAA fisheries and other bodies that have attempted to define the different terms and differentiate among their use in practical applications, others organizations have just adopted one of them while recognizing the lack of widely agreed definition. For example, after some technical consultation, the term EAF was adopted by the FAO Technical Consultation on Ecosystem-based Fisheries Management held in Reykjavik. The Reykjavik Conference adopted the term EAF rather than EBFM for a series of reasons:

- there was some reticence to use the term EBFM because it was felt that it put emphasis on managing the ecosystem while the term EAFM was seen as one that put emphasis on taking ecosystem consideration into account in fisheries.
- the translation of EBFM into other languages had a much broader and unintended connotation.
- it had convenient parallels with the "Precautionary approach" to fisheries.

The FAO adopted term states that:

- *"the purpose of an* ***ecosystem approach to fisheries*** *is to plan, develop and manage fisheries in a manner that addresses the multiplicity of societal needs and desires, without jeopardizing the options for future generations to benefit from a full range of goods and services provided by marine ecosystems".*
- "*an ecosystem approach to fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries".*

Terminology for this study:

For the purpose of this study, we will use the term EAF (or EAFM) following the international adopted FAO definition. This definition is also very similar to the one adopted by the European Union (see Table 2). We also acknowledge the utility and follow closely the efforts by USA NOAA and other entities to define and differentiate among the different levels of applications for EBM for the fisheries sector as portrayed in Table 3 of Link and Browman 2014.

We reiterate that all these terms are underlying the same broad concept; they all recognize that fisheries management must deal with a full set of ecological consequences (not only impacts on the target species) and needs to understand the social and economic implications of all fisheries activities.

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11. APPENDIX 1.2 - GOOD PRACTICE CASE STUDIES IMPLEMENTING THE ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

The EAFM reviewed in different regions of the world

Progress towards achieving ecosystem-based objectives in fisheries management varies around the world. It can be measured by assessing the state of implementation of several ecosystem-based principles as well as how governmental and fisheries institutions have incorporated these principles in their formal adoption of management measures and mandates. Having an ecosystem-oriented mandate is important as it facilitates the development of an ecosystem-focused vision that can drive the transition to EAFM. The adoption of ecosystem objectives and building of consensus on priorities and aims of an EAFM are part of that vision and involves several players such as managers and stakeholders but there is less information on this process. On the other hand, the development of the scientific basis that supports the selection and implementation of ecosystem objectives are components of EAFM that tend to be covered in more detail in the scientific literature and in the activities of various fisheries institutions.

This section of the report focuses on reviewing case studies from around the world that have adopted and are implementing an EAFM. The case studies are at different stages of implementing an EAFM, which allows highlighting best practices and effective approaches from different states of the EAFM implementation process.

The review of those "good practices" examples will focus on four components of an EAFM: (i) a first evaluation of the conceptual phase (ecosystem planning), covering things like the overall vision of ecosystem management plans, its incorporation in the overarching policy or mandate, and management objectives, (ii) an evaluation of the scientific knowledge and ecosystem science available to characterise ecosystem challenges and support decision making, (iii) an evaluation of the implementing phase, and (iv) an assessment of their performance implementing ecosystem based principles. The following case studies have been chosen and are described below:

- Case study 1: Ecosystem management in Alaskan region in which fisheries are managed by the North Pacific Fishery Management Council in the United States

- Case study 2: Ecosystem management as viewed and implemented by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)
- Case study 3: Development of an EAFM in the context of the Northwest Atlantic Fisheries Organisation (NAFO)

A Summary Table (Table 4) also provides case-specific material for each of the four components of the EAFM reviewed.

In addition, we also briefly reviewed where ICCAT and IOTC stand in terms of implementing an EAFM using the same approach as the case studies. This was done to provide a global picture and understand where these two tuna RFMOs stand compared to the three role model case studies reviewed. A Summary Table has also been presented for the two tRFMOs (Table 5).

Case study 1: EAFM in the Alaska region

The North Pacific Fishery Management Council (NPFMC) is one of the eight regional Fisheries Management Councils in the USA established to manage fisheries within their Exclusive Economic Zone. The NPFMC manages fisheries in four large marine ecosystems in Alaska: the Eastern Bering Sea, the Aleutian Islands, the Gulf of Alaska and Arctic (Figure 1- from Zador et al 2016).

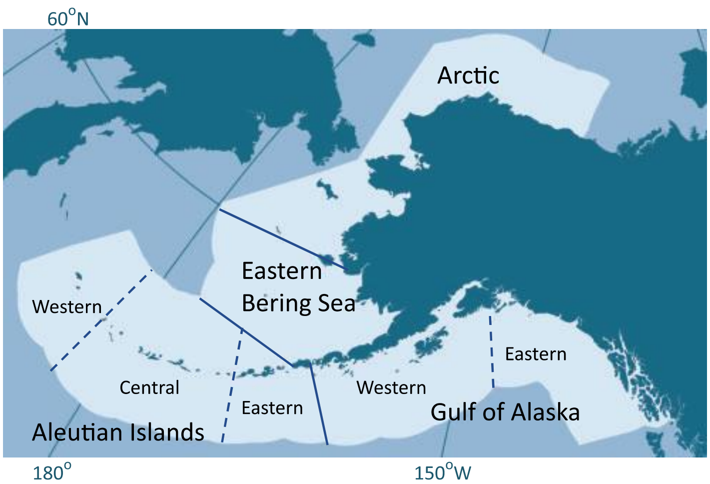

Figure 1. Large Marine Ecosystems in Alaska. The highlighted area shows the extent of the Exclusive Economic Zone (200 nautical miles) (Figure extracted from Zador et al. 2016).

The main commercial fisheries are comprised of groundfish fisheries (including species such as walleye pollock (*Gadus chalcogramma*), Pacific cod (*Gadus macrocephalus*), Arrowtooth flounder (*Atheresthes stomias*), sablefish (*Anoplopoma fimbria)*, rockfish fisheries (*Sebastes* spp.), the halibut fishery (*Hippoglosus stenolepis*), salmon fisheries and the crab and scallop fisheries (Zador *et al.*, 2016).

The most important and current fisheries issues in this region are bycatch control, discard policies habitat protections, protected species, and catch share allocations[20]

i) Ecosystem planning

The NPFMC established a Council Ecosystem Committee in the mid-1990s and it was reconstituted in 2005. It provides recommendations on EBFM, habitat and conservation issues[21]. In February 2014, the Council adopted an Ecosystem Policy which included a value statement, a vision statement, and an implementation strategy. This Ecosystem Policy also included long-term planning initiatives, fishery management actions, and science planning to support ecosystem-based fishery management[22].

The NPFMC has also adopted comprehensive ecosystem-based goals and objectives (conceptual and operational) for groundfish Fisheries Management Plans from 2004, which also ensures robust populations of marine species at all trophic levels, including marine mammals and seabirds (NPFMC, 2014). The multiple high level or conceptual ecosystem-related objectives include statements such as "preserve food web", "Incorporate ecosystem-based considerations into fisheries management decisions", "Avoid impacts to seabirds and mammals", "Avoid ecosystem overfishing". The NPFMC has also a strict policy of science-based decision-making and adherence to its own Statistical and Scientific Committee (NPFMC, 2014).

The NPFMC adopted the Aleutian Islands Fishery Ecosystem Plan (FEP) in 2007 (NPFMC, 2007b) and a FEP is also under development and consultation for the Bering Sea (Zador *et al.*, 2016). The objective of a FEP is to formalize and strengthen the delivery of ecosystem information to the Council, to provide a transparent tool for evaluating emergent trade-offs between conflicting management objectives (e.g. conservation and fisheries harvest), and to refine

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[20] https://www.npfmc.org
[21] https://www.npfmc.org/committees/ecosystem-committee/
[22] https://www.npfmc.org/management-policies/

fisheries advice under changing climatic conditions (NPFMC, 2007b). The FEP also intends to be an educational tool and a resource for the Council and any other interested stakeholders, which synthesizes the ecosystem context and highlights any relevant ecosystem observations for fishery management decisions (NPFMC, 2007a). The Aleutian Islands FEP included the development of a conceptual model of the ecosystem and a preliminary risk assessment, which allowed the identification of key ecosystem interactions, that examined the ecological and economic impacts of the different commercial activities on the region. This provided general guidance to the Council on priority areas and issues for management attention and further research and analysis (NPFMC, 2007b, a).

ii) Ecosystem science

There is a wide-range of scientific research, information, and tools that have been developed to support the implementation of EBFM in the Alaska region. This includes the designation of well-established ecoregions, the establishment of optimum yields limits for the groundfish fisheries to avoid ecosystem overfishing, the identification of vulnerable habitats and species, the development of ecosystem indicators and indicator-based report cards, and the development of ecosystem, multispecies and climate models to provide context for fisheries management decisions.

The Alaska Complex of Large Marine Ecosystems includes the following four ecoregions: the Gulf of Alaska, the Eastern Bering Sea, the Aleutian Islands, and Alaskan Arctic regions (**Error! Reference source not found.**). These regions are distinct and diverse in ecosystem structure and function as well as in terms of the range of human pressures (NOAA, 2016). Every year, an indicator-based report card is presented by the Ecosystem Committee to the Council which summarizes the status of top indicators selected by a team of ecosystem experts that best describes the ecological status of the four ecoregions. Each ecoregion has its own list of ecosystem indicators, as selected by the ecosystem experts, to provide ecosystem the context to support management decisions (Zador *et al.*, 2015). The indicator-based report card consists of a set of multi-year indicators with the objectives of illustrating their long- and short-term trends, and current status of different components of the ecosystem. The ecosystem report cards are also supplemented by a short bullet list with a small description of the ecosystem and a detailed ecosystem assessment. The ecosystem report cards in each region have been structured under different themes (e.g. variability theme to highlight the high variability of the region) and therefore are based on different indicators, driven mostly by the characteristics of the region, availability of data and knowledge of the team of experts involved in their development. Their development was the result of a long adaptive process and multiple versions as they were adapted to fit the management needs of the NPFMC (Zador *et al.*, 2016).

The NPFMC also adopted a 2 million tonnes multi-species optimum yield catch for the groundfish fishery in the Bering Sea and Aleutian Islands regions in 1981 to provide a precautionary limit on the harvest (NPFMC, 2014). This optimum yield was specified as 85 percent of the historical estimate of the Maximum Sustainable Yield (MSY) range for the target species. The specification of the optimum yield catch was influenced by several ecological, economic and social factors, also because it was recognized that the scientific knowledge was incomplete. This cap limits the cumulative groundfish removal in these regions in order to avoid ecosystem overfishing, and it has therefore limited the sum of total allowable catches for all species of groundfish. As a result, in order to avoid exceeding the 2 million tonnes cap, many stocks have been exploited below sustainable levels (Witherell *et al.*, 2000).

Many ecological and climate models have also been developed to increase the understanding of the structure, function and dynamics of the ecosystem in these regions. These include oceanographic models (Regional Ocean Modelling System); climate-enhanced food-web models such as Ecosim; bioenergetics-based multi-species catch-at-age models (CEATTLE); climate-enhanced ecosystem and single-species assessment models; bioenergetics models; climate-enhance recruitment models; and statistical analyses of ecological interactions to conduct ecosystem risk assessments and management strategy evaluations (NOAA, 2016).

Many of the adopted management measures and management decisions have been informed and based on these ecosystem science products. For example, in 2006 a combination of modelling outputs and ecosystem indicator status was used to inform and justify the reduction of quota for the Eastern Bering Sea walleye Pollock (Zador *et al.*, 2016)[23] .

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[23] The reduction account for the following ecosystem considerations: 1) The walleye stock assessment suggested a 19% decline in the stock and a northward shift of some of the stock into Russian waters, 2) the ecosystem indicators showed a large decline in zooplankton which are important pray for the walleye juveniles, 3) a multispecies model documented an increased predation by arrow tooth flounder on juvenile walleye Pollock.

With respect to habitat protection, all fishery management plans presented to the NPFMC include a description and identification of essential fish habitat, adverse impacts, and actions to conserve and enhance habitat. Adequate habitat is essential for maintaining the productivity of fisheries and some species, or some of their life stages, require a particular habitat for reproduction, feeding or shelter from predators. Therefore, maps of essential fish habitat areas are useful for understanding potential effects of human activities[24]. Vulnerable and threatened species have also been identified, and the NPFMC also seeks to minimize the impact of fisheries on these species through fisheries management measures.

Despite the huge proven efforts to develop sound-based ecosystem science to better link ecosystem information to fisheries management decisions, there still remain many knowledge gaps in the region (NOAA, 2016). Perhaps, one of the most pressing research needs is the development of explicit ecosystem thresholds that may be used to trigger a specific management response (e.g. as a percent decrease in quota) (Zador *et al.*, 2016). This will allow the NPFMC to advance from more strategic fisheries management into more tactical fisheries management.

iii) Implementation of the EAFM - Regulatory actions and activities supporting it

Several products, actions and activities are regularly conducted by the NPFCM to support the implementation of an EAFM in the Alaska region. An *Ecosystem Consideration Report* is prepared annually as part of the annual harvest specifications. The goal of this report is to provide stronger links between ecosystem research and fisheries management, and to spur new understanding of the connections between ecosystem components by bringing together the results of many diverse research efforts into one document. The Ecosystem Consideration Report includes the following sections: (1) Report Cards for each of the Large Marine Ecosystems (or ecoregion), (2) Executive Summary, (3) Ecosystem Assessment, and (4) Ecosystem Status and Management Indicators (Zador *et al.*, 2015).

The Indicator-based Ecosystem Report Cards summarize the status of top indicators that best describe the ecosystem and provide the ecosystem context of fisheries to the Council for management decisions every year (Zador *et al.*, 2015). One report card is prepared for each Large Marine Ecosystem. The indicators contained in the report cards are monitored and updated annually to ensure they are taken into

[24] https://www.npfmc.org/habitat-protections

consideration in fisheries management decisions. The Executive Summary section is used to provide a concise summary of the status of marine ecosystem in Alaska for a wide range of stakeholders including fishery managers, stock assessment scientist, and the public (Zador *et al.*, 2015). The Ecosystem Assessment section aims to synthesise historical climate and fishing effects in each Large Marine Ecosystem or ecoregion using information from the Ecosystem Status and Management Indicators, and the existing single species fisheries stock assessment reports. The ecosystem assessment also discusses a list of hot topics relevant for management on that year. In the future, the ecosystem assessment section would like to use a blend of data analysis and modelling to communicate not only the current status of the ecosystem but also possible future directions and scenarios (Zador *et al.*, 2015). The Ecosystem Status and Management Indicator section provides detail information and updates on the status and trends of several ecosystem components (physical, ecological and social relevant ecosystem components). These are used to provide early signals of direct human effects on the ecosystem components or monitor the efficacy of previous management actions on them (Zador *et al.*, 2015).

The Bering Sea FEP, which is currently under development and consultation, is evaluating the short- and long-term effects of climate change on fish and fisheries through management strategy evaluation under the guidance and participation of stakeholders (NOAA, 2016).

An effective communication strategy to communicate ecosystem science to fisheries managers has also arisen over the years and is based on a thorough understanding of the management system to prepare and adapt the ecosystem information to fit the management cycles and needs (Zador *et al.*, 2016). For example, every year the ecosystem information is presented to the Council before quota setting to allow for qualitative inclusion of ecosystem information into fisheries management decisions such as influence the quota decisions (Zador *et al.*, 2016).

iv) Performance evidence/evidence for implementation

There exist multiple examples and evidence where ecosystem science and research has been used and taken into account in fisheries management decisions and setting of management measures. Below we highlight a list of actions or management measures which have been informed by ecosystem science (NPFMC, 2014):

- A total cap for groundfish catches based on the productivity in the region.

- Individual Total Allowable Catches (TACs) for all species or species groups that ensure that the total cap of the region is not exceeded.

- The groundfish fishery is managed under harvest control rule with automatic rebuilding.

- The stock assessments include ecosystem considerations at least qualitatively.

- The TACs for the main commercial fish species, for example Pollock and Atka mackerel, which can be an important prey for marine mammals, have also been set to account for the predation needs of marine mammals. Their TACs can be spatially and seasonally divided into smaller subtacs to prevent prey removals from occurring and minimizing completion with marine mammals (Witherell *et al.*, 2000).

- There is no direct fishing on forage fish species such as capelin and krill in order to reduce the potential impacts of localised depletion of prey for the higher trophic levels they are prey for.

- Establishment of bycatch limits on some species of marine mammals and seabirds. For example there are incidental catch limits for Steller sea lions and the endangered short-tailed albatross (Witherell *et al.*, 2000).

- Gear modifications such as biodegradable panels, salmon/halibut excluding devices, seabird deterrents, elevated trawl sweeps), to minimise the impact of fisheries on bycatch species.

- Establishment of time/area closures and bottom trawl restrictions to protect essential fish habitats for fish, crabs and marine mammals.

v) Knowledge gained

Many lessons and best practices in operationalising an EAFM can been extracted from at least 20 year of experience linking ecosystem science with fisheries management in the Alaska Region by NPFMC (Warren, 2007; Zador *et al.*, 2015).

We briefly list a series of best practices summarized by Warren 2007 (Warren, 2007) that are widely respected in the North Pacific Region and have become international wide standards and benchmarks to implement EAFM:

Best practice 1 – Following scientific advice – The NPFMC has never authorized harvest over the limits set by scientists.

Best practice 2 – Setting precautionary catch limits –The TAC for the individual groundfish species when aggregated has never exceed the optimum yield cap for the entire groundfish fishery.

Best practice 3 – Development of a fishery ecosystem plans - The Council adopted the first fishery ecosystem plan for the Aleutian Islands ecoregion in 2007. A FEP is now under development and consultation for the Bering Sea ecoregion.

Best practice 4 – Establishment of habitat protection – The Council has established time/area closures and bottom trawl restrictions to protect vulnerable habitats.

Best practice 5 – Establishment of bycatch reduction – The Council has adopted gear modifications and time/area closures to minimise impact of fisheries on vulnerable and threatened species. The Council also has bycatch limits for vulnerable species and juveniles of commercial stocks.

Best practice 6 – Monitoring of removals by fisheries, including both target and incidentally caught species – Large vessels (> 125 feet) have 100% observer coverage to monitor removal by fisheries including both target and incidentally caught species. Vessels with 60-124ft have a required 30% observer coverage. Observer coverage for vessels smaller than 60ft is not mandated.

Best practice 7 – Protecting seabirds and marine mammals –The Council has adopted measures to reduce the entanglement of seabirds on longline and there are programs to remove lost gear from the beaches where it can entangle seabirds and marine mammals.

Best practice 8 – Protecting food webs – The Council has adopted several measures designed to prevent the depletion of prey needed by marine mammals and seabirds.

Best practice 9 – Incorporation of knowledge on environmental processes and climate change into fisheries management. The stock assessment of halibut is an example of incorporating information on the phase of the Pacific Decadal Oscillation to evaluate the robustness of the harvest strategy.

Best practice 10 – Research to improve understanding of climate effects on fish stocks and ecosystems – Climate-enhanced ecosystem and single species assessment models have been developed for predicting climate effects on marine species.

Best practice 11 – Research on ecosystem effects on fisheries – There has been a broad range of research on the effects of localized depletion of fish and other marine predators such as marine mammals, the impacts of fishing on trophic interactions, methods for reducing bycatch and entanglement of non-target species, etc.

Best practice 12 – Transparent and inclusive public discourse in fishery management – The Council, its Advisory Panel, and its Scientific Committee all operate in an open forum where many other organizations, scientist, and stakeholders can participate, provide inputs and review the data and analytic methods in the science.

Best practice 13 – Rigorous fishery enforcement of catch – The catch, bycatch and close-area regulations are strictly enforced and the penalties are heavy if ignored.

We also list a series of lessons summarized by Zador et al 2015 which can be used to inform future developments of ecosystem-based plans, research, activities, actions in tuna RFMOS and elsewhere.

Lesson 1 - Indicators should be based on ecological meaningful areas and should be chosen with the support of the Council or management body. Prior to 2010, in the process of developing a fisheries ecosystem plan for the Aleutian region, many indicators were chosen based on the Driver-Pressure-State-Impact-Response approach. Soon they realized many of the indicators were repetitive, did not integrate multiple interactions and did not characterize ecologically meaningful areas. Many of them were chosen at the fisheries management scale rather than a more ecologically-sound based scale. In short, this did not work well. Consequently, the Alaskan Fisheries Science Center scientists proposed a more regionalised approach to synthesise the information within more ecologically sound scales (Zador *et al.*, 2016). Now the indicators are based on Ecological Meaningful Areas (Large Marine Ecosystems in the Alaska region), and with the support of the Council, they have reduced the number of indicators to a succinct summary (ecosystem report cards) that are delivered to managers every year (Zador *et al.*, 2016).

Lesson 2 –Be flexible and adaptive in the process of selecting ecosystem indicators. In the process of developing ecosystem reports cards for each region in Alaska, the end products have been different despite using similar methods. In each region, the selection of indicators was influenced by geography, the extent of scientific/knowledge and data, and the particular expertise of the selection teams. This is good because it has allowed them to create adaptive products fitted to their needs.

Lesson 3 – Get to know well the annual management cycle to optimise the opportunity to incorporate ecosystem information into management decisions. To optimise the opportunity to incorporate ecosystem information into management decisions requires a good understanding of the management system in question. It is important to match temporal and spatial scales of the ecosystem information with the management process. For example, the ecosystem information needs to be updated every year in order to be useful. The ecosystem considerations report, which included the ecosystem status of several components of the ecosystem as well as potential concerns, is presented prior to the stock assessment harvest and quota recommendations to allow considering the ecosystem context. Therefore, scientists need to structure the ecosystem information to best fit the management cycle, and not the other way around.

Lesson 4- Ensure frequent communication and good visual presentation of ecosystem information for making it more useful. The indicator-based report cards have worked very well to communicate and synthesise ecosystem information to scientist, managers and other stakeholders. The frequent dialogue with managers and other stakeholders has allowed for adaptive products that are more useful at the end.

Lesson 5 – Involve diverse and multiple stakeholders in the process of selecting ecosystem indicators or in the development of any other ecosystem product which will be used to provide ecosystem context for management decisions. The creation of a “team of ecosystem experts” representing multiple stakeholders worked really well for the process of selecting relevant ecosystem indicators and developing the indicator-based report cards which had the support of the Council.

Case study 2: EAFM in CCAMLR

The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) is part of the Antarctic Treaty System and sets the framework for managing the exploitation of Antarctic marine living resources. The area under the Convention is the area South of the Antarctic Convergence (Figure 2).

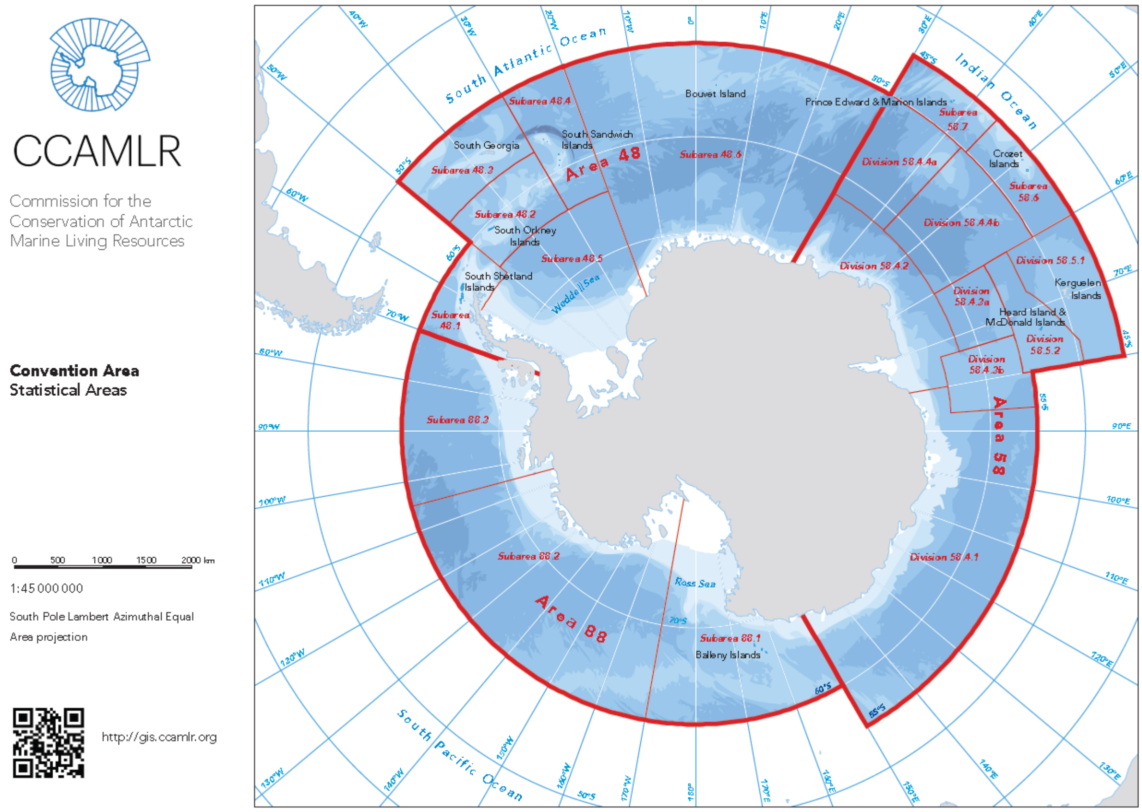

Figure 2 Map of the CCAMLR Convention Area. Last updated October 2017. www.ccamlr.org/node/86816

It was established by the Antarctic Treaty Consultative Parties to prevent over-exploitation of Antarctic krill which is a key prey species for the foodweb in the area. A number of other Antarctic species had already been overexploited including whale and seal populations that prey on krill. Therefore, taking action to ensure that exploitation of krill did not inhibit the recovery of those species was seen as necessary (Constable *et al.*, 2000).

An important characteristic of CCAMLR is its ecosystem focus. The principle purpose of the Convention was to represent an ecosystem conservation regime, not a regional fishery management regime with Maximum Sustainable Yield (MSY) objectives (ASOC, 2015). Because of that, relevant ecosystem concepts and objectives were included in the convention from the start as opposed to be considered at a later stage. This means that the consensus was already in place to support the ecosystem approach. Another important characteristic of CCAMLR is that it aims to apply ecosystem-focused fisheries management in waters beyond national jurisdiction.

i) Ecosystem planning

The Convention aims to conserve the Antarctic marine living resources without excluding the rational use of such resources. A number of ecosystem-focused principles underpin its implementation including:

- The size of any harvested population should not fall below a level that ensures the greatest net annual increment.
- Maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine resources and the restoration of depleted populations.
- Prevention of changes or minimization of the risk of changes in the marine ecosystem that are not potentially reversible over two or three decades.

The Convention also provides specific pointers to the type of knowledge and factors that need to be considered in management planning, including:

- direct and indirect impacts of harvesting,
- effects of the introduction of alien species,
- effects of associated activities on the marine ecosystem, and
- effects of environmental changes.

Although CCAMLR have not adopted a formal roadmap for achieving EAFM, they have agreed ecosystem-focused priority areas and impacts to tackle. For example, CCAMLR has highlighted three substantial problems mainly relating to fishing which have ecosystem impacts (Kock, 2000):

- incidental mortality of seabirds in fisheries, particularly in longline fisheries;
- entanglement of marine mammals in marine debris; and
- impacts of fishing on the seabed

In recognition of the importance of monitoring the effects of fishing on ecosystem, the CCAMLR process includes an ecosystem monitoring programme (CEMP) that is in operation since the early 90s[25]. The selection of indicators to monitor was based on the need to reflect the structure of the food system in the area but also create a pragmatic monitoring programme. The latter refers to considerations such as availability of baseline data, understanding of indicators' biology and finding indicator species that show measurable responses to changes in the availability of the harvested species (Constable *et al.*, 2000). The Programme monitors prey and predator species; the selection of the former reflects their importance in supporting the food chain while the latter were chosen for their level of dependency on the prey species monitored.

Working groups focusing on ecosystem monitoring and management and incidental mortality have been established to assess environmental trends and broader impacts of fishing using data collected through CEMP and other sources. They also provide advice on the status of the Antarctic marine ecosystems. Their recommendations and findings are part of the annual scientific report prepared for the Commission.

ii) Ecosystem science

Scientific work carried out to support the CCAMLR ecosystem objectives has already led to identification of ecosystem indicators and formal guidelines for data collection and scientific analyses of them.

Further, decision rules that account for the needs of predators have been developed and are part of the Generalised Yield Model that is used for setting quotas. The decision rules adjust the allowable catches to ensure that fishing does not compromise ecosystem functioning; i.e. there is enough prey left to support predators after the catches have been taken. An Ecosystem Productivity Ocean Climate model has also been used in the areas where krill fisheries operate and is used to evaluate the merits of different strategies for subdividing the region-wide krill catch limit into small-scale management (Constable, 2007).

Work has also focused on developing methodology for defining bioregions in the Southern Ocean and mapping/identifying information to support such regionalisation and its use for management (Constable, 2016).

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[25] https://www.ccamlr.org/en/science/ccamlr-ecosystem-monitoring-program-cemp

Although scientific work including collection of data and establishment of methods and principles to support the implementation of the ecosystem-based approach have been going on for more than 30 years, there are still important scientific gaps. For example, there is uncertainty about the link between changes in the exploitation of target species and response of the ecosystem indicators and vice versa. Similarly, research is still required to define the best ways to use information on the biological and physical heterogeneity in the Southern Ocean (bioregionalization) in the design of MPAs (CCAMLR, 2007). More areas of on-going research have been provided in Table 3.1.2.2.1.

iii) Implementation of the EAFM - Regulatory actions and activities supporting it

A number of well-established procedures are in place, which underpin the implementation of the EAFM and monitoring of the impacts of fishing. There is the requirement for scientific longline observes in all longline vessels and for new fisheries to engage with the Commission to get authorisation before commencing fishing activities, as well as obligatory data collection by Member States.

CCAMLR requires that all vessels fishing in CCAMLR fisheries carry an observer for some or all of their fishing operations. Observers record information on the gear configuration (including measures to reduce incidental mortality of seabirds and marine mammals), fishing operations (including catch composition), biological measurements of target and by-catch species, details of fish tagging and tag-recaptures, vessel sightings and data on indicators of vulnerable marine ecosystems[26]. All these data are recorded in standardised logbook forms.

Any request for authorisation for new fisheries needs to provide information on possible effects of the fishery on any dependent and associated species as well as known or anticipated impacts of bottom trawl gear on VMEs (CCAMLR, 2013). There is also an annual review and reporting of trends in the values of ecosystem indicators that is provided in the report of the Working Group on Ecosystem Monitoring and Management[27].

In line with its ecosystem objectives, TAC's for CCAMLR target species are tied to TACs for by-catch species. This means a fishery may be closed when the TAC for

[26] https://www.ccamlr.org/en/science/ccamlr-scheme-international-scientific-observation-siso

[27] See https://www.ccamlr.org/en/system/files/e-wg-emm-16-v2.pdf

one of the by-catch species is reached. The fishery report prepared for each target species also includes information on ecosystem effects. CCAMLR has also adopted conservation measures to protect Vulnerable Marine Ecosystems (VME); this is underpinned by methods for identifying VMEs and protocols that govern vessels actions once they encounter VMEs. Close monitoring of by-catch and vessel/gear interaction with vulnerable species and habitats allows prompt action to reduce impacts.

iv) Performance evidence/evidence for implementation

The previous section has provided some examples of how the ecosystem approach is already been used as part of the standard business of CCAMLR. This includes the incorporation of ecosystem considerations into stock assessment for target species and early efforts of the Scientific Committee to work closely with the decision-making body to strengthen communications and effectiveness of the scientific advice (Kock, 2000). As mentioned already, CCAMLR aims to regulate fishing activities in waters beyond national jurisdiction and it therefore brings together and needs to secure agreement among all member countries for management and other actions. That can create challenges and/or delays; an example of good practice that aims to overcome that is the calculation of allowable catches. CCAMLR has adopted pre-agreed decision rules for calculating yield to avoid delays in adopting the right allowable catches and deal with inertia in managers' response to uncertainty. Similarly, it calculates catches at different spatial scales to reduce the risk of local depletion and uses risk assessment models to cap catches of krill to minimise the effect of fishing on predators.

The efforts to account for ecosystem considerations in deciding management measures have already delivered ecosystem benefits including reduction in entanglement of marine mammals in marine debris and significant reduction in bycatch mortality. For the latter, CCAMLR estimates that seabird by-catch mortality in CCAMLR-managed fisheries has gone from 7,000 seabirds in 1997 to close to zero in 2013.[28]

v) Knowledge gained

CCAMLR has been a pioneer in incorporating ecosystem considerations into fisheries management and as such they have had the chance to implement and assess their

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[28] https://www.ccamlr.org/en/organisation/ccamlr-background-information

approach. However, it also means that they did not have much previous knowledge to build on. Therefore, their approach had to be flexible and incremental but also effective enough to build consensus among all its members. A short list of best practices and useful lessons from CCAMLR is provided below:

Best practice 1 – Monitoring of fisheries to understand their impact – Establishment of an ecosystem monitory program, extensive observer coverage and collection of data that cover a range of ecosystem aspects (bycatch, stock structure, escapement), which aim to build the evidence basis for understanding ecosystem impacts.

Best practice 2 – Risk assessment for new fisheries – An assessment and associated data collection is the first step before permission for a new fishery is given and aims to ensure that new fisheries develop at a speed that allow for evaluation of their impact.

Best practice 2 – Protecting food webs – Quota calculations explicitly account for the need to ensure that food availability for predators is not compromised.

Best practice 3 – Protection of seabirds and marine mammals and bycatch reduction – Long standing initiatives employing gear modification/restrictions, education, and change in fishing behaviour to reduce interaction and mortality. Further, the adoption of limits for by-catch means that a fishery may be closed when the TAC for one of the by-catch species is reached.

Best practice 4 – Habitat protection – As mentioned in the previous section, the Commission has protocols in place to minimize impact of vessels on VME and detailed reporting requirements to monitor encounters.

Best practice 5 – Pre-agreed processes to expedite decision making – The Commission has adopted transparent, scientific procedures to calculate quota that follow an agreed set of rules/steps and also addresses uncertainty to make the decision-making process more straightforward.

Lesson 1 – Ecosystem-focused fisheries management could be pursued without a full ecosystem based model. CCAMLR's ecosystem approach relied on very little existing knowledge when it was first introduced. Their adoption of ecosystem principles was incremental and was underpinned by a precautionary approach that was built into the assessment models and also supported by the collection of data.

Lesson 2 – Development of general concepts and principles to account for ecosystem impacts can be an effective approach to managing fishing activity when detailed knowledge of the ecosystem and its interactions is not available – The use of decision rules that explicitly account for ecosystem needs to set annual yields (mentioned above), could be one such principle. Another example is the use of fishery- independent surveys as a pre-requisite for opening any data-scarce fishery or in cases in which estimates of yield are largely uncertain.

Lesson 3 – In the light of scientific uncertainty, voluntary participation and consensus environment such as in CCAMLR might not provide a strong enough framework for achieving ecosystem objectives – In such cases, pre-agreed rules for calculating catches could be a way to reduces delays in adjusting catch limits due to lack of consensus and/or uncertainty in scientific advice (Miller, 2011).

Case study 3: EAFM in NAFO

The Northwest Atlantic Fisheries Organization (NAFO) is an intergovernmental fisheries science and management body, founded in 1979 as a successor to International Commission of the Northwest Atlantic Fisheries (ICNAF, 1949-1978). NAFO's overall objective is to contribute through consultation and cooperation to the optimum utilization, rational management and conservation of the fishery resources of the NAFO Convention Area. The NAFO Convention Area encompasses a large portion of the Atlantic Ocean and includes the 200-mile zones of Coastal States jurisdiction (USA, Canada, St. Pierre et Miquelon and Greenland). The total area under NAFO's Convention is 6,551,289 km2. Management by NAFO, however, applies only to the areas straddling and outside the EEZs (Exclusive Economic Zones). This is known as NAFO's Regulatory Area (NRA) and is 2,707,895 km2 (Figure 3).

Regulations for conducting fisheries in the NAFO Regulatory Area are outlined in the NAFO Conservation and Enforcement Measures, and include:

- Catch and effort limitations
- Bycatch measures
- Recovery and rebuilding plans
- Conservation and management of sharks
- Vessel and gear requirements
- Protection of VMEs
- Fisheries monitoring

The fishery resources managed by NAFO are:

- Straddling stocks:
    - cod in divisions 3NO
    - redfish in 3LN and 3O
    - American plaice in 3LNO
    - yellowtail flounder in 3LNO
    - witch flounder in 3L and 3NO
    - white hake in 3NO
    - capelin in 3NO
    - skates in 3NO
    - Greenland halibut in 3LMNO

- squid in sub-areas 3 & 4
- shrimp in 3L.

- Discrete stocks on the Flemish Cap: cod, redfish, American plaice and shrimp.
- Shared management with the North East Atlantic Fisheries Commission (NEAFC) of the oceanic redfish stock.
- Exceptions:
  - Highly migratory species like: salmon, tunas/marlins, whales.
  - Sedentary species like snow crab, lobster, bivalves.

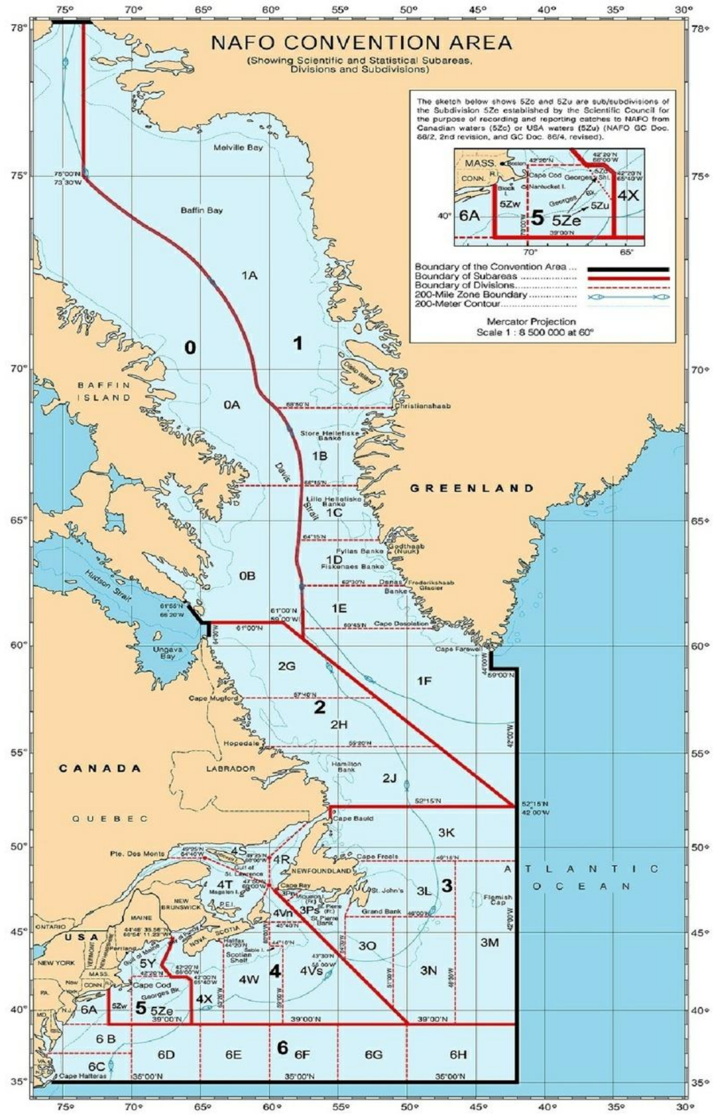

Figure 3.- The NAFO Convention Area

The main issues in the NAFO area are related with recovery plans for many demersal stocks that experienced a steep decline during the 1980s-1990s and have not been recovered to their traditional high productivity, like the American plaice, 3NO cod, Greenland halibut, etc.

i) Ecosystem planning

The implementation of an EAF is an overall goal for NAFO as indicated in the *Amendment to the Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries*:

NAFO is *"COMMITTED to apply an ecosystem approach to fisheries management in the Northwest Atlantic that includes safeguarding the marine environment, conserving its marine biodiversity, minimizing the risk of long term or irreversible adverse effects of fishing activities, and taking account of the relationship between all components of the ecosystem."*

This was an amendment to the Convention that started to be developed in 2007 and is still pending to be ratified on May 2017. But most Contracting Parties have already given their approval and it is expected that the new Convention will be agreed in 2018. However, NAFO still lacks a well-defined plan with clear operational targets, objectives and reference points. The only aspect of the EAF that has been more systematically applied has been related with identification and protection the VMEs.

In spite this, there are a number of projects (such as the EU Specific Contract 5 under the same framework as this project) dealing with the development and integration of the multispecies approach in NAFO, as well as lines of work like estimation of ecosystem and fisheries' production potential. These are expected to produce results that could be used to support fisheries management in relation to ecosystem and multispecies aspects of productivity and sustainable fisheries.

ii) Ecosystem science

The ecosystem science has been well developed in NAFO, although further development is still needed before a comprehensive framework for the ecosystem approach can be implemented. Since 2008, the Working Group on Ecosystem Studies and Assessment (WGESA), former Working Group for an Ecosystem Approach to Fisheries Management (WGEAFM), have been developing the roadmap for an EAF in NAFO (Figure 4).

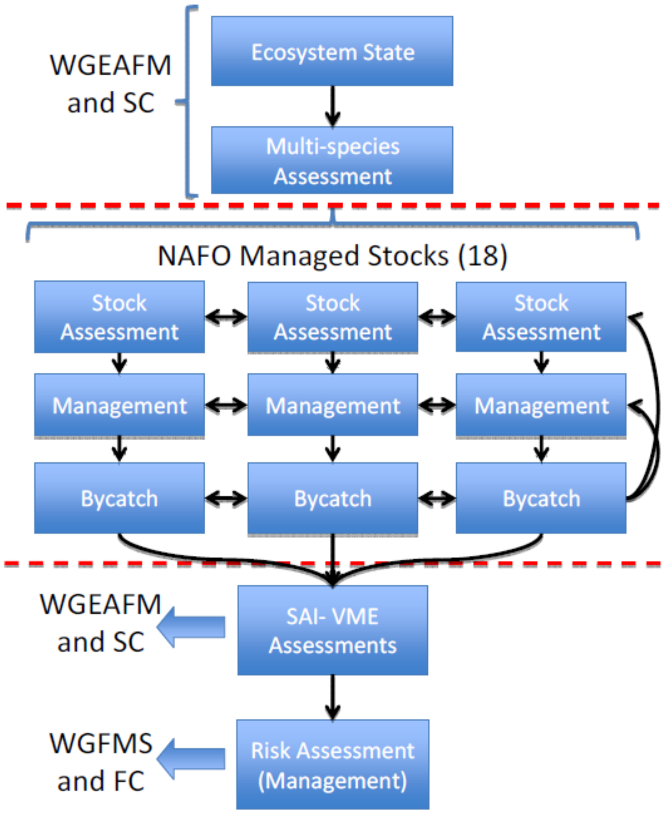

Figure 4 Schematic representation of a possible structure to develop Fisheries Assessments in NAFO. SC: scientific council, FC: Fisheries commission.

The roadmap (Figure 4) consist of a three-tier framework. The high-level components (top 2 boxes in Figure 4) represent the processes needed to incorporate sustainability at ecosystem level (i.e. state-dependent ecosystem productivity) and multispecies interactions into assessments. This will allow consideration of trade-offs between fisheries and multispecies sustainability. By considering these elements, the Fisheries Assessment will be incorporating some of the ecosystem and community information. For each individual stock, information will be provided on the state of those resources, as well as details for the individual fisheries, management practices, and description of by-catch issues. In this case, the box for bycatch also includes by-catch of VME species. The information of bycatch of VME-species feeds down to the Significant Adverse Impact (SAI) on VME box, where it is integrated. The structure depicted in Figure 4 is considered as a template to use to implement in practice the Roadmap to EAF.

To accomplish this roadmap, the main lines of work are:

- Identification of VME and assessment of SAI for these ecosystems.
- Delimitation of area-based ecosystem production units and candidate management units.
- Estimation of Ecosystem and Fisheries Production Potentials to estimate Ecosystem Maximum Sustainable Yield in the long term.
- Analysis of species interactions (commercial and non-commercial) and consideration of information to the advisory process.
- Analysis of ecosystem indicators in different ecosystem production units.

iii) Transition to the EAFM - Regulatory actions and activities supporting it

Every year, the WGESA chair meets with the NAFO Scientific Council and Fisheries Commission to explain the main conclusions from the group and to provide answers to specific questions to these scientific and management bodies. In addition, in 2012 a joint managers-scientists Working Group on Ecosystem Approach Framework to Fisheries Management (WGEAFFM) was created to promote decision-making within more iterative contexts.

However, NAFO does not still produce a systematic annual ecosystem assessment or provides formal advice on ecosystem issues in practice. The ecosystem advice sheet, a tool to provide standardized ecosystem related information over time and for direct use for managers, has been recently developed, and will still need some more improvements and testing.

iv) Performance evidence/evidence for implementation

The application of the EAF in management decisions is still in its infancy, and mainly related with the delimitation of VMEs and closed areas to fishing. However, the importance of having well established ecosystem production units and understanding species interactions is being increasingly mentioned within the management bodies. In this context, different projects have been recently financed by the EU and Canada (main contracting parties in NAFO) aiming at estimating the importance of species interaction and the incorporation of this element into the scientific advice.

"Move on" rules are specifically designed for the protection of VMEs. This consists of cancellation of fishing activity in the area, and transfer of fishing activity to at least 2 miles distance if deep sea corals, sponges and some other marine invertebrates are found in a fishing trawl in a concentration above the limits.

v) Knowledge gained

From the scientific side, the improvements since 2008 have been outstanding in most lines of work necessary for an EAF, starting with a well-defined road map. However, from the management side only the VMEs aspect of the EAF has been really applied. It can be considered that most of the work and improvements to implement an EAF in NAFO are still to come.

An independent performance review of NAFO listed the strengths and weaknesses, as well as opportunities and threatens to the development of an EAF in NAFO. Some of the conclusions of this work include:

- EAFM has not been defined by the Fisheries Commission: consequently there
- is some confusion regarding what actually is its aim. The threat is that an EAFM cannot be successfully implemented without clear definitions and goals. In order to solve this issue, a better dialogue between the SC and the FC should be promoted.
- Targets and deadlines have not been set for the implementation of the stages of EAFM: accordingly, it is not possible assessing the progress in the development and implementation of an EAFM in NAFO
- Fisheries Commission cannot work independently from Scientific Council (SC). The successful implementation of EAFM will require integration of objectives, stakeholders, legislation and policy, and technical and methodological instruments. NAFO must adapt in order to facilitate this multi-disciplinary integration. Weaknesses within organisational structures which limit effective EAFM implementation need to be resolved.
- There is no social or economic branch or expertise within NAFO. Incorporating economic science in fisheries is still under development but its importance will increase as more assessments of trade-offs will be needed to evaluate decisions that will affect different components of the fisheries system (species, fishing sectors, etc).
- Limited funding: on this regard, the creation of Memorandum of Understandings (MoUs) with outside organisations could help resolve problems of limited funds, expertise, and time.

However, it is an independent performance review, and it does not necessarily reflect the lessons learnt or the views within the management body of NAFO.

Best practices have already been covered in the previous sections and mainly includes the following areas/issues:

- Establishment of VMEs

- Design and adoption of move on rules

- Establishment of the joint Scientific Council-Managers working group WGEAFFM.

However, there are also areas that require further work including improving understanding of species interactions and their implications for multispecies management, recording of VME and commercial species by-catch, and developing fit-for-purpose ecosystem indicators and management.

Table 4 Reference cases – summary table

	Element	Region -Alaska	Region - Antarctic	Region- North Atlantic
Overview	Manage-ment body	North Pacific Fisheries Management Council (NPFMC) in the USA. One of the eight regional Fisheries Management Councils in the USA established to manage fisheries within their EEZ.	CCAMLR - Convention for the Conservation of Antarctic Marine Living Resources Commission	NAFO Fisheries Commission
	Main fisheries	Groundfish, rockfish, halibut, salmon, crab and scallop fisheries	Main fishery: Krill Other species: toothfish, mackerel icefish	Demersal fish species
	Main/ relevant	Bycatch controls, habitat protection, protected	Ecosystem-focused management of fisheries; best	Recovery plans in place

	issues	species, and catch share allocations	practice in ecosystem approach to fisheries management in waters beyond national jurisdiction; rational use of resources	
Ecosystem Planning	Fishery ecosystem vision	The Ecosystem Committee in the NPFMC in 2014 adopted an Ecosystem Policy, which included a value statement, a vision statement, and an implementation strategy.	The conservation of the entire Antarctic marine ecosystem (Convention Articles I and II)	• The ecosystem approach to fisheries is included in the amendment to the NAFO convention. • Vulnerable Marine Ecosystem (VME) protection plan.
	Ecosystem objectives (conceptual and	The NPFMC has adopted comprehensive ecosystem-based goals and objectives (conceptual and	• Maintenance of the ecological relationships between harvested, dependent and related populations.	• Conceptual and operational objectives in place but only on the VME side • Development of a more comprehensive EAF under

	operational)	operational) for groundfish Fisheries Management Plans.	• Restoration of depleted populations • Prevention of changes or minimization of the risk of change in the marine ecosystem	way
	Ecosystem plan or roadmap to implement EBFM	• Fishery Ecosystem Plan (FEP) for the Aleutian Islands ecoregion in place. • A FEP is now under development for the Bering Sea.	• No roadmap but agreed ecosystem-focused priority areas / impacts to tackle and ecosystem objectives. • New fisheries cannot expand faster than the rate at which the information to manage them in accordance with the ecosystem principles is collected.	No, only a partial plan for VME
	Ecosystem Working Group/ team/ lead entity	The Ecosystem Committee was established in the mid-1990s to provided	• Working Group on Ecosystem Monitoring and Management • Working Group on Incidental	• WGESA (Working Group Ecosystem Studies and Assessment) • STACFEN (Standing Committee on Fisheries

		recommendations on EBFM, habitat and conservation issues to the Council.	Mortality • Subgroup on Status and Trend Assessment of Predator Populations • Tailored WGs to tackle specific issues including collaboration with other Scientific bodies and use of external experts to build capacity[29]	Environment)
	System description to map main threats and ecosystem components	The FEP for the Aleutian Islands included a conceptual model for the identification of key ecosystem interactions.	Food web components and interactions identified	No
	Ecosystem	The FEP for the Aleutian	• Requests for new fisheries	No

[29] For example see Workshop on plausible ecosystem models for testing approaches to krill management, https://www.ccamlr.org/en/system/files/e-sc-xxiii.pdf, Annex 4.

	risk assess-ment	Islands also included an ecosystem risk assessment of the region.	authorisation need to submit information on possible fishery effects. • Risk management framework to avoid significant adverse impacts of bottom fishing gear on VME[30]	
Ecosystem Science (not necessarily used to	Establishment of ecoregions	Well-established Large Marine Ecosystem (ecoregions)	• Bioregions[31] • In addition, small scale management units to address local impacts	Ecosystem Production and Management Units.
	Development and selection of ecosystem	Each ecoregion has its own list of ecosystem indicators to provide	• Indicators have been identified that cover predator, prey, and	• At exploratory stage • A set of indicators have not been selected for each

[30] CCAMLR 2008

[31] CCAMLR, 2007.

support manage-ment decisions, yet)	indicators	ecosystem context and support management decisions.	environmental parameters. • Species more likely to reflect changes in the availability of harvested species are the focus of the indicators.	ecoregion
	Ecosystem productivity	• A precautionary limit of 2 million metric tonnes for the groundfish fishery in the Bering Sea and Aleutian Islands • The limit is based in part on the productivity of the system	Ecosystem Productivity, Ocean, and Climate modelling framework	• Ecosystem and Fisheries Production Potential (EPP and FPP) • Basis for an ecosystem MSY limits in the long term.
	Multi - species models	Bioenergetics-based multi-species catch-at-age models (CEATTLE) developed for the	Partly; Generalised Yield Model: Allowable catches are decided based on a decision rule that accounts for the	Yes, still many ecosystem production units without them.

		Eastern Bering Sea as requested by the Council.	needs of predators.	
	Ecosystem models	A variety of ecosystem models have been developed or are under development to conduct Ecosystem Risk Assessments and Management Strategy Evaluations: - oceanographic models (Regional Ocean Modelling System), - climate-enhanced food-web models such as Ecosim,	Bio-energetics models for key predators[32]	No

[32] See for example CCAMLR, 2016

		- climate-enhanced ecosystem and single-species assessment models, - bioenergetics models, - climate-enhance recruitment models, and - statistical analyses of ecological interactions		
	Identification of vulnerable habitats	Broad time/area closures and bottom trawl restrictions in place to protect vulnerable habitats.	• Protection and reporting processes in place. • Procedures for declaring Risk areas in VMEs also in place.[33] • VME Taxa Classification	Yes, VME

[33] CCAMLR, 2013

			Guide[34]	
	Identification of vulnerable and threatened species	Measures including gear modifications and time/area closures exist to minimize impact of fisheries on vulnerable and threatened species.	Depleted stocks, dependent species, and associated species have been identified[35] [36]	Yes, VME identified
	Other on-going research areas	Explicit ecosystem thresholds (e.g. as a percent decrease in quota) are under development that may trigger a specific management response.	• Krill Feedback Management procedure[37] • Impact of climate change including acidification[38] • Development of a State of the Antarctic Environment report[39]	• Interaction VME-commercial species • Multispecies MSY and Management Strategy Evaluation

[34] CCAMLR, 2009
[35] http://archive.ccamlr.org/pu/E/sc/cemp/species.htm, last accessed 04/05/17
[36] Agnew, D.J. (1997).
[37] CCAMLR 2011
[38] Constable, 2016

Regular activities and actions to support impleme-ntation	Monitoring of indicators	• Indicator-based ecosystem report cards developed for each ecoregion and presented to the Council every year. • An Ecosystem Consideration Report presented to the Council every year.	• Ecosystem Monitoring Program. • Scientific observers on all longline vessels fishing outside national waters in the Convention Area. • Field program monitoring entanglement incidents.	• Early exploration. • Not a systematic study and monitoring
	Ecosystem Assessment	The Ecosystem Consideration Report also includes a detailed ecosystem assessment, which is also updated	New findings on ecosystem interactions and updates on indicator trends are provided in the report of the Working Group on Ecosystem	No

[39] Anonymous, 2004

		and presented to the Council annually.	Monitoring and Management[40]	
	Reporting (state of environment, ecosystem status report card, ecosystem advice card)	The Ecosystem Consideration Report is prepared annually as part of annual harvest specifications and is composed of the following section: (1) Report Cards for each ecoregion, (2) Executive Summary, (3) Ecosystem Assessment, (4) Ecosystem Status	Fishery Report for each fishery includes ecosystem effects such as by-catch and seabird / mammals' mortality	• Ecosystem Advice Sheet (First template developed in 2016) • STACFEN annual report on oceanographic conditions and lower trophic level state • Annual WGESA report

[40] See Anonymous, 2016

		and Management Indicators. This report synthesizes the status and trends of several ecosystem components for all ecoregions and provide stronger links between ecosystem research and fisheries management.		
	Evaluation of management strategies	The Bering Sea FEP, which is currently under development and consultation, is evaluating the short- and long-term effects of climate change on fish and fisheries through MSE.	Agreed catch decision rules (HCRs) are simulation-tested under different scenarios using MSE.	No

	Communica-tion strategy	Ecosystem information is prepared and adapted to fit the management cycle. It is presented to the Council every year before quota setting to allow for qualitative inclusion of ecosystem information into fisheries management decisions.	Annual review of ecosystem work and findings by the Scientific Committee and reporting of latest values/trends to the Commission.	• Yes, annual meetings SC-FC • Joint working group WGEAFM
Performance and evidence for impleme-ntation	Setting of target and limit reference points based on ecosystem	• A total cap for groundfish catches based on the productivity of the region. • Individual TACs for all species or species groups that ensure	• Risk assessment-based capping of catches of krill to minimise the effect of fishing on predators. • An ecosystem-based risk assessment is required before any new fishing activities commence.	• Still very incipient. • VME delimitation and closed areas to fishing activity • Significant Adverse Impact and Move on Rules in relation to VME • Ecosystem Production and

(examples where ecosystem consider-ations have been accounted in manage-ment decisions)	information	that the total cap of the region is not exceeded. • There is not direct fishing on forage fish. • Establishment of bycatch limits for species not having their own fisheries management plan. • Gear modifications such as salmon/halibut excluders, biodegradable panels, seabird deterrents, elevated trawl sweeps to minimize impact on		Management Units • Ecosystem Production Potential EPP and Fisheries Production Potential FPP (Ecosystem MSY) • Multispecies MSY

		bycatch species.		
	Protection of vulnerable habitats	Establishment of time/area closures and bottom trawl restrictions to protect essential fish habitats	• Prohibition of certain gears from vulnerable areas. • Bottom fishing is ceased in any location where evidence of a VME is encountered	Habitat closures
	Recovery plans in place for overfished species	The groundfish fishery is managed under harvest control rule with automatic rebuilding	• Closed fisheries for several species and by-catch quota for vulnerable/threatened species • Trigger levels of by-catch to signal when a vessel must move from a fishing ground to avoid localised depletion.	Yes

EAFM in ICCAT and IOTC

The International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Indian Ocean Commission (IOTC) are two of the five tuna RFMOs in charge of managing and conserving tuna and tuna-like species globally (Figure 5).

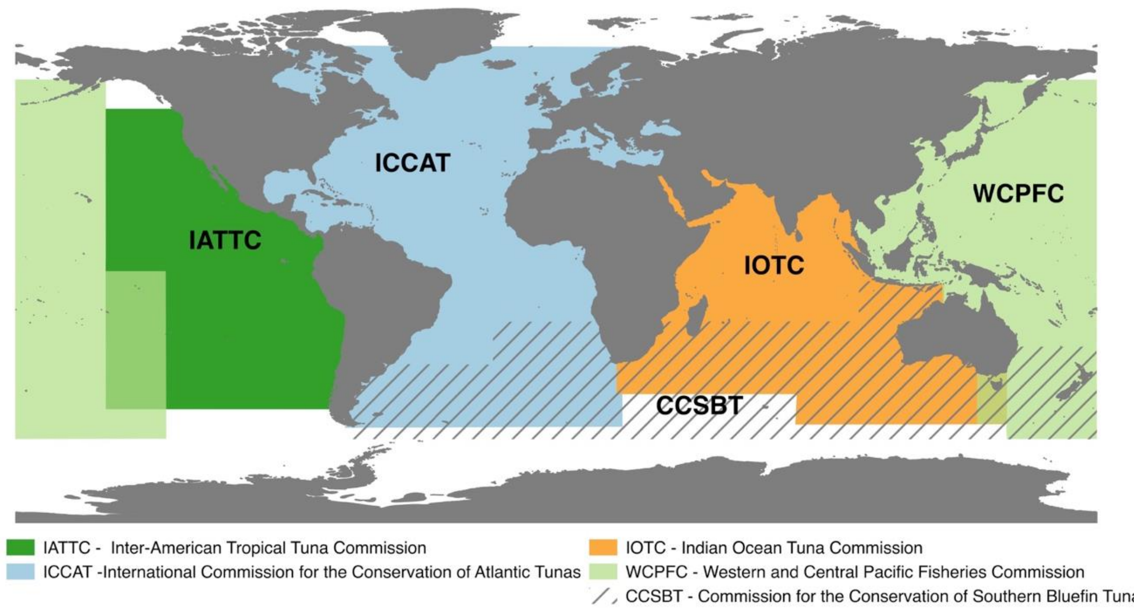

Figure 5 Tuna Regional Fisheries Management Organizations. Extracted from Juan-Jordá et al., 2017.

ICCAT and IOTC are in charge of managing tuna and tuna-like species, which include the principal market tunas, billfishes and the coastal tunas and bonitos. ICCAT and IOTC have also recently started to assess and manage some oceanic shark species.

The most important current matters in these tRFMOS consist of managing tuna and tuna-like species within sustainable levels, and to some extent, minimising the impact of their fisheries on bycatch species.

i) Ecosystem planning

The ICCAT and IOTC Convention Agreements do not make reference to the EAFM. Yet, ICCAT and IOTC have had the ability to assimilate some elements of existing global instruments for fishery governance such as UNCLOS and UNFSA and have incorporated them through the formal adoption of management measures (e.g. measures to minimize bycatch). In addition, ICCAT adopted in 2015 the Resolution 15-11[41] concerning the application of an ecosystem approach to fisheries management and Resolution 15-12[42] concerning the use of the precautionary approach. In addition, it is also currently discussing amendments to the Convention Agreement to include some elements of the precautionary approach and an EAFM. Still, it remains to be seen if these principles will be incorporated in the new Convention Agreement. The ICCAT Scientific Committee has also expressed the need to advance towards advice on EAFM in the Science Strategic Plan for 2015-2020, which has been recently adopted by the Commission. Despite these recent efforts, there is not clear vision or objectives to operationalise an EAFM in neither ICCAT nor IOTC.

ICCAT and IOTC have also established Ecosystem Working Groups which are in charge of reviewing ecosystem science and integrating ecosystem considerations into the scientific advice, which is then provided to their Commissions. Their working groups rely mostly on the participation of scientists from their member countries to carry out and review ecosystem-related research, and to generate recommendations regarding bycatch and ecosystem issues. In their term of reference, they state several conceptual objectives to advance the agenda on EAFM.

ICCAT and IOTC have not formally developed and adopted an operational EBFM plan or road map to guide the operationalization of an EAFM and ensure that ecosystem considerations are taken into account in fisheries management advice. The formalisation of an operational plan to implement an EAFM could be used as an opportunity to define and develop more effective mechanisms to formalise and strengthen the delivery of ecosystem information to their Commissions. Moreover, these groups have not developed a conceptual model of their system in order to identify main threats and what are the main ecosystem components they would like

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[41] Resolution 15-11 Resolution by ICCAT concerning the application of an ecosystem approach to fisheries management

[42] Resolution 15-12 Resolution by ICCAT concerning the use of a precautionary approach in implementing ICCAT conservation and management measures

to monitor to assess the full impact of their fisheries on the ecosystem. ICCAT and IOTC have not developed an ecosystem risk assessment. These would be very useful and an intermediate step towards developing an ecosystem plan.

ii) Ecosystem science

Both ICCAT and IOTC recognise the value of ecosystem research activities such as the development of ecosystem indicators to track ecosystem change or impacts of fishing on ecosystems, modelling of food web interactions, habitat analysis, etc. Nevertheless, these research activities have been relatively scarce in both tuna RFMOs. To date, the Ecosystem Working Groups of ICCAT and IOTC have mostly focused their efforts in developing qualitative and quantitative Ecological Risk Assessments (ERAs) for incidentally caught species of sharks, birds, turtles, marine mammals and other teleost fishes. These ERAs have been critical to set priorities and take management action following the precautionary approach in the absence of quality stock assessments for bycatch species.

The Ecosystem working groups of ICCAT and IOTC have not formally identified or established ecologically meaningful ecoregions to support the implementation of an EAFM. In terms of ecosystem indicators, the ICCAT and IOTC Working groups are currently developing ecosystem indicators to monitor impacts of fisheries on several components of the ecosystem. However, this work has been delayed partly because it is hard to estimate ecosystem indicators in the absence of quality standardised bycatch datasets at relevant spatial scales and in the absence of ecosystem models. The ICCAT and IOTC Ecosystem working groups are also trying to develop ecosystem report cards with the aim to advance the development of ecosystem indicators to monitor the effects of fishing as well as to establish a fruitful discussion within the Scientific Committee and the Commission for the need and the advantages of doing it so.

Furthermore, ecosystem models, food web models or multispecies models with interactions of relevant species and relevant components of ecosystems have not been developed to understand broader community-based and ecosystem level consequences of fishing in the ICCAT and IOTC Convention Area. However, it is worth mentioning some recent research efforts in ICCAT. Recent efforts in ICCAT to apply ecosystem modelling to Atlantic pelagic ecosystems include a preliminary food web model to assess the ecological value of Sargassum ecosystems for tuna and tuna-like species; and a preliminary Ecopath ecosystem model to test the effects of the development of the Fish Aggregating Devices fishery in the Gulf of Guinea. These models are however at the very early stages of development. Moreover, the SEAPODYM model has also started being developed in the Atlantic Ocean to understand the impacts of fisheries and climate change on both target (Dragon *et al.*, 2015) and bycatch species (Schirripa *et al.*, 2011), but are not yet been considered for management advice. Other ecosystem models like APECOSM (Maury, 2010), are also being developed and might be helpful in the future for RFMO decisions.

Research to identify habitats of special concern and habitat preferences and utilisation for relevant species in support of the implementation of an EAFM have been historically relatively scarce. In ICCAT, it is worth mentioning that a collaborative research program to map the relative significance of the Sargasso Sea as essential habitat for ICCAT tunas and tuna-like species has started (Luckhurst, 2014; Luckhurst & Arocha, 2015). Indicators describing habitat needs and preferences are under development and under discussion by the Scientific Committee. In the case of IOTC, habitats of special concern and habitat preferences and utilisation have not been formally requested, mapped or delineated for any species of interest, and it is not under discussion either. Furthermore, both ICCAT and IOTC have also developed an international cooperative tagging program in the Atlantic and Indian Oceans and it is involved in several tagging programs (e.g. the Atlantic-wide research program for bluefin tuna -GBYP and the AOTTP). However, these tagging programs have been mostly designed to increase the understanding on the population dynamics and life history of tunas (Fonteneau & Hallier, 2015), so their use in supporting habitat research has been limited by the Scientific Committee.

iii) Regular actions and activities to support implementation

ICCAT and IOTC have not conducted a formal ecosystem assessment yet, they provide only an annual report on the state of their commercially important target species (all principal market tunas and some billfishes and sharks) to the Commission.

Evaluations of management strategies are under development in ICCAT and IOTC to support single species management. However, they do not incorporate ecosystem considerations such as bycatch impacts or multispecies interactions.

The ICCAT and IOTC Ecosystem Working Groups, during their annual weekly meeting, prepare an ecosystem report highlighting the ecosystem research conducted during that year. They also include in the report their ecosystem advice and recommendations, which are further discussed by the Scientific Committee and if deemed important are then presented to the Commission.

No formal mechanism or communication strategy has been developed to effectively communicate ecosystem science to the Commission in order to provide ecosystem context to support and influence fisheries management decisions. Although the Scientific Committee presents the main recommendations of the Ecosystem Working Group to the Commission every year, this is not done effectively as it does not provide context to inform fisheries management or harvest specification for main target species.

iv) Performance evidence/*evidence* for implementation

The development and adoption of limit and target reference points, and especially, harvest control rules, for their target or bycatch species remains a challenge. IOTC is the only tuna RFMO that has developed and adopted stock-specific interim limit and target reference points associated with the biomass and fishing mortality rate indicators for all the target species (IOTC Resolution 15/10[43]). In the case of ICCAT, stock-specific reference points are currently under development and tested for some of its target species. These target and limit reference points under development are for singles species, and do not account for ecosystem considerations or impacts of fisheries on other species. The TACs of individual species adopted every year in the Commission meeting are not adjusted based on ecosystem considerations. Bycatch limits have not been established for any bycatch species in ICCAT and IOTC. There are not total catch limits for the system to avoid ecosystem overfishing.

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[43] Resolution 15/10 on target and limit reference points and a decision framework

The ICCAT Commission encourages research to identify vulnerable habitats for some of its target and bycatch species and it has been formally requested in multiple management measures. Yet, to date, vulnerable habitats have not been protected. IOTC has not identified or is currently protecting any vulnerable habitats.

Since its creation, ICCAT has adopted several recovery plans for some of its overfished species. North Atlantic Albacore has been successfully recovered to sustainable levels after the implementation of a recovery plan. Currently a recovery plan is underway for the Atlantic bluefin tuna stocks. IOTC has never adopted or implemented a recovery plan for any of its overfished stocks.

Table 5 tRFMOs and ecosystem approach – summary table for ICCAT and IOTC

	Element	ICCAT	IOTC
Overview	Management body	RFMO International Commission for the Conservation of Atlantic Tunas	RFMO Indian Ocean Tuna Commission
	Main fisheries	Tuna and tuna like species: Principal market tunas (5 spp. assessed) Billfishes (4 assessed) Oceanic sharks (3 assessed) Small tunas and other coastal species	Tuna and tuna like species: Principal market tunas (4 assessed) Billfishes (5 assessed) Oceanic sharks (1 assessed) Small tunas and other coastal species
	Main/ relevant issues	Main focus is on management of principal market tunas and minimization of bycatch for non-target species	

Ecosystem Planning	Fishery ecosystem vision	Their mandate does not make reference to an EAFM. However, several management measures address some ecosystem issues (e.g. minimize bycatch)	
	Ecosystem objectives (conceptual and operational)	Their mandate or management measures does not state clear conceptual or operational objectives to implement an EAFM. Several management measures address some ecosystem issues (e.g. minimize bycatch) (only conceptually, not operational objectives) The terms of reference of their ecosystem working groups have some conceptual objectives.	
	Ecosystem plan or roadmap to implement EAFM	They have not formally developed and adopted an operational EAFM plan.	
	Ecosystem Working Group/	Yes, they have a Working Group (which meets annually) in charge of reviewing ecosystem science and	Yes, they have a Working Group (which meets annually) in charge of reviewing ecosystem science and integrating

	team/ lead entity	integrating ecosystem considerations into the scientific advice meets annually. It focuses mainly on bycatch issues, but started some work to broadly address the EAFM.	ecosystem considerations into the scientific advice meets annually. It focuses on shark assessments, bycatch issues and recently started some work to broadly address the EAFM
	System description to map main threats and ecosystem components	It has not been developed.	
	Ecosystem risk assessment	It has not been developed.	

Ecosystem Science (not necessarily used to support manage-ment decisions, yet)	Establishment of ecoregions	They have not formally identified or established ecologically meaningful ecoregions to support the implementation of an EAFM.	
	Development and selection of ecosystem indicators	On-going work by the Scientific Committee to develop ecosystem indicators. Work being delayed in part because of data availability to monitor some ecosystem components (e.g. bycatch species, food webs) and clear directions and objectives from the Commission.	
	Ecosystem productivity	The ecosystem productivity of the system has not been estimated. There are no limits established to avoid ecosystem overfishing.	
	Multi-species models	Multispecies models have not been developed.	
	Ecosystem models	A preliminary ecosystem model (Ecopath) in Gulf of Guinea Region has been developed to test the effects of FADs in the ecosystem.	Ecosystem models have not been developed.
	Identification of vulnerable habitats	- Habitats of special concern and habitat utilization and preferences for some relevant ICCAT species have been formally investigated by	Habitats of special concern and habitat preferences and utilization have not been formally mapped or delineated for any IOTC species of interest, or are

		the SC - Indicators (associated with pre-established objectives) describing habitat needs and preferences are under development.	under discussion by the Scientific Committee
	Identification of vulnerable and threatened species	Ecological Risk Assessments (at least level 2) for sharks and seabirds to rank their vulnerability to fishing	Ecological risk assessments for sharks to rank their vulnerability to fishing
	Other on-going research areas	- Development of ecosystem report cards - Proposal of ecosystem indicators to populate the ecosystem report card	
Regular activities and actions to support implementation	Monitoring of indicators	Every year the Commission is updated on the current status and trends of their main commercial species (the assessed tuna and billfishes species). For the other components of the ecosystems (e.g. bycatch, food web interactions), the Commission has not adopted or monitors indicators about their state.	

	Ecosystem Assessment	Ecosystem Assessments have not been conducted.
	Reporting (state of environment, ecosystem status report card, ecosystem advice card)	The Ecosystem Working Group only reports on the state of main target species and not the rest of ecosystem components (bycatch, food web interactions, etc.). There is some work under way to develop Ecosystem Report Cards to better quantify and monitor several components of the ecosystem.
	Evaluation of management strategies	Evaluations of management strategies are under development to support single species management. They do not incorporate ecosystem considerations such bycatch impacts of those fisheries or multispecies interactions.
	Communica-tion strategy	- No formal communication strategy has been developed to effectively communicate ecosystem science to the Commission. - The Scientific Committee presents the main recommendations of the Ecosystem WG to the Commission every year but it is not effectively communicated. It does not provide context to inform fisheries management or

		harvest specification for main target species.	
Performance and evidence for implementation (examples where ecosystem consider-ations have been accounted in manage-ment decisions)	Setting of target and limit reference points based on ecosystem information	- Limits and target reference points are under development for some target species. - The total allowable catches of individual target species are not adjusted based on ecosystem considerations - No bycatch limits have been adopted. - No total catch limits for the system to avoid ecosystem overfishing	- Limits and target reference points have been adopted for all target species. - The total allowable catches of individual target species are not adjusted based on ecosystem considerations - No bycatch limits have been adopted. - No total catch limits for the system to avoid ecosystem overfishing
	Protection of vulnerable habitats	The Commission encourages research to identify vulnerable habitats for some target and bycatch species. Yet, to date, vulnerable habitats have not been protected.	Vulnerable habitats have not been protected.

	Recovery plans in place for overfished species	The have implemented several recovery plans for overfished target species (e.g. Atlantic bluefin tuna)	No recovery plans in place for overfished species.

Review of relevant projects to guide selection of indicators

In addition to the case studies of good practice covered in the previous section, there are a number of programmes and frameworks that have focused on ecosystems indicators and their application to inform ecosystem-based management. This section provides a description of such work to illustrate the effort in this area that has taken place in the past 5 years or so. The scale of the examples presented here ranges from individual projects to the much bigger framework established by the EU Commission through the MSFD.

Program 1: Indicators for the Seas – IndiSeas program

i) Aims and objectives

IndiSeas is an international collaborative scientific program established in 2005. It is a multi-institute[44] collaborative effort where one or two scientists from each Large Marine Ecosystem collaborates in the project. The IndiSeas program has two main goals: (1) to evaluate the effect of fishing on the health status of marine ecosystems using a set of indicators in a comparative framework, and (2) to provide a generic dashboard of tools to visualize and interpret the ecological indicators in order to facilitate its use to support decision making in an EAF (Shin & Shannon, 2010; Coll *et al.*, 2016). The IndiSeas program is driven by the need to define, test and prioritize robust indicators to track the pressures on marine ecosystems and track their status to inform management decisions in a context where multiple anthropogenic and climate-related pressures are impacting ecosystems.

ii) Ecosystem science - indicators

While the Indiseas program has selected a panel of ecological and biodiversity indicators, as well as environmental and human-dimension indicators to characterise marine ecosystem states and trends, here we only summarise the ecological and biodiversity dimension of the program. In phase I of the IndiSeas Program (2005-2010), a short list of seven ecological indicators was selected to quantify the effects

[44] http://www.indiseas.org/about-us

of fishing on marine ecosystems (Table 6). In Phase II of the IndiSeas Program (2010-2015), the list was extended with an addition of six biodiversity and conservation-based indicators to emphasize the broader biodiversity and conservation risks in exploited ecosystems (Table 6).

The process to select the IndiSeas Indicators can be summarised in three steps. First, a potential list of indicators was selected from the scientific literature for consideration by the group of experts with no restriction on the number of indicators. A second step consisted of evaluating the indicators using screening criteria so each candidate indicator was scored by a group of experts. The indicators were selected using the following criteria: ecological meaning, sensitivity to fishing, data availability, management objectives and public awareness. In addition, indicators had to be comparable across marine ecosystems worldwide (Shin *et al.*, 2010b; Shin & Shannon, 2010). In the last step, a set of indicators was proposed for examination and analysis in a subset of comparable ecosystem case studies (Shin *et al.*, 2010a; Coll *et al.*, 2016) for the purpose of quantifying and comparing their states. These three steps led to the selection and proposal of the Phase I and Phase II IndiSeas Indicators (Table 6).

Ecological as well as biodiversity and conservation-based indicators complement each other to evaluate the overall impact of fishing on exploited marine ecosystems (Coll *et al.*, 2016). All indicators have been defined so that a decrease in their value is expected with an increase in fishing pressure. Therefore, a decreasing trend would indicate an increasing impact of fishing on the ecosystem.

Most of the IndiSeas Phase I indicators are based on survey-data and some on landings data. The Phase II indicators are based on survey data, landings data and some are derived from ecosystem models such as Ecopath with Ecosim (EwE).

Phase I and II Indiseas indicators have now been calculated for 29 exploited marine ecosystems worldwide, including temperate, tropical, upwelling and high latitude ecosystems (Coll *et al.*, 2016). Comparative analysis of indicators across these 29 ecosystems have provided great insights on the relative trends and states of these ecosystems as well as on how drivers influences the dynamics of ecosystems (Coll *et al.*, 2016).

Potentially, all the IndiSeas indicators (Table 6) could be applied to monitor the impacts of fisheries targeting HMS on marine ecosystems keeping in mind one caveat. Most of the IndiSeas indicators are based on data collected in scientific research surveys. Survey derived data is not generally available or collected in the tuna RFMOs, as this type of surveys are hard to be conducted in oceanic systems at relevant spatial and temporal scales. Therefore, we propose that most IndiSeas indicators could instead be derived and tested using fisheries-dependent data (e.g. data collected in the commercial vessels, data derived from fisheries stock assessments) keeping in mind the caveats and limitations of such adjustment.

iii) Lessons learnt and good practices

Many lessons and best practices can be extracted from the IndiSeas Program with more than 10 years of experience generating ecological indicators to characterise the status of marine ecosystem to support decision-making in an EAFM.

We briefly list a series of lessons and best practices summarised in several publications of the IndiSeas program (Shin *et al.*, 2010a; Shin *et al.*, 2010b; Shin & Shannon, 2010; Shin *et al.*, 2012), which can be used to inform future development ecosystem based plans, research activities, and actions in tuna RFMOs and elsewhere.

Lesson – One indicator is not enough – It is advised that multiple indicators are needed to monitor the impacts of fishing on ecosystem and characterise their current state. It can help to resolve inconsistencies in information communicated by various indicators that measure different attributes of the ecosystem. Each indicator provides complementary information that is useful for summarizing the ecosystem status in response to fishing and other pressures.

Lesson – More effort is needed to standardize data sets - There is a general need to standardise methodologies for data collection and processing in order to facilitate the estimation of ecosystem indicators and the comparison of ecosystem status across several ecosystems around the world.

Lesson – Comparative approaches are useful - The comparative approach was very useful in the Indiseas Program for several reasons. The number of selected ecosystem provided a constraining framework to facilitate the selection of a limited set of indicators that could be applied to all the regions. It also facilitated the establishment of baseline levels and reference points. Reference points are typically very hard to estimate for the majority of ecological indicators, and the spatial comparison across ecosystem provided an extended range of indicator values to inform potential baseline levels and reference points for the indicators.

Lesson –Fishing is just one piece of the puzzle – Indiseas Indicators were formulated to show a decrease as increasing fishing pressure increases, but they do not vary exclusively in response to fishing. While fishing has been identified as the most important pressure impacting marine ecosystem (Costello *et al.*, 2010), other pressures such as climate change and natural environmental variability also need to be considered. The use of the comparative approach can facilitate the exploration and differentiations of multiple pressures impacting ecosystem dynamics.

Good practice – Short list and comparable – One of the strengths of the Indiseas program is that they have come up with a relatively short list of ecological indicators that allows comparison across several exploited ecosystems. The IndiSeas program has demonstrated that by picking a small set of indicators, that are easily measurable, readily available and comparable across ecosystem, they can be used to reflect how fishing is impacting the ecosystems and to evaluate the performance of different fisheries management measures.

Good practice –Aim for a consultative and participative process - The IndiSeas program ensures that ecosystem experts from all the ecosystems analysed participate actively by providing local data and local knowledge in order to calculate and interpret the indicators and comparative analysis of ecosystem status.

Good practice – Visualize your indicators -Visualisation tools are a critical element to facilitate the communication and interpretation of indicators in a comparative setting to a wide range of stakeholders.

Good practice –Development of a platform to disseminate results -The IndiSeas program developed a website in 2009 to disseminate its results beyond the scientific audience to reach a wide range of stakeholders. The platform presents the indicators and the exploitation status for a range of ecosystem using a set of visualisation tools. It also provides ecosystem descriptions with language adaptable to target a wide range of stakeholders. This platform aims to inform fisheries scientist, managers, policy makers and the public at large about the status of marine ecosystems in response to fishing.

Table 6 IndiSeas-phase I ecological indicators used to track the impacts of fishing on exploited marine ecosystems and IndiSeas-phase II new ecological indicators used to track the broader impacts of fishing on exploited marine ecosystems in relation to biodiversity and conservation-based issues (Coll *et al.*, 2016).

	***IndiSeas* indicators**	**Label**	**Acronym**	**Used for state (S) or trend (T)**	**Survey (S), catch (C) or model based (M)**
Phase I					
1	1/coefficient of variation of total biomass of surveyed species	Biomass stability	BS	S	S
2	Mean fish length in the surveyed community	Fish size	LG	S, T	S
3	Mean maximum life span of surveyed fish species	Life span	LS	S, T	S
4	Proportion of predatory fish in the surveyed community	Predators	PF	S, T	S
5	Proportion of under and moderately exploited stocks	Sustainable stocks	SS	S	C
6	Total biomass of surveyed species	Biomass	TB	T	S
7	Mean trophic level of the landed catch	Trophic level	TLc	S, T	C

Phase II					
1	Mean intrinsic vulnerability index of the fish landed catch	Mean vulnerability	IVI	T	C
2	Proportion of non-declining exploited species	Non-declining species	NDES	S	S
3	Catch-based marine trophic index	Trophic index	MTI	S, T	C
4	Mean trophic level of the surveyed community	Trophic level of the community	TLsc	S, T	S
5	Mean trophic level of the modelled community	Trophic level of the model	TLmc	S, T	M
6	Proportion of discards in the fishery	Landings / discards	D	S, T	C

Program 2: Marine Strategy Framework Directive (MSFD) – Indicators of Goof Environmental Status (GES)

i) Aim and objectives

The Marine Strategy Framework Directive (MSFD)[45] aims to achieve Good Environmental Status (GES)[46] of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. It was adopted on 17 June 2008 and came into force on 15 June 2008. In 2010 the Commission produced a set of detailed criteria and indicators to help Member States implement the Marine Directive[47].

The Directive enshrines in a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. It is the first EU legislative instrument related to the protection of marine biodiversity, as it contains the explicit regulatory objective that "biodiversity is maintained by 2020", as the cornerstone for achieving GES.

In order to achieve GES by 2020, each Member State is required to develop a strategy for its marine waters (or Marine Strategy). In addition, because the Directive follows an adaptive management approach, the Marine Strategies must be kept up-to-date and reviewed every 6 years.

ii) Ecosystem science and indicators

The MSFD establishes European marine regions and sub-regions based on geographical and environmental criteria. The Directive lists four European marine regions – the Baltic Sea, the North-east Atlantic Ocean, the Mediterranean Sea and the Black Sea – located within the geographical boundaries of the existing Regional Sea Conventions. Cooperation between the Member States of one marine region and with neighbouring countries which share the same marine waters, is already taking place through these Regional Sea Conventions.

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[45] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32008L0056

[46] The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive. http://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm

[47] 2010/477/EU: Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010) 5956) Text with EEA relevance. http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32010D0477(01)

The MSFD sets specific steps towards achieving the transition to better protected marine biodiversity and ecosystems (GES) creating a framework that enables comparison among countries and also aims to support transfer of knowledge across the Member States. In particular, the marine strategies developed by each Member State should contain:

- An initial assessment of the current environmental status of national marine waters and the environmental impact and socio-economic analysis of human activities in these waters
- A determination of what GES means for national marine waters
- Environmental targets and associated indicators to achieve GES by 2020
- A monitoring programme for the ongoing assessment and the regular update of targets
- A programme of measures designed to achieve or maintain GES by 2020

There are 11 descriptors which determine what the environment will look like when GES has been achieved:

- Descriptor 1. Biodiversity is maintained
- Descriptor 2. Non-indigenous species do not adversely alter the ecosystem
- Descriptor 3. The population of commercial fish species is healthy
- Descriptor 4. Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5. Eutrophication is minimised
- Descriptor 6. The sea floor integrity ensures functioning of the ecosystem
- Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- Descriptor 8. Concentrations of contaminants give no effects
- Descriptor 9. Contaminants in seafood are below safe levels
- Descriptor 10. Marine litter does not cause harm
- Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Each descriptor has a set of criteria and associated indicators, which are distinctive technical features. The aim of the indicators was to provide a measure and/or indication of the status of criteria that a Member State (MS) can use to make an assessment of the status of a Descriptor. These criteria and indicators were first defined in the Commission's Decision of 1 September 2010 on criteria and methodological standards on

GES of marine waters (Decision 2010/477/EU[48]). However, they were subsequently updated in 2017[49] to capture knowledge gained through the first round of evaluation of MS progress and harmonise with other European Directives (including Habitats and Birds Directives). One of the aims of that update was to provide "clearer, simpler, more concise, more coherent and comparable set of GES criteria and methodological standards".

Due to the diversity of the EU Seas, MS may choose which descriptors to apply, and within each descriptor which criteria and indicators to use. However, these decisions must be justified to the EU and not endanger consistency and comparison between regions and sub -regions.

Indicators identified as having potential relevance to HMS fall under descriptors 1, 3 and 4. They include conventional ones such as population abundance and spawning biomass to less common ones such as the proportion of selected species at the top of food webs and physical, hydrological and chemical conditions of habitats. Further information on specific indicators are provided under sub-task 1.2.

iii) Lessons learnt and good practices derived from implementing the MSFD

The European Commission's assessment of the first phase of implementation of the MSFD[50] has provided useful insight into challenges and improvements. A summary of some of the lessons learnt through this process as well as good practices covered in the assessment is provided below:

Lesson- Ecosystem indicators can be the catalyst for stronger regional collaboration - The work on MSFD has triggered further collaboration at regional level; for example, to support reports on the state of the sea in a region and identify regional-level indicators. The work so far has highlighted the importance of regional cooperation for implementing MSFD and the need for regional work to influence national implementation processes.

Lesson – Still many knowledge gaps - The assessment showed that there are still considerable knowledge gaps about marine systems and issues that affect them and that makes it difficult to achieve the level of sophistication in ecosystem-based assessments such as that MSFD requires.

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[48] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010D0477(01)&from=EN
[49] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32017D0848
[50] http://ec.europa.eu/transparency/regdoc/rep/1/2014/EN/1-2014-97-EN-F1-1.Pdf

Lesson – Importance of making use of all knowledge available - There were cases in which full advantage of knowledge had not been taken, leading to a fragmented view of the state of the marine environment. Knowledge built through regional collaborations or through assessments carried out for other relevant legislation needs to be an integral part of an ecosystem approach.

Good practice - Streamline research - Tailored-made projects have been funded by the EU to provide additional support to Member States in addressing challenges and knowledge gaps specific to their area. This creates the opportunity to streamline research to address the most pressing challenges and for Member States to lead the work to fill those knowledge gaps.

Good practice - Improved efficiency in reporting - Reporting at Member State level has been adjusted to take advantage of existing reporting requirements that are already in place for other relevant legislation to simplify and streamline the reporting process under MSFD. This approach is based on the principle of "report once, use many times".

Good practice - Systematic and effective data collection - The "Marine Knowledge 2020" initiative was identified as a good example of efforts towards improving accessibility and inter-operability of marine data. The assessment recognised the importance of such mechanisms of knowledge sharing and identified opportunities for further improvements in data collection and sharing between EU and regional organisations building on the Marine Knowledge 2020 initiative.

Program 3: Development Of innovative Tools for understanding marine biodiversity and assessing GES -DEVOTES

i) Aim and objectives

The DEVOTES project aimed at developing tools to support the implementation of the Marine Strategy Framework Directive (MSFD) by European Member States and Regional Seas Conventions. DEVOTES specifically addressed the MSFD biological descriptors (D), such as Biodiversity (D1), Food-webs (D4) and Seafloor integrity (D6). Despite the Descriptor on Species of commercial interest (D3) not having been the direct focus of the project, some work has been done for this descriptor and the insights from DEVOTES can be of use to this project.

The DEVOTES project had five key objectives:

1. Improve our understanding of the impact of human activities and climate change on marine. This helped to identify the barriers and bottlenecks that prevent Good Environmental Status (GES) from being achieved.

2. Test relevant existing indicators, and develop new, innovative ones to assess biodiversity at several ecological scales (species, habitats, ecosystems), including functional diversity, metagenomic and metagenetic analyses and approaches.

3. Develop, test and validate innovative integrative modelling and cost-effective monitoring tools to further improve our understanding of ecosystem and biodiversity changes in space and time.

4. Implement cost-effective indicators, monitoring and assessment strategies.

5. Propose and disseminate strategies and measures for ecosystems' adaptive management strategies.

ii) Ecosystem science and indicators

As indicated above, DEVOTES aimed at supporting the implementation of the MSFD in European waters by improving the understanding of human activities and variations due to climate change on marine biodiversity. This included testing the indicators proposed by the EC and the Member States and develop new indicators for assessment at species, habitat and ecosystem level, in order to assess the environmental status of the marine environment.

To support this process, a catalogue of indicators was produced. The original contributions to the indicator catalogue were collected from the DEVOTES partners, and mainly focusing on the biological descriptors. Therefore, some geographical areas and D3 (species of commercial interest), may be underrepresented in this catalogue of more than 600 indicators.

With regards to HMS, the second and fourth objectives, and the outcomes obtained through the WPs associated to such objectives, can be of special relevance to this project.

Indeed, the following outputs can be of use to this project:

- Deliverable 3.1 Existing biodiversity, non-indigenous species, food web and seafloor integrity GEnS indicators. This deliverable includes a description and analysis of the DEVOTOOL indicator catalogue and the software itself. Although the indicators that are included in DEVOTOOL mainly relate to descriptors D1, D4, and D6, it could also be used with e.g. D3 indicators. Regarding the content of the DEVOTOOL, please see below.

- Deliverable 3.2 Report on the criteria for good indicator selection. It provides a framework for assessing quality of indicators of good environmental status. This framework has been published in Queirós et al 2016[51] and can be used for the selection of HMS related indicators. It evaluates whether candidate biodiversity indicators meet quality criteria that underpin the MSFD. Testing and scoring protocol was based on 8 quality criteria (simplified from the 16 criteria defined by ICES): 1) Scientific basis; 2) Ecosystem relevance; 3) Responsiveness to pressures; 4) Possibility to set targets; 5) Early warning capacity; 6) Concreteness; 7) Cost-Efficiency; 8) Existing and on-going data). A test application of the quality criteria for indicators under three GES descriptors (1, 5, and 6), various habitat components (seaweeds, seagrasses, benthic macrofauna, and plankton), and assessment regions (Danish, Lithuanian, and UK waters) was carried out.

- Deliverable 3.3 Report on the good indicators and methods for setting reference and target values. Main outcomes of this deliverable is a set of quantitative criteria for choosing targets and ecosystem indicators[52] following and can be of use for choosing targets of HMS indicators.

- Deliverable 6.3. Manual, guidelines and software for biodiversity assessment. This deliverable provides information on the NEAT software, which is described below.

- **DEVOTool:** this freely available software (http://www.devotes-project.eu/devotool-the-next-steps/), allows stakeholders, Regional Sea Conventions, Member States, EEA, etc., to search for indicators to environmental assess status, select and refine indicators, and then use them in the assessment tool developed in DEVOTES. It has been updated this year and now it has more than 600 indicators.

[51] Queirós, A. M., Strong, J. A., Mazik, K., Carstensen, J., Bruun, J., Somerfield, P. J., ... & Özaydinli, M. (2016). An objective framework to test the quality of candidate indicators. Frontiers in Marine Science, 3, 73

[52] See Rossberg, A. G., Uusitalo, L., Berg, T., Zaiko, A., Chenuil, A., Uyarra, M. C., ... & Lynam, C. P. (2017). Quantitative criteria for choosing targets and indicators for sustainable use of ecosystems. Ecological indicators, 72, 215-224

- **NEAT (Nested Environmental status Assessment Tool)** provides a mean for assessing the environmental status of marine areas according to the MSFD. The tool is hierarchically structured to assess environmental status for different ecosystem components, within different habitats, ensuring optimal weighting of indicators for the overall status assessment. This tool integrates spatial and temporal information, at different scales, together with indicators from different descriptors (which can be selected from DEVOTool). The tool is flexible and can be used for specific MSFD descriptors, for groups of descriptors or for all descriptors combined. Finally, the tool includes an uncertainty assessment of the status, providing confidence estimates of the status classification. The software is freely available at http://www.devotes-project.eu/neat), and the last version 1.3 was released in June 2017.

In order to select the most relevant indicators for this project, searches within the catalogue were made using different filters. First, indicators related with D3 were filtered. Secondly, the following key words were subsequently used to select additional indicators: *fish, *bird, *mammal, *bycatch. From all indicators, a total of 66 were finally selected as potential use to this project (Appendix 1.2). Despite some of them may have been very similar (e.g. abundance of species of key functional groups, abundance of predatory species, etc.), it was decided to maintain them separate, as their original purpose might be different.

iii) Lessons and good practices derived from implementing the DEVOTES project

Good practice -Data availability - For most indicators identified within DEVOTES as potentially relevant for HMS, data can be obtained through existing monitoring programmes. In that sense, the implementation of indicators is potentially straight forward if monitoring programs exist.

Good practice - Complexity of indicators - Many of the indicators identified within DEVOTES as potentially relevant for HMS are based on simple statistics, therefore they do not require highly specialized people to implement them.

Lesson -Refinement and development/validation of indicators - Despite many existing indicators, there are certain gaps as some may need refining or making them operational within the context of HMS, that is, e.g. defining reference conditions.

Lesson - Different names for same indicators - During the DEVOTOOL development many indicators were identified as being the same but recorded under different names at different locations. This required name harmonization.

Lesson - Similarity between indicators - DEVOTOOL provides a series of indicators that are very similar in content, but different in focus. Such indicators have been kept as different indicators, since their focus is different and their potential application too.

Lesson - State *versus* pressure indicators - Within DEVOTOOL indicators are classified into state, pressure or response indicators. These indicators are complementary and ideally each type of indicator should be available to monitor the impact of an activity and its management on the system.

Good practice – The use of a quality criteria to select indicators - The criteria developed by Queirós et al. 2016 provides a transparent and standardized structure for indicator selection for assessment purposes (Queirós *et al.*, 2016). This protocol could potentially be applied to HMS-related indicators.

Good practice – Target setting of indicators - Setting targets in relation to ecosystem resilience (i.e. the ability to recover rapidly and predictably from pressures) and to select indicators and their target ranges was developed (Rossberg *et al.*, 2017). The focus is on the assessments of the low-resilience components that recover slowly after pressures have been removed or decreased. The aim is to define GES boundaries that ensure sustainable use of ecosystem services and allows considerations of their suitability for current societal needs. Although this was mainly applied to the three descriptors of DEVOTES, it could potentially be applied to HMS-related indicators.

Good practice -NEAT tool and indicators: Previous versions of NEAT was developed for integrating only indicators that respond to pressures following a linear response. However, it has been highlighted that, especially in fisheries, several indicators can respond following a bell shape where there is an optimum value below and above which the status is bad. Additially, indicators that provide presence/absence information can also be relevant indicators. The most recent version of NEAT has been adapted to fill this need. Therefore, NEAT can now be applied in the assessment of HMS, with not indicator type limitations.

Program 4: Applying an ecosystem approach to (sub)regional habitat assessment –EcApRHA project

i) Aim and objectives

The EcApRHA project[53] addressed gaps in biodiversity indicator development for the OSPAR region and was the first EU funded project coordinated by the OSPAR Secretariat. The EcApRHA project has been a 15-month project co-financed by the EU DG Environment and ran from December 2015 to February 2017.

The project has focused on overcoming challenges that were identified while delivering regional biodiversity indicators for the application of the MSFD (Marine Strategy Framework Directive (56/2008/EU), especially for Descriptors 1, 4, and 6 for pelagic habitats, benthic habitats and food webs.

OSPAR has identified a set of 16 common biodiversity indicators and a set of candidate indicators that require further development before they are considered to be operational; EcApRHA worked on these candidate indicators. Geographically, the project has mainly focused on the OSPAR Regions the Greater North Sea, Celtic Seas and Bay of Biscay/Iberian coast, but excluding the Wider Atlantic.

ii) Ecosystem science and indicators

Following a multiyear process, indicators had been proposed through a working group of OSPAR (ICG-COBAM) in order to capture aspects of biodiversity and food webs that were considered relevant by scientific experts and of use to managers. Indicators of pelagic and benthic habitats and food webs, proved particularly difficult to assess (due to difficulties collating and examining data, in the identification of pressure-state links and subsequently setting baselines and assessment targets) and those with outstanding issues, were picked up by the project. In particular, the OSPAR common indicators developed within the EcApRHA project:

- PH1/FW5 (Changes of plankton functional types (life form) index Ratio)
- PH2 (Plankton biomass and/or abundance)
- PH3 (Changes in biodiversity index), BH2 (Multi-metric indices), BH3 (Physical damage habitats)
- FW4 (Changes in average trophic level)

The OSPAR candidate indicators developed within the EcApRHA project:

- BH1 (Typical species composition)
- BH4 (Area of habitat loss)

[53] http://www.ospar.org/work-areas/bdc/ecaprha, (Grant number 11.0661/2015/712630/SUB/ENVC.2)

- FW2 (Production of phytoplankton)
- FW6 (Zooplankton community size structure in relation to biomass/abundance)
- FW7 (Biomass and abundance of functional groups)
- FW9 (Ecological Network Analysis)

Indicators identified through the case studies of relevance to HMS are:

- PH1/FW5 (Changes of plankton functional types (life form) index Ratio)
- PH2 (Plankton biomass and/or abundance)
- FW4 (Changes in average trophic level)
- FW2 (Production of phytoplankton)
- FW6 (Zooplankton community size structure in relation to biomass/abundance)
- FW7 (Biomass and abundance of functional groups)

iii) Lessons and good practices derived from implementing the EcApRHA project

Good practice – integration of data sources – Where multiple data sources exist (e.g. of primary production or zooplankton abundance) studies should be developed so that indicators can draw on a range of data sources. However, care must be taken to represent spatial complexity in the data. In particular, fixed point data (stations) and broad scale survey data (e.g. Continuous Plankton Recorder) may not be suitable to aggregate directly. Rather the outputs can be considered together following separate analyses.

Lesson – indicators require routine monitoring – Although plankton indicators have been developed for OSPAR MS, infrequent funding for the surveys means that updated assessments are uncertain. For indicators to be fully embedded within ecosystem level assessments long-term funding should be agreed.

Lesson – Exploitation and management history is important – For indicators of trophic level in exploited seas, it is fundamental that results be interpreted in the light of fisheries and exploitation history of the area. Some oscillations in the trends observed can be easily explained knowing the fluctuations in fishing effort and which species are considered the key target species for fishers.

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12. APPENDIX 1.3 - INDICATORS DERIVED FROM REVIEW OF GOOD PRACTICE EXAMPLES AND RELEVANT PROJECTS/INITIATIVES

This appendix corresponds to the Excel file called "Review Indicators.xlsx " which can be found as a separate file. Available upon request (email: *EASME-EMFF-CONTRACTS@ec.europa.eu)*.

13. APPENDIX 1.4 - CRITERIA FOR INDICATOR SCREENING

Table 1. List of indicator screening criteria (in bold) with detailed considerations required to conduct scoring (where scores are either H = high, F = fair, M = moderate, L = low) reproduced from Rice and Rochet (2005).

Concreteness Concrete property of physical/biological world (H), or abstract concept (L)? Units measurable in the real world (H), or arbitrary scaling factor (L)? I Direct observations (H), or interpretation through model (L)?

Theoretical basis (number of competing theories to allow contrast is important) (i) Not contested among professionals (H) (ii) basis credible, but debated - can account for patterns in many data sets (H-F, depending on how other models fit the same data) (iii) credible, but competing theories have adherents and empirical support is mixed (M) (iv) adherents, but key components untested or not generally accepted (M-L) *If indicator derived from empirical observations:* (i) concepts readily reconciled with established theory (H) (ii) concepts not inconsistent with, but not accounted for by, ecological theory (M) (iii) concepts difficult to reconcile with ecological theory (L) Theory allows calculation of reference point associated with serious harm (M)

Public awareness

Is it a property with a high (H) or low (L) public awareness outside the use as an indicator?

Does public understanding correspond well (H) or poorly (L) with technical meaning of Indicator?

If awareness high, is public likely to demand action that is:

(i) proportional to indicator value as determined by experts (H)

(ii) disproportionately severe (M)

(iii) largely indifferent (L)

Does the nature of what constitutes ‘‘serious harm’’ (used to define a reference point) depend on values that are widely shared (H) or vary widely across interest groups (L)?

Internationally binding agreements, national or regional legislation require that a specific indicator be reported at regular intervals (H), to agreements/legislation require environmental status reporting, but indicator not specified (M) to no such requirements (L)

Cost

Uses measurement tools that are widely available and inexpensive to use (H), to needs new, costly, dedicated, and complex instrumentation (L)

Measurement

Can variance and bias of indicator be estimated? Yes (H); No (L)

If variance can be estimated, is variance low (H) to high (L)

If bias can be estimated, is bias low (H) to high (L)?

If indicator biased, is direction usually towards overestimating risk (H), or towards underestimating risk (L)

If both can be estimated, have variance and bias been consistent over time (H), or have they varied substantially (L)

Probability that indicator value exceeds reference point can be estimated with accuracy and precision (H), to coarsely or not at all (L)

Indicator measured using tools with known accuracy and precision (H), to unknown or poor/inconsistent (L)

Value obtained for indicator unaffected by sampling gear (H), to sampling methods can be calibrated (M), to calibration difficult or not done (L)

Seasonal variation unlikely or highly systematic (H) to irregular (L)

Geographic variation irrelevant or stable and well quantified (H), through random (M) to systematic on scales inconsistent with feasible sampling (L)

Taxonomic representivity: indicator reflects status of all taxa sampled/modelled (High), through ecologically predictable subset of species (M), to only specific species with no identifiable pattern of representivity (L)

Availability of historical data

Necessary data are available for: periods of several decades (H) to only relatively recent period (M), to opportunistic or none available (L)

Necessary data are: from the full area of interest (H), to restricted but consistent sampling sites (Moderate), to opportunistic and inconsistent sources, or none (L)

Necessary data have high contrast, including periods of harm and recovery (H), to high contrast but without known periods of harm and recovery (M), to uninformative about range of variation expected (Low)

The quality of the data and archiving is known and good (H), to data scattered with reliability but not systematically certified, and archives not maintained (L)

MP (e.g. environmental indicator)

Data sets are freely available to research community (H), to private or commercial holdings (L)

Sensitivity (length of time-series used for testing important)

Indicator responds to fishing in ways that are:

(i) smooth, monotonic, and with high slope (H)

(ii) smooth, monotonic, and with low slope (M)

(iii) smooth, monotonic over a restricted range of effort characteristics (M-F)

(iv) unreliable (M-F, depending on when it fails to inform about fishing effects)

(v) insensitive or irregular. Magnitude of response does not depend on magnitude of signal in effort (L)

Responsiveness (length of time-series used for testing important)

Indicator changes within 1-3 years of implementation of measures (H), to indicator only reflects system responses to management on decadal scales or longer (L)

Specificity (contrast in data set used for testing important)

Is impact of environmental forcing on indicator known, and small (H) or strong (L)?

If environmental forcing affects indicator, effect systematic and known (H), to irregular or poorly understood (L)

Relative to other factors, Indicator

(i) known to be unresponsive (H)

(ii) responds to specific factors in known ways (M)

(iii) thought to be unresponsive (F)

(iv) responds to many factors in only partly understood ways (L)

Table 2. Indicator criteria reproduced from Kershner et al. (2011).

Primary Considerations

1) Theoretically-sound (TS) - Scientific, peer-reviewed findings should demonstrate that indicators act as reliable surrogates for ecosystem key attribute(s).

2) Relevant to management concerns (RM) - Indicators should provide information related to specific management goals and strategies.

3) Responds predictably and is sufficiently sensitive to changes in a specific ecosystem key attribute(s) (REA) - Indicators should respond unambiguously to variation in the ecosystem key attribute(s) they are intended to measure, in a theoretically- or empirically-expected direction.

4) Responds predictably and is sufficiently sensitive to changes in specific management action(s) or pressure(s) (RMAP) - Management actions or other human-induced pressures should cause detectable changes in the indicators, in a theoretically- or empirically-expected direction, and it should be possible to distinguish the effects of other factors on the response.

5) Linkable to scientifically-defined reference points and progress targets (LT) – It should be possible to link indicator values to quantitative or qualitative reference points and target reference points, which imply positive progress toward ecosystem goals.

Data Considerations

6) Concrete (C) - Indicators should be directly measureable.

7) Historical data or information available (HD) - Indicators should be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.

8) Operationally simple (OS) - The methods for sampling, measuring, processing, and analysing the indicator data should be technically feasible.

9) Numerical (N) - Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments.

10) Broad spatial coverage (BSC) - Ideally, data for each indicator should be available throughout its range in Puget Sound.

11) Continuous time series (CTS) - Indicators should have been sampled on multiple occasions, preferably without substantial time-gaps between sampling.

12) Spatial and temporal variation understood (STV) - Diel, seasonal, annual, and decadal variability in the indicators should ideally be understood, as should spatial heterogeneity or patchiness in indicator values.

13) High signal-to-noise ratio (HSN) - It should be possible to estimate measurement and process uncertainty associated with each indicator, and to ensure that variability in indicator values does not prevent detection of significant changes.

Other Considerations

14) Understood by the public and policy makers (UP) - Indicators should be simple to interpret, easy to communicate, and public understanding should be consistent with technical definitions.

15) History of public reporting (HR) - Indicators already perceived by the public and policy makers as reliable and meaningful should be preferred over novel indicators.

16) Cost-effective (CE) - Sampling, measuring, processing, and analysing the indicator data should make effective use of limited financial resources.

17) Anticipatory or leading indicator (A) - A subset of indicators should signal changes in ecosystem attributes before they occur, and ideally with sufficient lead time to allow for a management response.

18) Regionally/nationally/internationally compatible (CM) - Indicators should be comparable to those used in other geographic locations, in order to contextualize ecosystem status and changes in status.

Post-hoc Analysis

19) Complements existing indicators - This criterion is applicable in the selection of a suite of indicators, performed after the evaluation of individual indicators in a post-hoc analysis. Sets of indicators should be selected to avoid redundancy, increase the complementary of the information provided, and to ensure coverage of key attributes.

14. APPENDIX 2.1. - LIST OF INDICATORS AND APPLICATION OF THE QUEIROS ET AL 2016 CRITERIA

This appendix corresponds to an Excel file called "Appendix 2.1 – Indicators Queiros et al 2016", which can be found as a separate file. Available upon request (email: *EASME-EMFF-CONTRACTS@ec.europa.eu).*

15. APPENDIX 3.1 - DETAILED DESCRIPTION OF THE BIOGEOGRAPHIC CLASSIFICATIONS

The reviewed biogeographic classifications include both coastal and oceanic classifications of the marine pelagic environment. The classifications presented below did not meet all the criteria relevant for the development of ecoregions in line with the EAFM in tuna RFMOs, but they provided useful insights and lessons to inform the development of candidate ecoregions.

Below we described all the biogeographic classifications reviewed:

1.Large Marine Ecosystems

2.Longhurst's Biogeographical Provinces

3.Marine Ecoregions of the World

4.Pelagic Provinces of the World

5.Reygondeau's Biogeography of Tuna and Billfish Communities

6. Global Open Ocean Biomes

LARGE MARINE ECOSYSTEMS (LME)

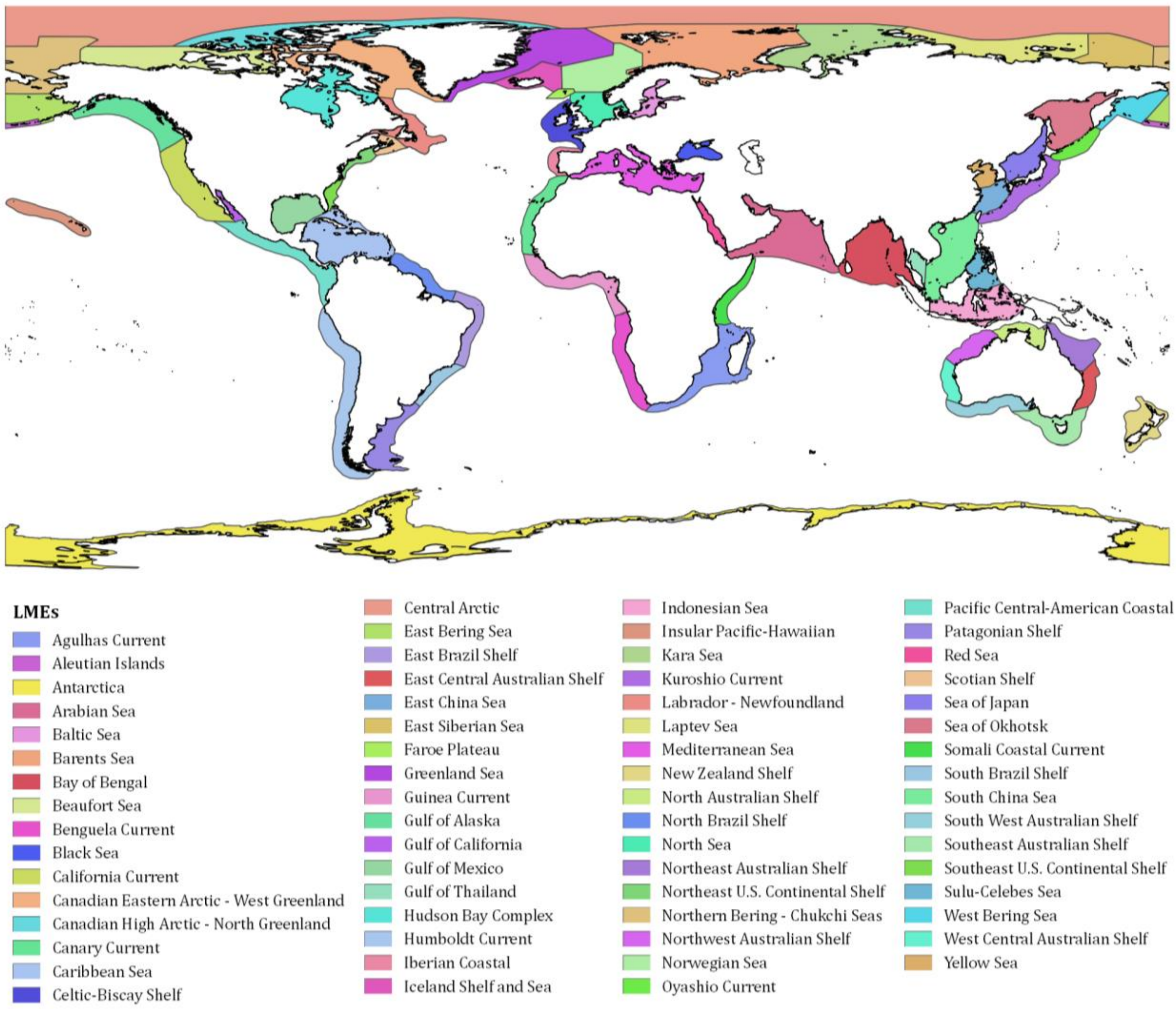

Figure 1. Large Marine Ecosystems division including 66 ecosystems encompassing all coastal areas globally (NOAA, 2017).

Background - The development of the Large Marine Ecosystems dates back to the 80s when it was commissioned by National Oceanic and Atmospheric Administration (NOAA) in response to increasing threats to the coastal regions and therefore the need for their delineation in order to manage them more successfully (Sherman, 1988, 1994; Sherman & Duda, 1999; Sibert, 2005). This classification is known for developing the core methodology which forms the basis of many of the current classification systems today. In 1994, inspired by the United Nations (UN) Conference on Environment and Development (UNCED), held in 1992, on improvement and conservation of coastal regions, Sherman proposed the LME classifications as an ecosystem-oriented management regime (Sherman, 1994). It has a strong socioeconomic component to inspect cost effectiveness of the methodology, and suitability for use in management which makes it helpful for stakeholders.

Objectives and main drivers of the classification - The aim of the classification was to delineate all the coastal areas into regions of appropriate scale to be practical for policy development, management and monitoring of fishery resources due to growing anthropogenic pressures in the marine realm. Since 1994, NOAA has also been cooperating with many other institutions like the Global Environment Facility (GEF), the IUCN and UN, in order to use LMEs as management units in other countries as well as in the USA within the developing ecosystem approach to fisheries of the 90s (Sherman, 1994; Sherman & Duda, 1999; Sibert, 2005). Also, the classification aims to be management friendly, reflect the concept of sustainability, and be cost effective.

Methodology and data used - The LME regions are based on a set of oceanographic features including bathymetry and hydrography, and a set of community features including productivity and trophic relationships, as well as ecosystem health assessment, which are revised through extensive expert consultations (Sherman, 1994). Data used for the classification included fisheries-independent research surveys (e.g. fish eggs and larvae research surveys, bottom and pelagic fish research surveys) on spatial grids varying between 20-100 km at variable temporal scale; biological and environmental studies within the same scales to identify the processes controlling recruitment, like predator-prey interactions or biological production; as well as measurements obtained during multidisciplinary fish abundance research surveys to describe their physical, chemical, and biological environments (Sherman, 1988). Seaward boundary usually reflects either the boundary of continental shelves, or the outer boundary of coastal currents activity (Watson *et al.*, 2000). The research done and methodology employed are described for each of the regions defined in 14 volumes published on LMEs up to date (Sherman, 1994; NOAA, 2017).

Description of the classification - The LMEs are based on extensive research and analyses that has resulted in the classification of 66 regions (Figure 1) (NOAA, 2017). It is a product of a continuously evolving process, which has tried to accommodate scientific basis with geopolitical features. The LMEs are regions of approximately 200,000 km^2 in size, characterized by specific oceanographic and biological characteristics which make them different to one another; each one developed by an extensive research process reviewed by expert groups (Watson *et al.*, 2000; Spalding *et al.*, 2007). The regions are used to inform marine resource management with ecosystem advice by NOAA.

Purpose and their current use - Since its creation, the LME classification system has been used to direct research on fisheries management and transboundary management of fisheries, pollution handling, habitat restoration and protection, recruitment and production measurements and in general, marine governance (Watson *et al.*, 2004; Spalding *et al.*, 2007; 2010). In addition to this, LMEs have been used for analyzing relationships between biodiversity and ecosystem services (Worm *et al.*, 2006). The current classification is supported by the GEF, IUCN and UN, and LMEs have been used in various research projects worldwide (2009; 2010; NOAA, 2016).

Relevance for the management of tuna and tuna-like species within an ecosystem approach - This biogeographic classification is spatially limited only to the continental shelf areas and does not cover the open ocean areas. It has therefore a limited application to inform the development of ecosystem indicators to monitor the impacts of tuna and billfish fisheries on oceanic systems. However, ICCAT is also in charge of managing and conserving some coastal species such as small tunas, bonitos and Spanish mackerels. Therefore, this classification system could potentially be used to inform the management and conservation of the more coastal species under the purview of ICCAT.

This is one of the first marine classifications developed and one of the most commonly used to operationalize the EAFM in coastal regions, therefore, despite not being fully relevant to inform fisheries management of oceanic tunas and billfishes, some best practices and advices can still be derived:

The division into provinces that are both ecological and practical is the result of a long interactive process where expert knowledge and feedbacks from fisheries managers and conservation practitioners is needed.

It is important to start the process, making informed decisions based on the best science available and following the precautionary approach: further improvements and additions can follow and included over time.

LONGHURST BIOGEOGRAPHICAL PROVINCES (BGCPs)

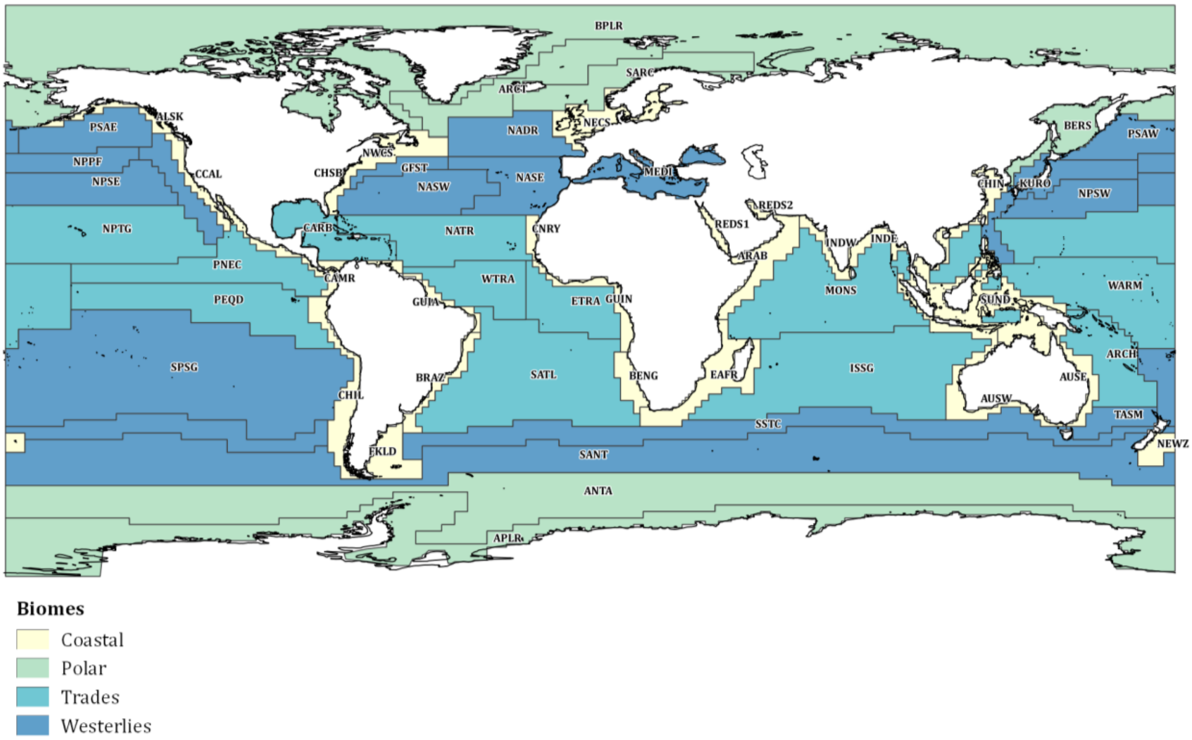

Figure 1 - Longhurst Biogeochemical provinces (BGCPs) delineated with black lines, and the biomes to which they belong are color-coded (Longhurst, 2007).

Background - One of the most elaborate biogeographic classifications of the ocean into ecological provinces is the Longhurst's classification in biogeochemical provinces (Figure .2) (Longhurst, 1998). The idea for this classification arose from the work on the spectral irradiance field and its applications to oceanography, which suggested that primary production and its descriptors could be used to partition the ocean into provinces (Sathyendranath & Platt, 1988). Longhurst also incorporated important ocean's geological features and principles of oceanography into his classification, in particular global circulation patterns. In the 90s, when the first edition of the book "Ecological Geography of the Sea" was published (Longhurst, 1998), the lack of information and technological advances did not allow for inclusion of some important aspects like the coupling between pelagic and benthic processes, or the coupling between plankton and higher trophic organisms. With the increase in the number of available data sources, technological advances and new possibilities for data interpretation, a revision of the book was published in 2007, as a second edition, based on the same, but updated, principles (Longhurst, 2007).

Objectives and main drivers of the classification - The main driver behind the Longhurst's classification system into biogeochemical provinces was to provide ecologists with a thorough manual on regional oceanography to facilitate the study of ocean ecosystems on a quantitative level; it also allowed the mapping of these ecosystems (Longhurst, 2007). His goal was to make the classification applicable to various kinds of research and this was achieved by using only the available data sets, with no expert opinions, in order to make it more measurable and replicable (Longhurst, 1998; Costello, 2009; UNESCO, 2009).

Methodology and data used - The data used to determine boundaries between regions was collected from several databases and studies conducted globally during a period of rapid advancement in oceanography. The data used can be divided into biological and physical oceanographic datasets. The physical oceanographic data was used to reflect discontinuities in physical processes in the ocean which delineated the main biomes in the classification. The biological features, such as phytoplankton distribution and concentration, and primary productivity, were interpreted from satellite imagery projects – SeaWiFS (1997-2002) and MODIS, for the second edition. The biological and physical data sets were validated for use in ocean separation into distinct regions by using an extensive dataset on phytoplankton - the Continuous Plankton Recorder dataset (Beaugrand, 2002; Beaugrand *et al.*, 2002). Together with datasets on oceanographic features that were used to delineate biomes, the analyses of the biological data and satellite imagery produced Longhurst's division into bio-geochemical provinces. Compared to the first edition of the delineation, these boundaries were made dynamic by considering subtle shifts in values between adjoining cells.

Description of the classification - Based on observed or inferred discontinuities in physical processes that affect the stability of the water column, four main biomes were defined for the ocean - Polar, Westerlies, Trades and Coastal biomes. The author argues that: "…processes that force stratification of the surface layers thereby also determine characteristically different phytoplankton regimes…" (Longhurst, 2007). Fronts and frontal systems like the Polar, Subtropical and Equatorial frontal systems are places in the open ocean that give the least ambiguous boundaries. In addition to those, the horizontal boundary defined by the pycnocline, separating the epipelagic region from the deeper water at around 1000m depth, is of immense ecological significance and represents the bottom boundary of interest in the delineation of the biomes.

The Polar biome describes regions where mixed layer depth is influenced by the brackish, surface layer, which forms in spring due to ice melting and brine expulsion along the margins of the ice cover forming a strong pycnocline. The Westerlies biome is defined by influences of the local winds and irradiance pattern which are impacting the mixed layer depth. Wind forcing and geostrophic adjustment are forcing the mixed layer depth in the Trades biome. Finally, the Coastal biome represents all the coastal areas which are very dynamic and diverse in processes which can modify the nutrient inputs and the mixed layer depth, most notably in upwelling regions and production at coastal divergences.

The four biomes were further partitioned into provinces, mostly based on surface chlorophyll concentrations and strong chlorophyll gradients. Other parameters such as mixed-layer depth and photic depth, were also used to further partition the biomes. This resulted in the delineation of 57 bio-geochemical provinces, out of which 22 are coastal. The parameters used in the delineation of provinces are relevant only in the upper part of the water column which is influenced by light and wind stress, so the horizontal boundary of the provinces is at the depth of approximately 200m.

Purpose and their current use - Several studies have tested the partitioning of the Longhurst´s BGCPs, proving the reliability of the established boundaries (Longhurst, 2007). Longhurst´s BGCPs have also been used extensively in various research topics e.g. in relation to fisheries management (Pauly *et al.*, 2000), as units for plotting biodiversity variations in the oceans (Olson & Dinerstein, 2002), for predicting species habitats (Mannocci *et al.*, 2014), as well as in ecosystem and community research (Reygondeau *et al.*, 2012). The study of Reygondeau will be described in more detail later on, since it defines biogeographic regions based on global tuna and billfish distributions. An older study by Fonteneau also investigated the distribution of tuna species in the Eastern Pacific Ocean and their association with Longhurst provinces, concluding that their distributions are in accordance with the provinces boundaries (Fonteneau, 1997).

Relevance for the management of tuna and tuna-like species within an ecosystem approach - For implementing an EAFM in the management of tuna and tuna-like species, the Longhurst biogeographic classification could potentially inform the determination of fisheries management regions, for a series of reasons:

It classifies both the coastal and oceanic environment making it relevant for oceanic tunas, billfishes and sharks as well as the coastal species under the purview of ICCAT.

The two tiers of the hierarchical classification (biomes and provinces) poses an advantage since the different spatial levels and subdivisions could be used for different scale management purposes. One of the potential drawbacks could be the large number of provinces within each biome, which might make its use impractical from an operational point of view in the context of managing highly migratory and widely distributed oceanic species.

It has a strong basis on the physical features of the water columns, which are important factors in determining species distributions as well as informing the delineation of ecosystem-resembling regions with distinct biophysical characteristics. Although Longhurst recognized boundaries are of dynamic nature (Longhurst, 2007), he argues that for practical purposes it is imperative that static boundaries are identified and used with the purpose of representing the real state of the oceans. One of the drawbacks of this classification system is that it is focused mainly on a set of abiotic properties of the water columns, and it is not based on species and community data, except from phytoplankton concentration.

MARINE ECOREGIONS OF THE WORLD (MEOW)

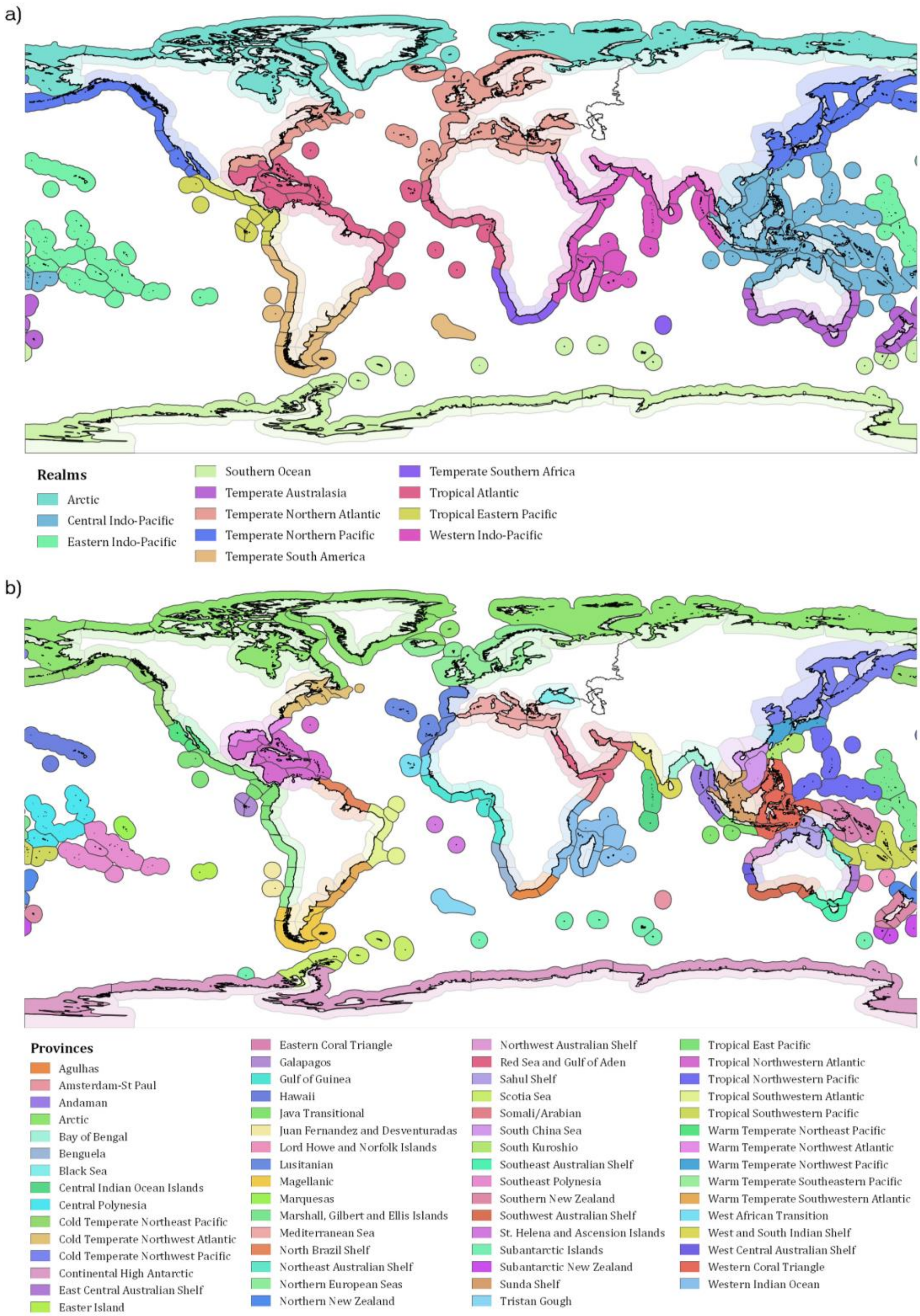

Figure 2 - Marine ecoregions of the world. a) Marine realms of the MEOW classification; and b) Marine provinces of the MEOW classification. Ecoregions are further subdivisions of the provinces, and are delineated with black lines (Spalding *et al.*, 2007).

Background - The marine ecoregions of the world (MEOW) were created in 2007 with the main purpose of reconciling the differences between the existing coastal classifications (Briggs's provinces, LMEs, Sullivan Sealey and Bustamante's provinces, Boschi provinces) and to provide a more global, comprehensive classification of the coastal areas (Spalding *et al.*, 2007). The main aim was to make a classification that is consistent, has global coverage, and uses a good methodological approach, so it could be used for management and conservation of marine resources and ideally avoid the need of making numerous regional coastal classifications.

Objectives and main drivers of the classification - The main drivers for the development of this biogeographic classification was to create a system that was appropriate for management of resources, conservation planning and other actions, allowing multiscale analyses, while respecting the natural boundaries imposed by physical and biological variability in the oceans. Their approach highlights the importance of areas' connectivity for the potential establishment of a system of protected regions that would be ecologically representative. In their opinion, the ideal system should be hierarchical, nested and based on taxonomy, patterns of dispersal, isolation and evolution of species, as well as on the oceanographic drivers that influence them. They adhered to three principles: (i) strong basis on biogeography by including relevant composite studies; (ii) practical and usable; and (iii) parsimonious, or similar to the already existing systems which was achieved by adopting the nested hierarchy. This classification focused on coastal and shelf waters, specifically benthic and shelf neritic biotas, because most of the world marine productivity lies in these waters.

Methodology and data used - This classification is largely based on reviews and synthesis of existing biogeographic boundaries based on various taxonomic and oceanographic data inputs, which were chosen in the first data-gathering phase, then finally selected based on data availability. The scope of work included "…over 230 works in journals, NGO (non-governmental organization) reports, government publications, and other sources" (Spalding *et al.*, 2007). The main objectives and methodologies were analyzed and compared in all these studies to inform the classifications. Finally, a large expert group provided further insights and exchanged opinions, until a draft classification was established and finalized during a three-day workshop. This produced a subdivision in a high number of small regions, which reflect the evolutionary history and degree of endemicity of their biota (Spalding *et al.*, 2007; Costello, 2009). This classification is the result of a more comprehensive process that uses expert knowledge to finalize the classification, resulting in a more qualitative and less replicable classification system.

Description of the classification - The resulting classification is nested hierarchically. It consists of 12 realms, 58 provinces and 232 ecoregions (Figure 3). The outer boundary for the system was set at the 200m isobath.

The realms, as largest spatial divisions, are based on the terrestrial concept of realms (Udvardy, 1975) and are defined as "…very large regions of coastal, benthic, or pelagic ocean across which biotas are internally coherent at higher taxonomic levels…" (Spalding *et al.*, 2007). The driving factors for the division at this scale are water temperature, historical and broad scale isolation of the species, and the proximity of the benthos (Spalding *et al.*, 2007).

Realms can be further divided into provinces similar to BGCPs or LMEs (Figure 3a). In this classification, they are described as "large areas defined by the presence of distinct biotas that have at least some cohesion over evolutionary time frames" (Spalding *et al.*, 2007). They are characterized by a certain level of endemism and distinctive abiotic features like geomorphological, hydrographic, or geochemical influences.

Finally, ecoregions are nested within provinces (Figure 3b). These are the smallest-scale units in the MEOW classification. These areas are characterized by "relatively homogeneous species composition, clearly distinct from adjacent systems" (Spalding *et al.*, 2007). Conditions affecting delineation at this scale are of mostly local nature, for example isolation, upwelling, nutrient inputs, freshwater influx, temperature regimes, ice regimes, exposure, sediments, currents, and bathymetric or coastal complexity.

Purpose and their current use - The MEOW classification is often used, together with LMEs and BGCPs classifications, in applied studies requiring knowledge on biogeographic classifications of marine resources to inform management and conservation (Costello, 2009; UNESCO, 2009). It has also been used in various conservation projects by organizations like WWF and Nature Conservancy (Spalding *et al.*, 2007). They have also been used as units for calculating human impacts on marine ecosystems on a global level (Halpern *et al.*, 2008), for predicting climate change threats in different regions (Belanger *et al.*, 2012), and for mapping threats posed by invasive species (Molnar *et al.*, 2008). As for its application in fisheries management, it is suggested that its structure would complement the EAFM approach in coastal waters (Crowder & Norse, 2008).

Relevance for the management of tuna and tuna-like species within an ecosystem approach - Similar to the LME biogeographic classification, the MEOW classification is spatially limited only to the shelf areas and does not cover the open ocean areas. Therefore, it has a limited application to inform the development of ecosystem indicators and assessment to monitor the impacts of tuna and billfish fisheries on oceanic systems. However, since ICCAT is also in charge of managing and conserving some coastal species of small tunas, bonitos and Spanish mackerels, this classification system could potentially be used to inform the management and conservation of the more coastal species. Some best practices and advice from this classification are:

The classification of provinces that are ecological and practical is the result of a long interactive process where expert knowledge and feedback from fisheries managers and conservation practitioners is needed.

A hierarchical and nested classification system, with appropriate scales of features that enter the hierarchy at the scale that it is known to affect the species distributions is also an advantage. The different spatial levels and subdivisions could potentially be used for different management purposes and planning.

PELAGIC PROVINCES OF THE WORLD

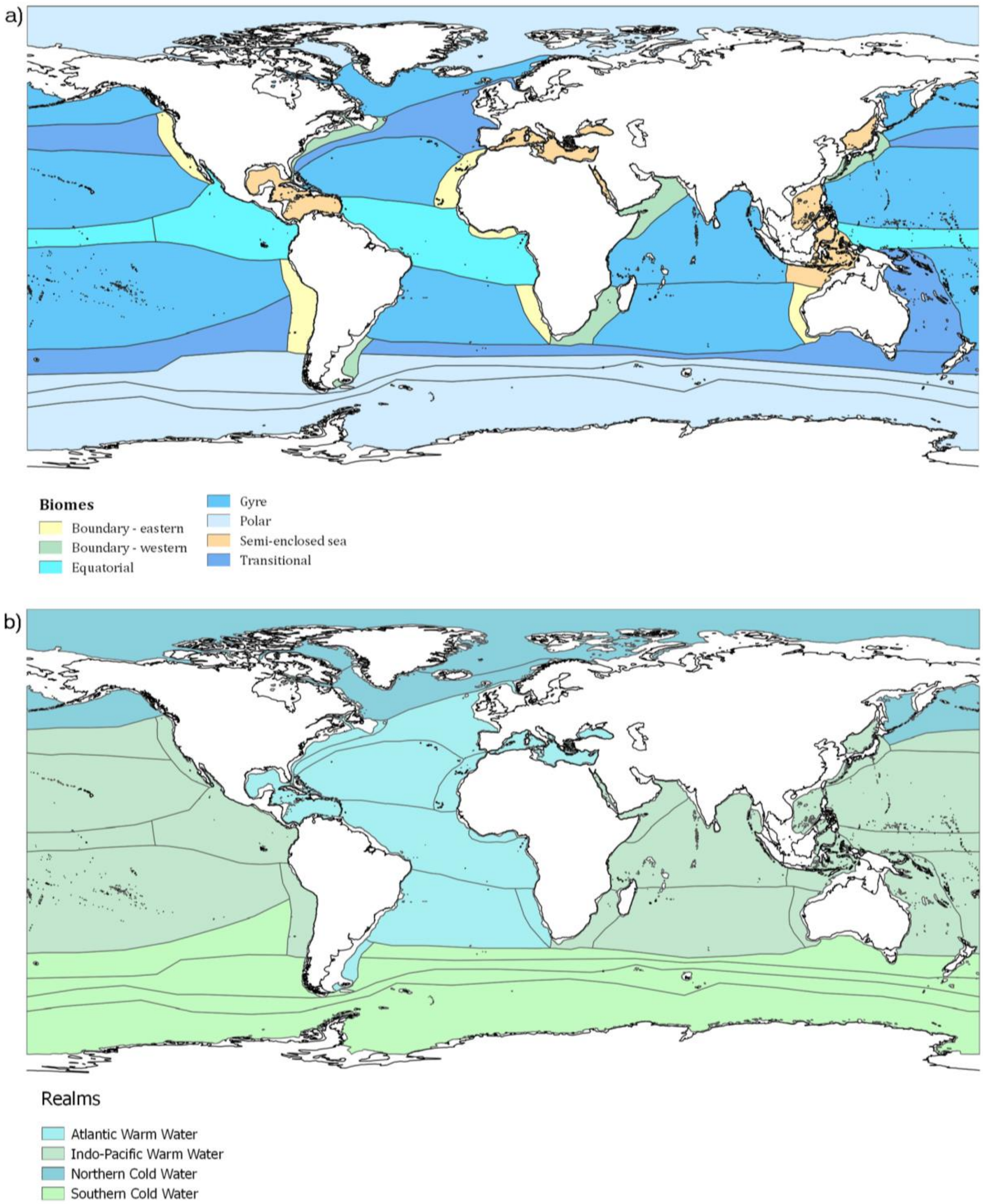

Figure 3 – Pelagic provinces of the world classification: a) Pelagic biomes of the world, and b) Pelagic realms. Individual provinces are delineated with black line (Spalding *et al.*, 2012).

Background - After the development of the MEOW classification and the recognition of the increasing anthropogenic pressures upon the high seas, Spalding and colleagues developed a classification covering the pelagic regions of the open ocean that builds up on MEOW (Spalding *et al.*, 2012). The classification is based on various qualitative inputs of data and principles, similar to the MEOW classification, with the main difference that it had to compensate for the biological data gaps that occur in open ocean as well as to use different community variables. The need for making this classification has been supported by the idea that many existing classifications could be simplified and synthesized into one that would be appropriate to address the policy issues involving the high seas.

Objectives and main drivers of the classification - The Pelagic Provinces of the World classification (PPOW) is based on the same principles of the MEOW classification. It aims to be based strongly on biogeography knowledge, to minimize the differences between existing regional and global classifications, and finally to be practical for its implementation (Spalding *et al.*, 2007). Reconciling the differences between existing politically and ecologically oriented regional classifications, such as those from RFMOs and the United Nations Environment Programme (UNEP) Regional Seas, has resulted in this classification having an increased use in protecting species and habitats. Following this approach, the authors aimed to make the PPOW classification by encompassing and solidifying the existing ones with updated information while aiming for better representation of species distributions (Spalding *et al.*, 2012). This classification focused completely on the oceanographic drivers and the patterns of species distributions they produce. The PPOW classification was also broadened to include coastal boundary currents and semi-enclosed seas in order to include biota that is occurring in both open ocean and coastal environments.

Methodology and data used - The PPOW classification is entirely based on the synthesis of existing knowledge. The major sources of input that helped the delineation were existing biogeographic assessments in the peer-reviewed literature and expert knowledge from the workshops.

Existing pelagic taxonomic or non-taxonomic classifications like the ones by Ekman, 1953; Steuer, 1933; Hedgpeth, 1957; Brinton, 1962; McGowan, 1971; Beklemishev, 1960; Dietrich et al., 1957; Hayden et al., 1984; Bailey, 1998; Longhurst, 1998; LMEs classification and many more have been studied to help determine best way to delineate the pelagic ocean (Spalding *et al.*, 2012). The methodology from the MEOW classification had to be adapted in order to use it in pelagic waters, and to account for the different communities that live in the coastal and pelagic ecosystems. This epipelagic classification thus draws from existing biogeographic knowledge and taxonomic information at a “lower taxonomic resolution” compared to the MEOW one, based on phytoplankton communities' distribution in the pelagic ocean (Spalding *et al.*, 2012). In part, it also builds on a series of workshops that were held for discussing and crafting the MEOW classification in 2007 (Spalding *et al.*, 2007), and also on a workshop which focused on revising the ecological criteria and biogeographic classification systems relevant to MPAs held in Azores in 2007 (CBD, 2010).

Description of the classification - The PPOW classification (Figure 4) delineates open ocean pelagic waters up to 200m depth. It includes 37 pelagic provinces which are broadly grouped into 4 realms (Northern Coldwater, Indo-Pacific Warm water, Atlantic Warm water and Southern Coldwater) or into 7 major biomes (polar, gyre, eastern boundary currents, western boundary currents, equatorial, transitional and semi-enclosed seas). They stressed that even though these boundaries are dynamic and varying in the real world, they need to be fixed for practical reasons (Spalding *et al.*, 2012).

The provinces were defined as large areas of epipelagic ocean where mostly large-scale oceanographic drivers have impacts on species distributions patterns. They are distinguished by the presence of species assemblages that have a mutual history of co-evolution. Biomes are defined as groups of provinces with similar oceanographic processes, and therefore structurally similar ecosystems but with potentially completely different species assemblages (Figure 4a). Finally, the largest scale unit defined are the realms (Figure 4b). In the realms, biotas are presumably internally coherent at genus or family taxonomic levels and they should have shared evolutionary history, which gives realms high endemism levels (Spalding *et al.*, 2012).

Purpose and their current use - Considering the growing importance of applying EAFM on the high seas (Ardron *et al.*, 2008; CBD, 2010; Ban *et al.*, 2014), this classification could have many applications. It has already been proposed as a pelagic classification within the Global Open Oceans and Deep Seabed (GOODS) classification (UNESCO 2009). It could also provide framework for research, management and conservation for many RFMOs and institutions that have interest in these matters in the high seas.

Relevance for the management of tuna and tuna-like species within an ecosystem approach - Similar to BGCPs of Longhurst, the PPOW could potentially inform the determination of fisheries management regions towards the implementation of EAFM for tuna and tuna-like species, for the following reasons:

It focuses on classifying the oceanic environment, without the coastal areas, therefore it could be useful to inform the management and conservation of the more oceanic and migratory species like our target species, tunas and billfishes.

The hierarchical and nested classification system (realms, biomes and provinces) poses an advantage since the different spatial levels and subdivisions could be used for adaptive management at multiple scales.

Compared with BGCPs of Longhurst, this classification is based on both oceanographic attributes and the patterns of species distributions, which is an asset in our case because the addition of community data should represent the ecosystem component better compared to the classifications where it is lacking.

The PPOW is based on a detailed review of existing biogeographic classifications for the open ocean and it uses expert knowledge to reconcile the differences between existing politically and ecologically oriented regional classifications, such as those from some RFMOs and the UNEP Regional Seas.

The number of provinces in this classification is smaller compared to the classification by Longhurst, which makes these provinces more favorable from a fisheries management point of view, especially for far ranging, highly migratory species as tunas and billfishes.

We concluded that it would be worth to examine the overlap of PPOW ecoregions with tuna and billfish distributions and chose this classification to proceed with the analysis.

REYGONDEAU´S BIOGEOGRAPHY OF TUNA AND BILLFISH COMMUNITIES

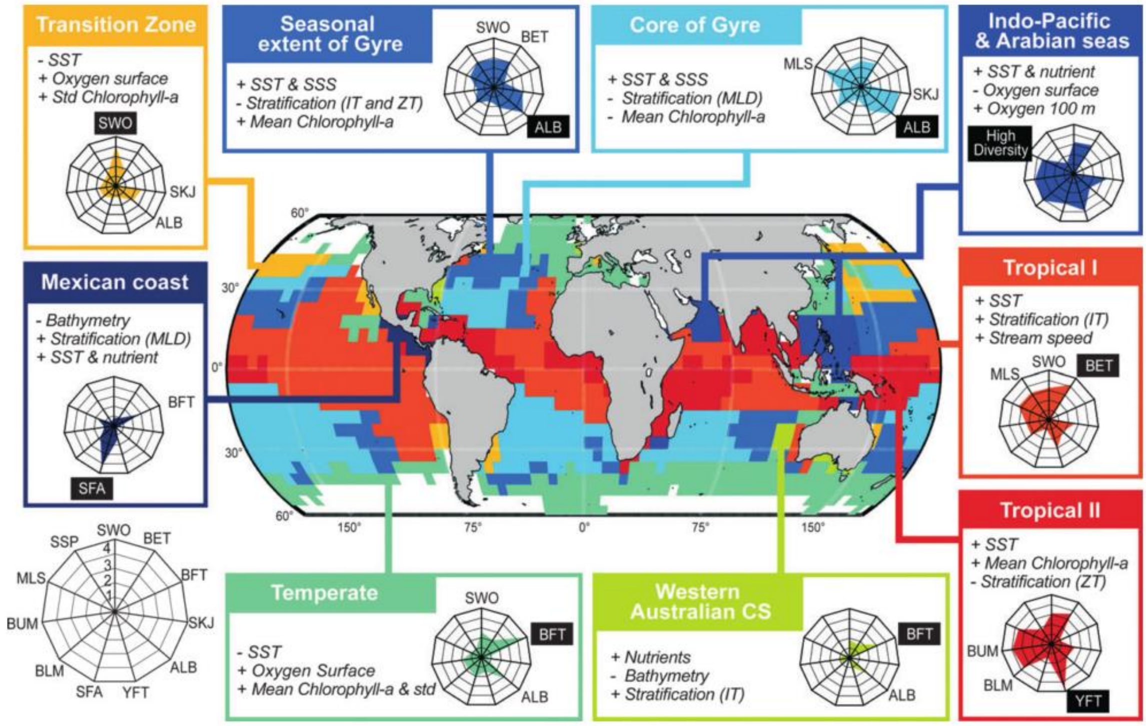

Figure 4 - Biogeography of tuna and billfish communities. Ecoregions are illustrated with different colors and the species communities in each ecoregion are described on the radar plots (Reygondeau *et al.*, 2012).

Background - Since the relevance of BGCPs of Longhurst for modelling lower trophic level species' distributions has been proven, the authors of this study aimed to investigate if these might be relevant for higher trophic level species as well (Beaugrand, 2002; Woodd-Walker *et al.*, 2002; Gibson-Reinemer *et al.*, 2017). In recognizing the ecological and economic importance of highly migratory top predators such as tunas and billfishes, this study investigated the relationship between tuna communities in the Atlantic, Indian and Pacific Oceans and their environment (Reygondeau *et al.*, 2012).

Objectives and main drivers of the classification - This study builds on BGCPs of Longhurst with the main objectives of identifying global tuna and billfish communities, defining their distributions, describing the species compositions of the communities they form and identify the main environmental drivers. This study also aimed to investigate if these environmental drivers have a significant impact on the species distributions -and thus communities' formation - by comparing tuna and billfish communities partitioning with the BGCPs of Longhurst.

Methodology and data used - The analysis consisted of three main steps: (1) division of the oceanic biosphere into ecoregions based on tuna and billfish spatial patterns of CPUE, (2) characterization of the environment for each ecoregion, and (3) comparison of the identified ecoregions with Longhurst's BGCPs.

Fisheries statistical data was used to model tuna and billfish distributions and define the ecoregions. Fisheries data was obtained from the Japanese and Taiwanese long line fleets. These fleets were chosen because of their long history and wide area of coverage as well as number of species of tuna and billfishes caught. Fisheries data included 15 species, covering the period from 1953 -2007, and it consisted of catches and effort. These fleets accounted for approximately 70% of longline catches in the investigated period globally. To account for possible discrepancies with effort data between different gears, a special CPUE index was developed. Using the CPUE indices for tuna and billfish species, the ecoregion division was based on extensive statistical analyses comprised of data transformation for selection of the most appropriate species, clustering into ecoregions using a general hierarchical agglomerative clustering model (Lance & Williams, 1967), making different cut-offs based on Bray-Curtis distance, and conducting probability analyses for each of the ecoregions using the Non-Parametric Probabilistic Ecological Niche model (NPPEN).

The characterization of the environment for each ecoregion was based on 12 environmental variables that were chosen based on the approach used by Longhurst in defining the BGCPs. These included: average annual data for sea surface temperature, nitrate, silicate, phosphate concentrations, sea surface salinity, sea surface dissolved oxygen, 100m depth dissolved oxygen, chlorophyll a concentration, sea surface currents, mean annual mixed layer depth, bathymetry, and intensity and depth of thermocline. To characterize the environment of each ecoregion, principal component analysis (PCA) was conducted assigning the environmental variables to each of the ecoregions separately. Finally, the defined ecoregions were compared to the BGCPs of Longhurst.

Description of the classification - This study demonstrates that despite the highly migratory nature of tuna and billfish species, these species have a clear spatial partitioning into well-defined communities or ecoregions. This study identified nine ecoregions of the world's oceans based on the tuna and billfish catches (Figure 5). Indicator values were calculated for all species and all ecoregions which resulted in the inclusion of 11 species to inform this classification. Regions were characterized by either single or multiple species dominance, or diversified communities where there were no dominant species at all. The concept of multiple species dominance applies to areas where multiple species co-exist being dominant at different depths and bring up the need to consider the ecoregions in 3D. Each of the ecoregions is influenced by different environmental features that were compared to the BGCPs of Longhurst. The ecoregions showed high homogeneity (68.8% on average but higher in the open ocean regions) with the BGCPs. Considering the migratory nature of the species and the difference in the resolution between the two studies (1x1 in BGCPs, versus 5x5 in this study), this was considered an unexpectedly high value which suggests that spatial distribution and cooccurrence of these species might be controlled to some extent by the environmental conditions captured by the BGCPs (Reygondeau *et al.*, 2012).

Purpose and their current use - The authors discussed that their study could inform on the management and conservation of tuna and tuna-like species, especially under the different scenarios of climate change, but it did not try to address the ecoregion separations for the practical implementation of EAFM for HMS. This is a relatively recent study and to our knowledge it has not been used yet to inform fisheries management in any of the tuna RFMOs.

Relevance for the management of tuna and tuna-like species within an ecosystem approach - This study could potentially be used to inform the current management of tuna-and tuna-like species in ICCAT and other tuna RFMOs, guide current efforts in the monitoring of the impact of fisheries on the different components of the ecosystem (bycatch species, food web structure, biodiversity), and identify if those impacts differ by region. In addition, it is noteworthy that this study demonstrates that tuna and billfish species have a clear spatial partitioning into well-defined communities or ecoregions despite their wide distributions and highly migratory behavior. However, three drawbacks of the proposed ecoregions for the management of tuna and tuna-like species are also observed:

Using fisheries dependent data to infer ecological processes (which was also pointed out by other studies) it is not recommended since it can be inherently biased by the changing fishing behavior of the fleets. However, fishery dependent data for HMS has a better spatial coverage than any costly fishery independent survey aimed to HMS. In fact, few, if any, fishery independent surveys are available for HMS spanning their entire distribution. Therefore, the use of fishery dependent data is a compromise to be made in order to improve our knowledge on pelagic biological diversity and patterns of species distributions and to inform biogeographic classifications in the open ocean.

The main tuna and billfish communities identified in this study (and associated ecoregions) do not include or are not representative of all tuna and billfish species found in oceanic ecosystems. For example, by only analyzing the catches by longliners and excluding the purse seiners catches, the important commercial species of skipjack tuna (which is not typically caught by longliners) was not well represented in these communities. In order to have a more representative set of species, the analysis would need to consider several sources of fisheries data and at least include the main fishing gears and fleets. Additionally, other oceanic fish species such as sharks also caught by these gears were not included in their analysis. However, this would be a difficult task as shark catch data is mostly not publicly available.

The large number of ecoregions found in each ocean (12 in the Atlantic Ocean) could make their use impractical from an operational point if detailed ecosystem assessments for each region, with a potential set of ecosystem indicators, are needed to monitor routinely the impacts of fisheries on those regions.

GLOBAL OPEN-OCEAN BIOMES

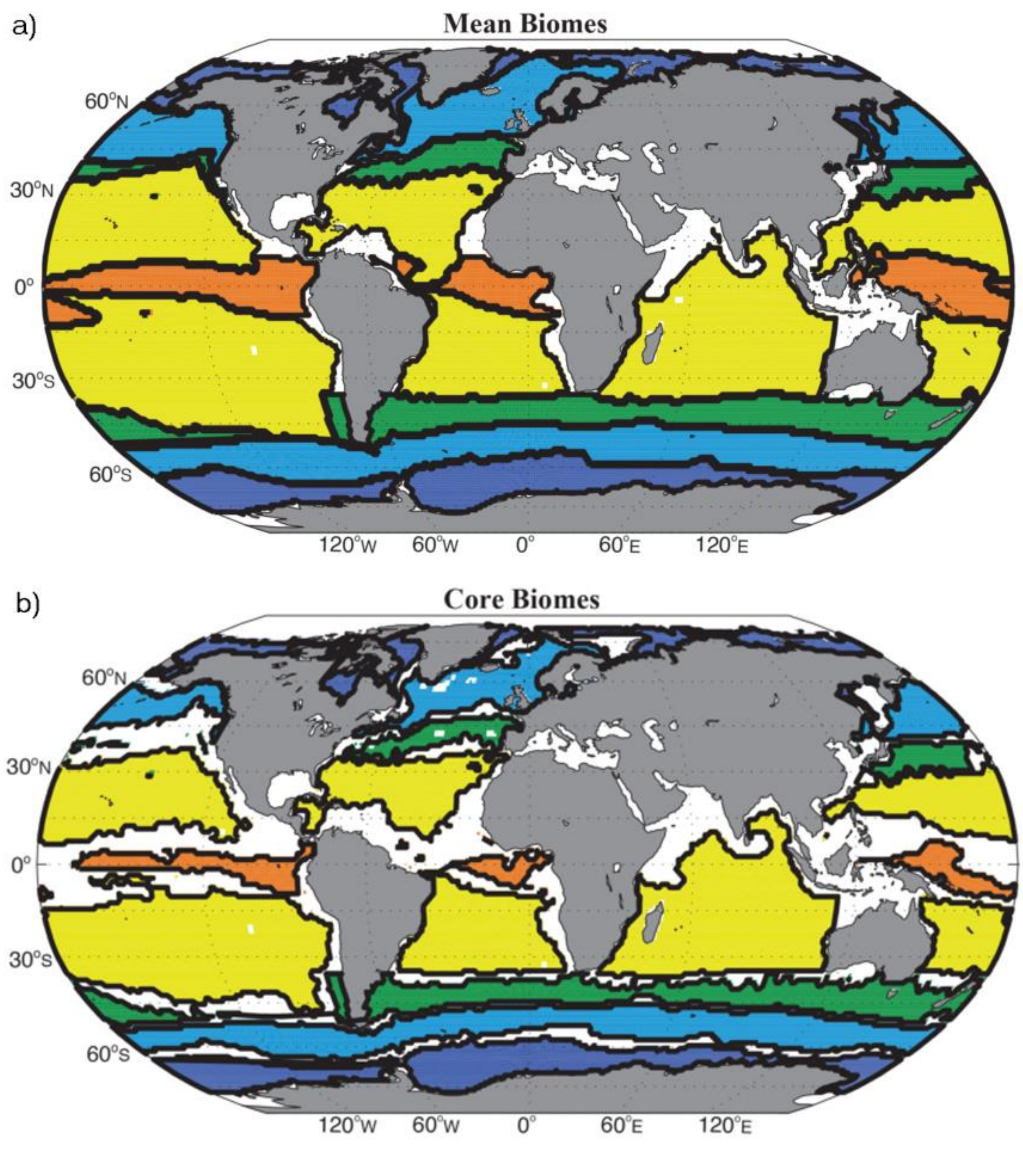

Figure 5 - Global open ocean biomess. a) Mean biomes (each unit is one biome) and, b) Core biomes. Biomes are comprised of cells which remain contant within the study period, and the blank areas are cells that change biome assignment during the study period. Color legend: dark blue - ice biomes (ICE); cyan - subpolar seasonally stratified biomes (SPSS); green - subtropical seasonally stratified biomes (STSS); yellow - subtropical permanently stratified biomes (STPS); orange - equatorial biomes (EQU) (Fay & McKinley, 2014).

Background – The majority of the biogeographic classification previously reviewed were presented as having static boundaries, but efforts are underway to set boundaries that reflect their dynamic nature. In this study the authors explore the variability of shifting boundaries in the open ocean. They also compare their dynamic biogeographic classification to the works of Reygondeau and colleagues (Reygondeau *et al.*, 2013) and Longhurst (Longhurst, 2007), which also utilized dynamic boundaries in the delineation of the open ocean.

Objectives and main drivers of the classification - The goal of this study was to partitioning the global open ocean into biogeochemical biomes that are as large as possible. This classification is based on geochemical properties, at the highest possible scale without causing discontinuity of the proposed regions (Fay & McKinley, 2014). It aims to differentiate between bio-geochemically active areas of the oceans from areas with more stable properties which are distinct enough to be divided into biogeochemical biomes. This classification aims to be useful for future studies in ocean biogeochemistry and carbon cycling.

Methodology and data used - This classification uses oceanographic data such as maximum mixed layer depth (maxMLD), spring/summer chlorophyll a concentration (Chl a), sea surface temperature (SST), and sea ice fractional coverage, which is similar to previous studies on ocean biogeography (Longhurst, 2007; Reygondeau *et al.*, 2013). The study period encompassed data from 13-year period (1998-2010).

The authors first divided the ocean into basins (Atlantic, Pacific, Indian, and Southern Ocean) and then these basins into biomes, using the abovementioned criteria. To obtain the biome maps, data was smoothed to remove the outlier grid cells within each biome. The classification resulted into two types of biomes: the mean biomes and core biomes. Mean biomes (Figure 6a) were calculated using the mean values of the variables during the study period, while core biomes (Figure 6b) were created by selecting only the grid cells that had remained within the same biome definition in all the 13 years of time-varying biomes.

Description of the classification - Three kinds of analyses were conducted in order to produce maps of mean, time varying, and core biomes. Seventeen open ocean biomes were detected in total across all the ocean basins. These biomes are characterized by dynamic boundaries, with annual shift for the time varying biomes, and they do not include the coastal regions. Ocean areas not defined by these biomes are portrayed as blank on the mean and core biome maps. On the mean biomes map these areas represent regions that do not fit the study criteria and are therefore excluded. On the core biomes map, in addition to that, these represent areas that changed the biome assignment during the study period. The number of biomes resulting from this classification (17 biomes) is very similar to the 35 open ocean provinces resulting from the Longhurst's BGCPs classification, which makes sense considering they both used similar datasets to inform the classifications.

Purpose and their current use - The authors recommend using this classification in future carbon cycling and biogeochemical studies, in order to improve existing models based on this type of data (Fay & McKinley, 2014). Their results have been used in a couple of works: i) one study has reported trends in global ocean surface pH according to the open ocean biomes (Lauvset *et al.*, 2015), and ii) another study has attempted to distinguish between anthropogenic and natural carbon fluxes in a model of ocean carbon sink, and to model its expected future changes due to climate change (McKinley *et al.*, 2016).

Relevance for the management of tuna and tuna-like species within an ecosystem approach - This classification is spatially limited due to the type of data used in the classification, resulting in core biomes that do not cover the whole open ocean. Consequently, this marine biogeographic classification might not be relevant to inform fisheries management for tuna and tuna-like species, or to inform the development of ecosystem indicators and assessments to monitor the impacts of the fisheries on oceanic systems.

Even though this classification system might not be relevant to inform fisheries management directly, some best practices and advice can be derived:

The temporal variability is very pronounced in the ocean and this makes challenging to set both dynamic and static boundaries. For fisheries management purposes, it is imperative that static boundaries are defined. Since climate change is changing the ocean environment as well as affecting the species distributions and abundances, it would be necessary that established boundaries (static or dynamic) will be revised in the future to account for that.

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16. APPENDIX 4.1. - REVIEW OF FRAMEWORKS TO ESTABLISH REFERENCE POINTS

As mentioned in the previous section, the determination of reference points with which to compare the state of ecosystem indicators is a complex task for a variety of reasons, mainly the lack of data, long time series, as well as knowledge of the response or the ecosystem (and hence the ecosystem state indicators) to environmental and human pressures. This difficulty is reflected in the shortage of works that has addressed the problem of determining reference points for use in resource management. However, in recent years, due to the need for such reference points for the ecosystem approach to be operational, different projects and specific papers have been developed, which we summarise here:

a. Ocean Health Index

The Ocean Health Index is a tool for the ongoing assessment of ocean health intended to be applicable for ecosystem index-based management worldwide (Halpern *et al.*, 2012). By providing a mean to advance comprehensive ocean policy and compare future progress, the Index can inform decisions about how to use or protect marine ecosystems. This index is the result of a collaborative effort of partnership between different organizations like the National Center for Ecological Analysis and Synthesis, Sea Around Us, Conservation International, National Geographic, and the New England Aquarium (http://www.oceanhealthindex.org).

In one of the scientific papers published from the work developed on OHI, (Samhouri *et al.*, 2012), a protocol to estimate reference points for a very wide range of ecological indicators is presented (Figure 1). The framework is compatible with different levels of scientific understanding and data availability and emphasizes practical approaches that can be used to evaluate ecosystem status at local, regional, or even global scales. A set of decision trees is developed, which provide guidance for choosing among three types of reference points (or levels) to use in the assessment of the current ecosystem state:

(1) Functional relationships: a reference level based on an understanding of its functional relationship with environmental conditions (equivalent to modelling option from (Rossberg *et al.*, 2017)). This therefore requires at least an understanding of the functional relationship.

(2) Time-series approaches: a reference level of the same ecosystem or ecosystem component based on some historical status representing a desirable status, e.g. pristine or sustainably exploited. This therefore requires at least a long enough time-series.

(3) Spatial comparisons: a reference level of a comparable ecosystem or ecosystem component elsewhere in the region or across the globe. This requires a comparable situation elsewhere.

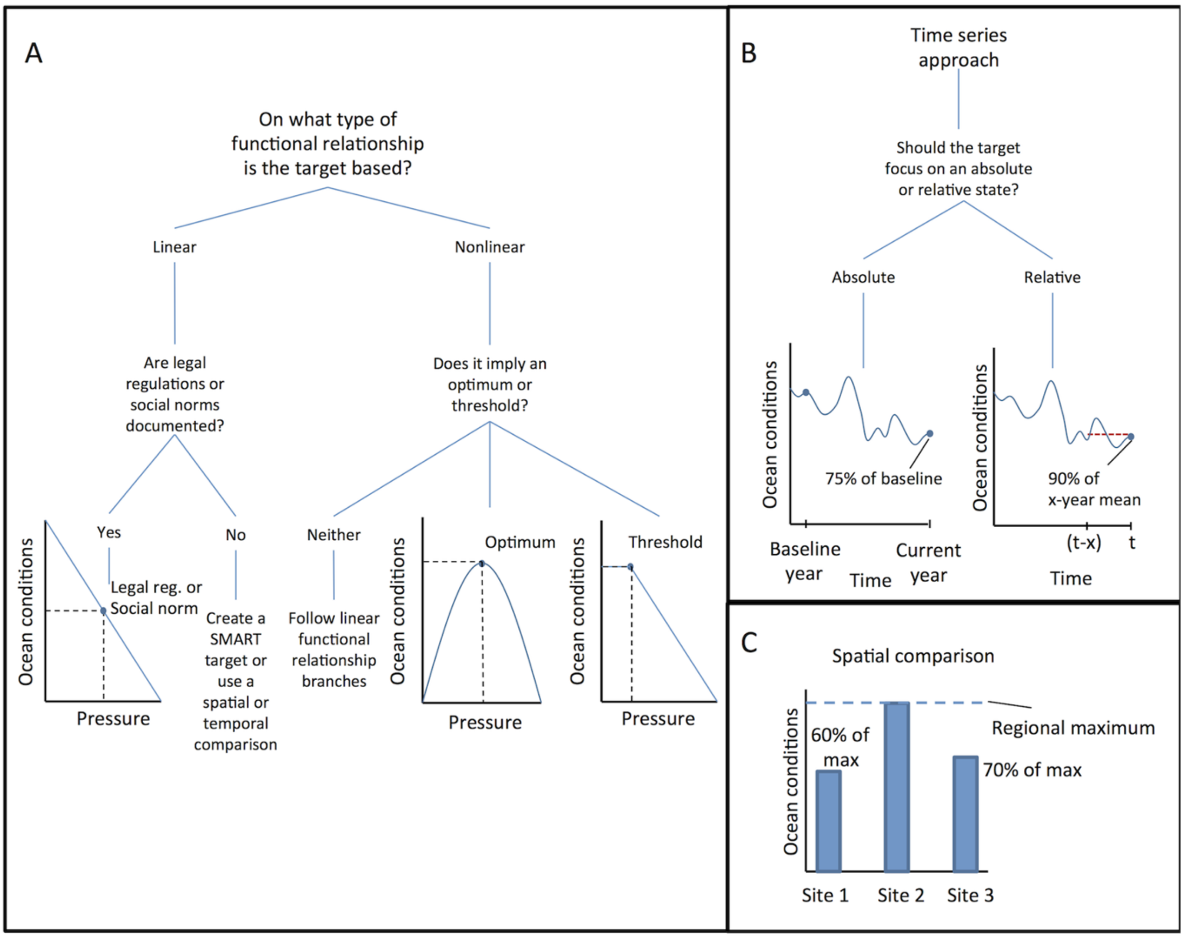

Figure 1. Decision trees for choosing between three types of targets based on (A) functional relationships, (B) time series approaches, and (C) spatial comparisons. Taken from Samhouri et al (2012).

Functional relationship is the modelling option, when the relationship between the state indicator and the human pressure (and / or natural pressure) is known. The way of acting in three different functional relationship scenarios is defined: linear, nonlinear and sudden change. If functional relationships are not known, but long time series are available, two approaches can be considered: to search for the reference value in a past time (e.g. reference points in the structure and size of coral communities), or use moving windows that include the period immediately prior to the year of evaluation and estimate the mean (or median) used as a reference point. If time series are not available, it is possible that the same ecological indicator has been collected in different geographical areas. In these cases, the determination of reference points can be done by comparing different areas and taking the value of the area that is in the best conditions as a reference value.

b. DEVOTES: Rossberg et al., 2017.

DEVOTES was an EU project focusing on the development of tools to assess the impact of human activity and climate change on biodiversity (one of the 11 descriptors of the EU Marine Strategy Framework Directive), and the socio-economic consequences of achieving a Good Environmental Status (GES). They proposed and refined a set of ecological indicators and developed an integrative tool ("Nested Environmental Status Assessment Tool") to assess the state of ecosystem in relation to reference points. DEVOTES considered the applicability of ecosystem models and empirical approaches to determine reference points for indicators that can support management decisions. The DEVOTES publication by Rossberg et al. (2017) presents a methodology that can be used to select ecological indicators and to determine the target ranges within which we want to maintain the indicators and from which the indicator can recover to its natural range (within an acceptable period of time), should anthropogenic pressure be removed (Rossberg *et al.*, 2017).

The proposal of the DEVOTES project to estimate reference points (Rossberg *et al.*, 2017) is based on the idea that sustainable development is one that meets the needs of society in the present but does not compromise the capacity of the ecosystem to fulfil the needs of future generations. This is what the paper strongly calls sustainable use. This idea is the one that has been advocated by FAO and ICES and within the MSFD. However, since future use is not known, the approach is to manage so that if the human activity were eliminated the system will recover to an acceptable state in a given time R, which should be relatively short. In this work, it is suggested that R should be 30 years, i.e. one generation time. The value of R should be consistent with the concept of strongly sustainable use but the actual value is a societal choice given a balance between acceptable risk and current use. Acceptable values of the ecological indicator are those that fall within a target range the shall be that one which determines the limit to the level of exploitation so that if the human pressure disappears the status of the indicator will recover within the time R to a level within 95% of the natural distribution of that indicator.

The difficulty arises in estimating the target ranges for the different indicators, and how to estimate the variation of the state indicator with respect to the pressure indicator. The proposed solution is modelling; that requires knowledge of the functional relationships between changes in the pressure and state indicators. At the same time, modelling is also the basis for selecting the indicators, because when subjecting the system to pressure the simulations will show which state indicators are better to represent the effect of changes in pressure indicators. In addition, modelling is what will allow us to determine the number of years it will take to recover the ecological indicator (and therefore the system) to levels within 95% of its range of natural variation (Figure 2). This modelling should ideally be ecosystem-based, considering the highest number of ecosystem variables, since it is a question of considering the greatest number of interactions between indicators and pressures that determine the value of the selected indicator or state indicators. But they should not necessarily be holistic models since partial models (i.e. considering only a section of the ecosystem, a selection of trophic relationships…) may be sufficient to estimate reference points. The range of variation of an ecological indicator under natural conditions can be determined through modelling, but also through prior knowledge, for which time series are very useful.

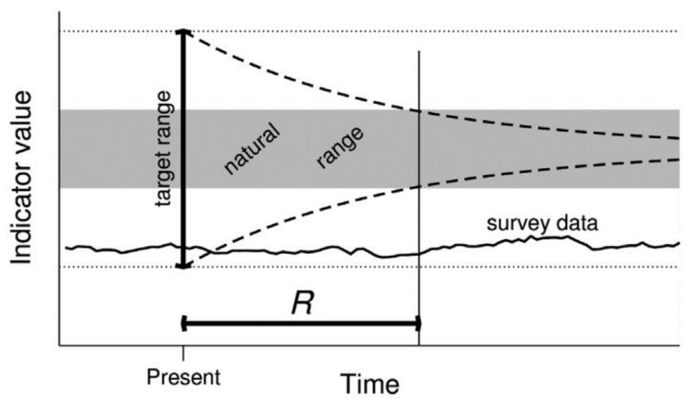

Figure 2 Illustration of proposed approach for choosing target ranges by Rossberg et al (2017). The target range of an indicator is determined as the range of values from which it takes, on average, at most a time R to reach the natural range in a hypothetical situation without anthropogenic pressures. Dotted lines indicate the width of the target range, dashed lines hypothetical average relaxation trajectories, the grey area the natural range, and the ragged solid line a conceivable trajectory of the indicator for an ecosystem in strongly sustainable use. In practice, the target range may need to be narrowed to take measurement uncertainty and model uncertainty into account.

c. Probst et al., 2013

This study performs an indicator-based assessment of North Sea fish and shellfish species as required by the Marine Strategy framework Directive (MSFD) (EC, 2008, 2017) and the newly developed L_{max} by (Probst *et al.*, 2013). Since many reference values (targets or limits) were lacking, a simple time-series analysis was used to assess the current status of 43 North Sea fish stocks against previous years (starting from 1984).

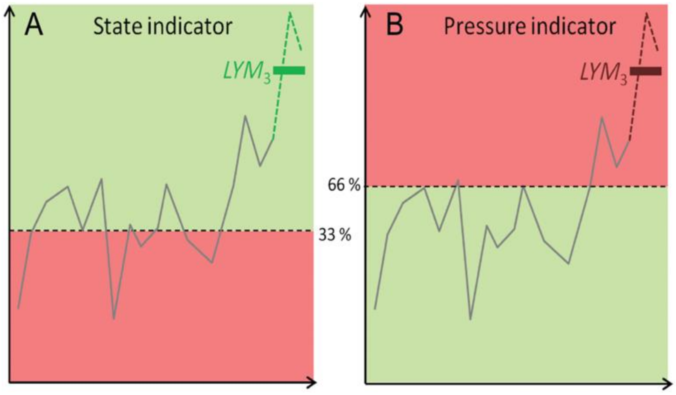

Figure 3. Assessment of indicator metric time-series with a two-stage approach. The basis of the assessment is the relationship between the last-three-year-mean (LYM3) and the 33%- and 66%-percentiles of the observed time-series. A) If the LYM3 (green or red bar) of a state indicator (Spawning Stock Biomass SSB, CPUE or $L_{max5\%}$) is above the 33%-percentile of the remaining time-series (grey), the state indicator is assessed as "green". B) If the LMY3 of a pressure indicator (Fishing mortality- F, Harvest rate - HR) is above the 66%-percentile the pressure indicator is assessed as "red". From Probst et al. (2013).

The assessment of each indicator followed a two-stage approach to identify a "green" or "red" status. In each indicator time series, the last three-year-mean (LYM3) was compared against reference values for the indicator. The LYM3 was chosen as representative of the current state to mitigate impacts of annual fluctuations and uncertainty in the last year of the indicator time-series. For indicators from analytical stock assessments the reference values were F_{MSY} (Fishing mortality that allows Maximum Sustainable Yield of the stock) and $MSYB_{trigger}/B_{PA}$ (relation between the Spawning Stock Biomass at the limit of Maximum Sustainable Yield and the limit Spawning Stock Biomass from a precautionary approach perspective) as defined by the ICES working groups. For stocks, where no F_{MSY} or $MSYB_{trigger}$ was defined, and for all other metrics (Harvest Rate HR, Catch Per Unit of Effort CPUE and L_{max}5%), the LYM3 was compared with the 33%-percentile (SSB for stocks without MSY $B_{trigger}$, CPUE, $L_{max5\%}$) or 66%-percentile (F for stocks without F_{MSY}, HR) of the remaining time-series (Figure annex 4.1.3). The 33%- and 66%-percentiles were chosen as limit values for state and pressure indicators, respectively, because these percentiles allow a 16% deviation of LYM3 from the long-term median. An advantage of this approach is that it allows the integration of these indicators into an overall assessment where, depending on the required confidence levels, a fixed number of indicators is only needed to fulfil the assessment requirement, i.e. a "green" status, in order to result in an overall pass at the integrated level.

d. Probst and Stelzenmüller, 2015.

In this study, two time-series analysis methods are combined in a time-series-based benchmarking and assessment framework (TSBA). These two methods are breakpoint analysis (BPA) and linear regression. BPA identifies periods of relative stability within a time series (Bai & Perron, 1998). The 'breakpoints'-function of the 'strucchange'-package for R identifies points in time, in which a time series shifts from one stable state into another, the so-called break points (a similar procedure has been developed for "Regime Shift" detection in excel, http://www.beringclimate.noaa.gov/regimes/). The algorithm of the 'breakpoints' function fits the optimal number of linear, zero-slope regressions to the time series by minimizing the residual sum of squares (Bai and Perron, 2003). To analyse the trend of the last 5 years of the indicator time series linear regression was applied to assess whether the slope of the regression was significantly deviating from zero. BPA and analysis of trends have complementary strengths and weaknesses. BPA provides absolute reference values based on observed stable periods, but the method is insensitive to very recent changes in the indicator time series having occurred in the last 1–5 years. The analysis of trends is sensitive to most recent changes but does not provide absolute reference values. Instead, Analysis of trends rather indicates positive or negative trends. Therefore, the combination of both methods within a TSBA was regarded as adequate to assess the short- (1–5 years) and long-term (more than 5 years) status of the indicator time series. A similar approach has been taken by OSPAR to evaluate changes in the size composition in fish communities (https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/fish-and-foodwebs/size-fish-composition/).

B_{PA} was used by Probst and Stelzenmüller (2015) to determine absolute reference points or reference levels. For each period of stability, a mean with confidence interval was calculated. The period with the last stable mean was defined as the assessment period

(AP) of the time series, whereas the values of the remaining time series (the reference period, RP) were used to derive reference points.

Depending on the chosen assessment rationale (whether the status of the ecosystem should not become worse than has been observed previously ("prevent further decline", PFD), or a degraded status should be reverted ("improve leading to recovery", IMP)) these reference points could be referred to as the best period or the average of the RP (Figure 4). Under the PFD-rationale the average of the AP (MAP) was reaching the assessment reference point when it was not significantly smaller than the average of the RP (MRP, Figure 4). Under the IMP-rationale the MAP was reaching the assessment reference point when it was significantly higher than the mean of the best period (BMRP).

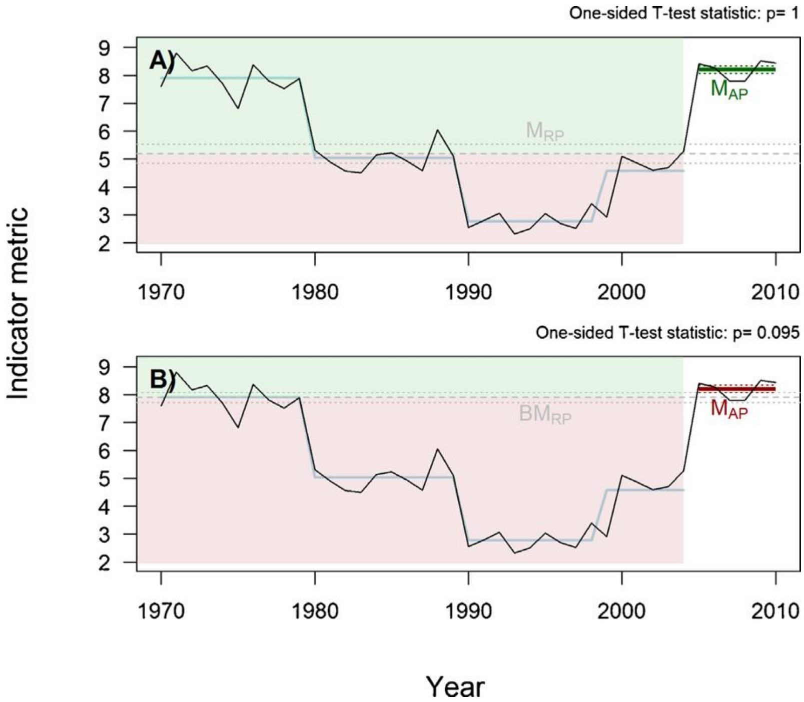

Figure 4. Assessment of the exemplary indicator time series (modern segment) against the two assessment rationales. (A) In the "prevent-further-decline"-rationale (PFD) the assessment result is 'good' if MAP (green bar) is not significantly smaller than MRP (grey dashed line ± S.D.). (B) With the "improvement"-rationale the assessment results are 'not good', because MAP is not significantly higher than the best mean of the BMRP. From Probst and Stelzenmüller (2015).

<u>e. Shephard et al., 2015</u>

This paper deals with those indicators for which there is no clear knowledge about the relationship between human pressure (which is the focus of management measures) and the state of the biological-ecological aspect that is intended to be preserved in good condition and for which the indicator is directly representative. Indicators meeting this requirement and having a good pressure-state connection, and for which reference points and targets are also known, are the so-called operational indicators.

This paper aims to introduce surveillance indicators (SI) into the MSFD (Marine Strategy Framework Directive) Action-Pressure-State-Response. What is presented is the utility of surveillance indicators to potentially modulate management measures when these SIs are outside the bounds. Therefore, for these SIs there are no reference points but bounds, which must be determined from time series analysis. They defend using a method similar to that presented by Probst (2013) to define bounds. But even when reliable time series are not available to define bounds, the SIs should be considered since they may alter the reference points of the operational indicators.

The way in which the use of SI is considered in the APSR framework is summarized in the Figure 5.

The purpose of surveillance indicators is not to monitor everything that can be monitored, but to acquire a supplementary class of indicators that have a valuable and specific role to play in the way that operational indicators are used to implement the MSFD. Examples of surveillance indicators that can be applied to 4 of the 10 descriptors of the MSFD are given:

Descriptor 1: maintain biodiversity. An indicator of spatial distribution is proposed as an aid to modulate the diversity indexes. But this same SI can also be useful for the descriptor 3.

Descriptor 3: maintain commercial species. For example: indicators of condition, growth, etc. To modulate SSB_{lim} or F.

Descriptor 4: food webs. All foodweb indicators are considered surveillance by Shephard et al. (2015) since pressure-state responses are difficult to identify.

Descriptor 6 sea floor integrity. Water temperature as a connection of the dynamics of water bodies with productivity and the arrival of organic matter at the bottom (this relates to item 6.2 of the descriptor (structure).

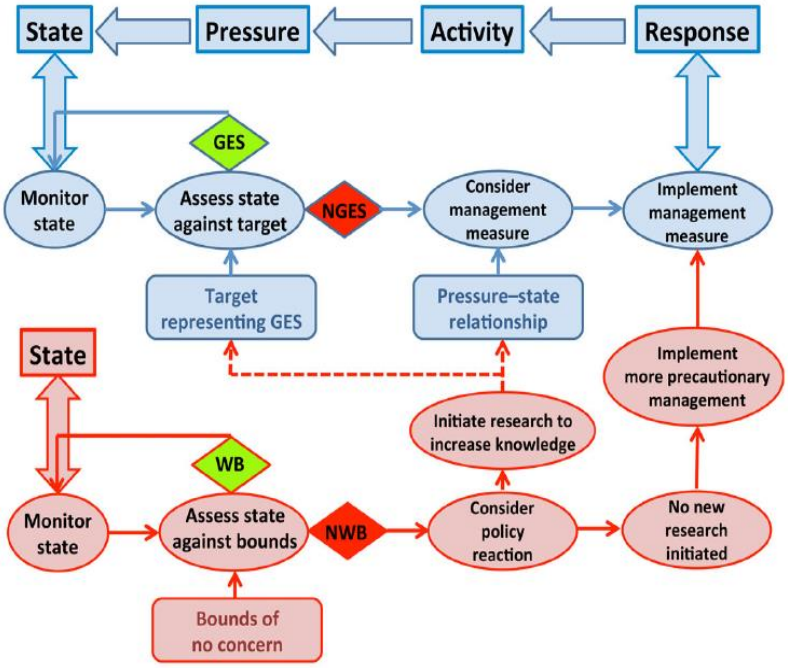

Figure 5. Diagram illustrating how surveillance indicators (red process) can complement operational indicators (blue process) in an APSR approach to the MSFD. Operational indicators evaluate whether state is meeting (GES) or failing (NGES) "GES" reference points. Surveillance indicators evaluate whether state is within bounds (WB) or not within bounds (NWB), where these bounds represent the upper and lower limits of a range in state for which there is no "specific cause for concern". From Shephard *et al.* (2015).

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17. APPENDIX 4.2. - REVIEW OF THE FRAMEWORKS DEVELOPED ON INTERNATIONAL PROJECTS AND MANAGEMENT ORGANIZATIONS TO FACILITATE THE TRANSFERENCE OF ECOSYSTEM INFORMATION TO MANAGERS AND STAKEHOLDERS

a. The North Pacific Fisheries Management Council (NPFMC).

Introduction

The North Pacific Fishery Management Council (NPFMC) manages groundfish fisheries (including species such as walleye pollock (*Gadus chalcogramma)*, Pacific cod (*Gadus macrocephalus)*, arrowtooth flounder (*Atheresthes stomias)*, sablefish (*Anoplopoma fimbria*), rockfish fisheries (*Sebastes* spp.), the halibut fishery (*Hippoglosus stenolepis*), salmon fisheries and the crab and scallop fisheries in four large marine ecosystems in the Alaska EEZ. Over the last 10-15 years, the NPFMC has been actively engaged in implementing the ecosystem approach to manage its fisheries. Accordingly, it has designed and developed over time a process and a series of products that aim to support its implementation, in order to better link ecosystem information and science into its management advice and decisions.

Approach for integration of ecological information and assessment

Below, we list and summarize a series of actions, activities and relevant products that are generated regularly by the NPFMC and implemented to support an EAFM. Their approach can be divided into four broad initiatives:

I) Strong development of an ecosystem-based management policy

The Council adopted a policy with a strong ecosystem focus in February 2014, which includes a Value Statement, Vision Statement, and Implementation Strategy to guide its ecosystem approach. This Ecosystem Policy also includes long-term planning initiatives, fishery management actions, and science planning to support ecosystem-based fishery management. Additionally, since 2004, the Council has also comprehensive ecosystem-based goals and objectives for its groundfish fisheries management plans to ensure robust populations of marine species at all trophic levels, including marine mammals and seabirds (NPFMC 2014). It also has a strict policy that mandates to use the best available science for its decision making and adherence to the advice from its Statistical and Scientific Committee (SSC).

II) The creation of an Ecosystem Committee

The NPFMC created its Ecosystem Committee in 1996. Its purpose was to provide advice to the Council on ecosystem issues, to interact with the groundfish Plan Teams, consider North Pacific management in the light of national ecosystem discussions, and suggests new ways to implement in ecosystem-based management. This committee has been instrumental on (1) defining ecosystem based fisheries management in the context of the NPFMC, (2) providing advice on the national requirements on Essential Fish Habitat actions, (3) providing directions to develop the Ecosystem Considerations Chapter in the annual groundfish Stock Assessment and Fishery Evaluation Reports, (4) developing the Fishery Ecosystem Plans within the region, and (5) coordinating with NOAA and other initiatives regarding ecosystem based management.

III) Development of fishery ecosystem plans and ecosystem reports

a) The creation of Fisheries Ecosystem Plans for each of their managed Large Marine Ecosystems (or ecosystem region).

For each ecosystem region, the NPFMC has developed (or is currently under development and consultation) a Fishery Ecosystem Plan (FEP) (Figure 1). The objective of a FEP is to formalize and strengthen the delivery of ecosystem information to the Council, to provide a transparent tool for evaluating emergent trade-offs between conflicting management objectives (e.g. conservation and fisheries harvest), and to refine fisheries advice under changing climatic conditions (NPFMC, 2007a). The FEPs usually include an initial ecosystem overview of the region which describes and integrate existing research and information about the main physical, ecological and socio-economic components of the ecosystem and their interactions. It also can include a conceptual model of the ecosystem and an ecosystem risk assessment, which allows the identification of key ecosystem interactions that examined the ecological and economic impacts of the different commercial activities on the regions. These products provide general guidance to the Council on priority areas and issues for management attention and further research and analysis (NPFMC 2007a). The FEP also intends to be an educational tool and a resource for the Council and any other interested stakeholders since it synthesizes the ecosystem context for fishery management decisions (NPFMC, 2007b).

b) Development of an annual Ecosystem Considerations Report including Ecosystem Assessments and ecosystem Report Cards

An Ecosystem Consideration Report is prepared annually as part of annual harvest specifications which includes an ecosystem assessment for each ecoregion (Figure 1). The goal of the Ecosystem Consideration Report is to provide stronger links between ecosystem research and fisheries management and to spur new understanding of the connections between ecosystem components, by bringing together the results of many diverse research efforts into one document. It was first produced in 1995 and since then it has evolved and been adapted to fit the management needs of the NPFMC. It relies on the contributions from a broad range of scientists. Currently the Ecosystem Consideration Report includes four main sections (1) Report Cards for each ecoregion, (2) Executive Summary, (3) Ecosystem Assessment, (4) Ecosystem Status and Management Indicators (Zador, 2015).

The Ecosystem Report Cards, which are created for each ecoregion, are used to summarize the status of top indicators that best describe the ecosystem and provide ecosystem context to the Council to inform fisheries management decisions every year (Zador, 2015). Therefore, the indicators contained in the Report Cards are monitored and updated annually to ensure they are taken into consideration in fisheries management decisions. The Report Cards, which are highly visual and succinct, are supplemented by a detailed region-based Ecosystem Assessment (see below).

The Executive Summary section is used to provide a concise summary of the status of marine ecosystem in Alaska for a wide range of stakeholders including fishery managers, stock assessment scientist and the public (Zador, 2015).

The Ecosystem Assessment section aims to synthesize historical climate and fishing effects in each ecoregion using information from the fourth section (Ecosystem Status and Management Indicators) and the existing single species stock assessment reports. The Ecosystem Assessment also discusses a list of hot topics relevant for management year. In the future, this section would like to use a blend of data analysis and modeling to communicate not only the current status of the ecosystem but also possible future directions and scenarios (Zador, 2015). The Ecosystem Status and Management Indicator section provides detailed information and updates on the status and trends of all the indicators that are used to monitor the different ecosystem components (physical, ecological, social relevant ecosystem components) of each ecoregion. Each indicator comes with a detailed description including how it is calculated, data sources and data requirements, a description and interpretation of its trends and current state capturing the uncertainty of the indicators, factors causing the observed trends and a final section with its implications and link to fisheries management. These are used to provide early signals of direct human effects on the ecosystem components or monitor the efficacy of previous management action on those ecosystem components (Zador, 2015).

Communication to stakeholders

Different approaches, tools and strategies are used to present and communicate efficiently to the Commission on the ecosystem science reviewed and produced by the Ecosystem Committee.

I) Strong involvement of stakeholders and public input and advice

The NPFMC, its Advisory Panel, and its Scientific Committee all operate in open forum where many other organizations, scientists, managers and other stakeholders can participate, provide inputs and review the data and analytic methods in the science.

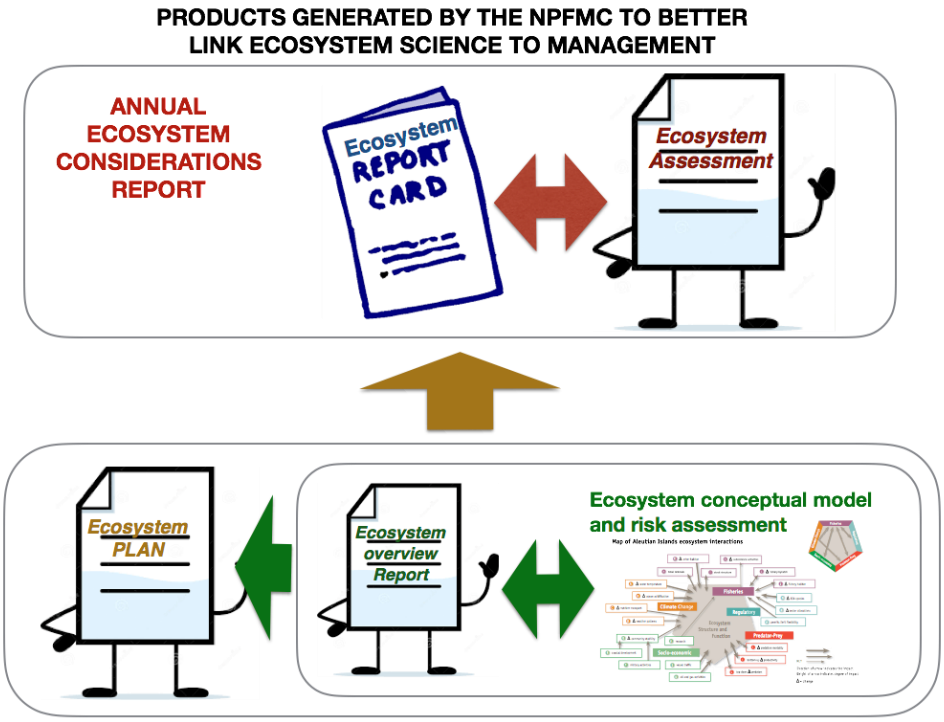


Figure 1. Written Ecosystem Reports produced by the NPFMC to better link ecosystem science to fisheries management.

II) How ecosystem science is fitted within the management advice cycle

The principal avenue for providing ecosystem science to the Council is through the Ecosystem Considerations Report presented to the managers at the Annual Council Meeting as part of stock assessments (Figure 2). At the annual meeting, the ecosystem considerations report is used to present the ecosystem status of the review and provide context for the managers for quota-setting deliberations, serving as a type of ecosystem advice (Zador *et al.*, 2017).

The Council is also involved in the preparation of the report since there is frequent communication between scientists and the Council. Once the Ecosystem Consideration Report is first compiled, it is presented and reviewed by several Council Bodies (the Regional Plan Team and the Scientific and Statistical Committee). These bodies are composed of a wide range of experts including scientist from government agencies and academia. Since its creation, the process of producing it and reviewing on an annual basis has resulted in an adaptive product that fits the management needs of the Council.

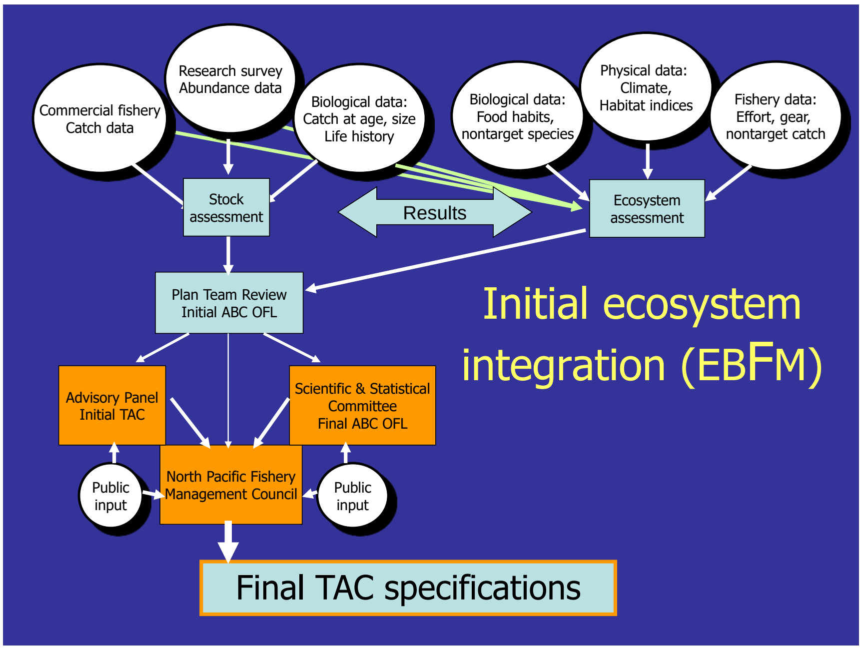


Figure2. How ecosystem science and advice is fitted within the management cycle (Source: Kerim Aydin)

III) The timing to communicate ecosystem information

An effective communication and timely strategy to communicate ecosystem science to fisheries managers has also arisen over the years. It is pivotal to understand very well the management system in order prepare and adapt the ecosystem information to fit the management cycles and needs (Zador et al., 2017). For example, every year the ecosystem information is presented to the Council before quota setting to allow for qualitative inclusion of ecosystem information into fisheries management de,cisions (Zador et al. 2017).

IV) The creation of highly visual communicative products

The indicator-based Ecosystem Report Card presented annually in the Ecosystem Consideration Report is the result of a long adaptive process and many years of consultations which have resulted in an adapted product that now serves the management needs of the Council. For their development, a "team of ecosystem experts" were created which were represented by multiple and diverse stakeholders, including scientist and managers, in order to select the ecosystem indicators that best describe the ecosystem and ecosystem components of each ecoregion. Every visual aspect of the indicator-based card has been planned and debated. An example of an indicator report card is illustrated in Figure 3. This report card is intended to portray a set of indicators for which the long-term and short-term trends are shown, as well as the current status of the different ecosystem components. The cards are supplemented by a short bullet list (a page long) with a small description of each indicator.

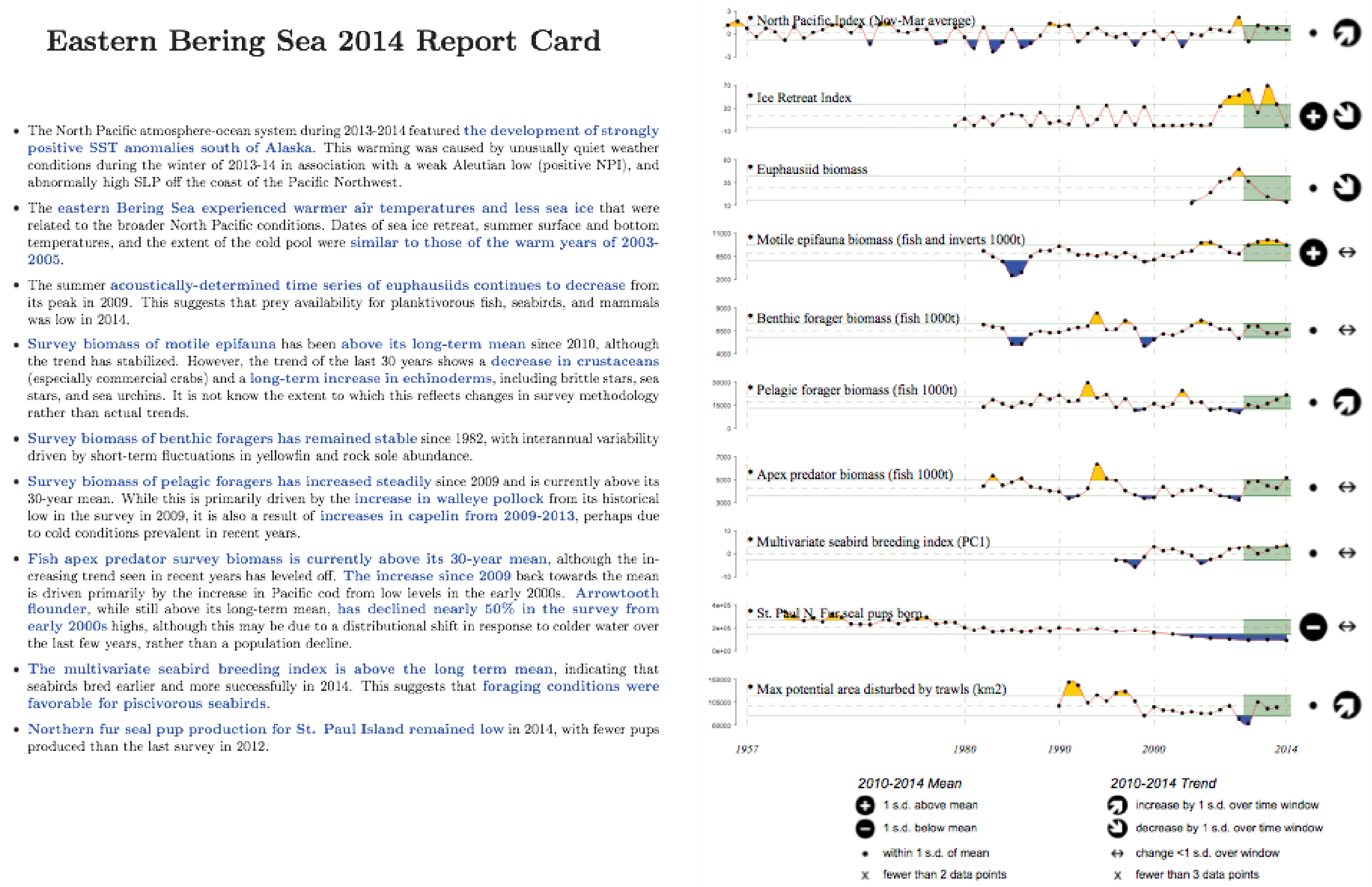
V) The creation of educational an outreach products

The Council adopted an outreach policy in 2008 with the objective of increasing the Council's efforts to engage different stakeholders. Over the years, it has also created multiple outreach and educational products to elevate the importance of accounting ecosystem science in fisheries management and engage different stakeholder. For example, after the Fisheries Ecosystem Plan for the Aleutian Islands was created, the Council prepared an educational, highly visual and communicative brochure with the purpose of providing a brief summary of information found in the Aleutian Fishery Ecosystem plan (Figure 4).

Lessons learnt

Many lessons were learnt in the process of developing Fisheries Ecosystem Plans and the indicator-based report cards and ecosystem assessments among many other ecosystem related activities (Zador et al., 2017).

Lesson 1 - Indicators should be based on Ecological Meaningful Areas and should be chosen with the Support of the Council or management body. Prior to 2010, in the process of developing a Fishery Ecosystem Plan for the Aleutian region, many indicators were chosen based on the Driver-Pressure-State-Impact-Response approach. Soon, they realized that many of the indicators were repetitive; did not integrate multiple interactions; and did not characterize ecologically meaningful areas. Many of them were chosen at the fisheries management scale rather than a more ecologically-sound based scale. In short, this did not work well. Consequently, scientists proposed a more regionalized approach to synthesize the information within more ecologically sound scales (Zador et al., 2017). The indicators were then based on Ecological Meaningful Areas (now LME in the Alaska region), and with the support of the Council, they have reduced the number of indicators to a succinct summary (ecosystem report cards) that are delivered to managers every year and that are supplemented by the detailed Ecosystem Assessment (Zador et al., 2017).



Eastern Bering Sea 2014 Report Card

- The North Pacific atmosphere-ocean system during 2013-2014 featured the development of strongly positive SST anomalies south of Alaska. This warming was caused by unusually quiet weather conditions during the winter of 2013-14 in association with a weak Aleutian low (positive NPI), and abnormally high SLP off the coast of the Pacific Northwest.
- The eastern Bering Sea experienced warmer air temperatures and less sea ice that were related to the broader North Pacific conditions. Dates of sea ice retreat, summer surface and bottom temperatures, and the extent of the cold pool were similar to those of the warm years of 2003-2005.
- The summer acoustically-determined time series of euphausiids continues to decrease from its peak in 2009. This suggests that prey availability for planktivorous fish, seabirds, and mammals was low in 2014.
- Survey biomass of motile epifauna has been above its long-term mean since 2010, although the trend has stabilized. However, the trend of the last 30 years shows a decrease in crustaceans (especially commercial crabs) and a long-term increase in echinoderms, including brittle stars, sea stars, and sea urchins. It is not know the extent to which this reflects changes in survey methodology rather than actual trends.
- Survey biomass of benthic foragers has remained stable since 1982, with interannual variability driven by short-term fluctuations in yellowfin and rock sole abundance.
- Survey biomass of pelagic foragers has increased steadily since 2009 and is currently above its 30-year mean. While this is primarily driven by the increase in walleye pollock from its historical low in the survey in 2009, it is also a result of increases in capelin from 2009-2013, perhaps due to cold conditions prevalent in recent years.
- Fish apex predator survey biomass is currently above its 30-year mean, although the increasing trend seen in recent years has leveled off. The increase since 2009 back towards the mean is driven primarily by the increase in Pacific cod from low levels in the early 2000s. Arrowtooth flounder, while still above its long-term mean, has declined nearly 50% in the survey from early 2000s highs, although this may be due to a distributional shift in response to colder water over the last few years, rather than a population decline.
- The multivariate seabird breeding index is above the long term mean, indicating that seabirds bred earlier and more successfully in 2014. This suggests that foraging conditions were favorable for piscivorous seabirds.
- Northern fur seal pup production for St. Paul Island remained low in 2014, with fewer pups produced than the last survey in 2012.

Figure 3. Example of an indicator-based Ecosystem Report Card generated by the NPFMC. Eastern Bering Sea Ecosystem Report Card with a set of ecosystem assessment indicators. See bullet point text for descriptions, an * indicates time series updated annually.

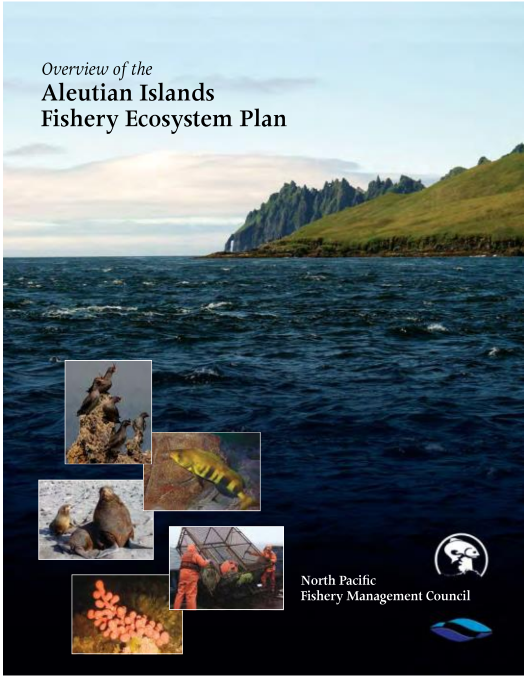


Figure 4. An example of an educational highly visual tool. A highly visual brochure that provides an overview of the Aleutian Islands Fishery Ecosystem Plan.

Lesson 2 –Be flexible and adaptive in the process of selecting ecosystem indicators for each ecoregion. In the process of developing ecosystem reports cards for each ecoregion, it was learnt that the process itself should be flexible and adapted to fit the different needs and realities of each region. Despite starting using similar methods in each ecoregion, the ecosystem-report cards ended up being different. In each region, the selection of indicators were influenced by geography, the extent of scientific/knowledge and data, and the particular expertise of the selection teams.

Lesson 3 – Get to know well the annual management cycle to optimize the opportunity to incorporate ecosystem information into management decisions. To optimize the opportunity to incorporate ecosystem information into management decisions required a good understanding of the management system in questions. It is important to match temporal and spatial scale of the ecosystem information with the management process. For example, the ecosystem information needs to be updated every year in order to be useful. Scientists need to structure the ecosystem information to best fit the management cycle, not the other way around. It is also important the timing in which ecosystem information is communicated to the Council. The ecosystem considerations report including ecosystem status, and potential concerns, are presented prior to the stock assessment harvest and quota recommendations to allow setting the ecosystem context.

Lesson 4- Important to ensure frequent communication and good visual presentation of ecosystem information for making it more useful. The indicator-based report cards have worked very well to communicate and synthesize ecosystem information to scientist, managers and other stakeholders. The frequent dialogue with managers and other stakeholders has allowed for adaptive products which make them more useful at the end. It is important to create flexible products that allows for adaptation.

Lesson 5 – Important to involve diverse and multiple stakeholders in the process of selecting ecosystem indicators or in the development of any other ecosystem product which will be used to provide ecosystem context for management decisions. For example, the creation of a "team of ecosystem experts" representing multiple stakeholders worked really well for the process of selecting relevant ecosystem indicators and for developing the indicator-based report card that had the support of the Council.

b. Commission for the Conservation of Antarctic Marine Living Resources (CCMLAR)

Introduction

CCAMLR recognises the need to account for the effects of fishing on harvested species (target species), as well as dependent species and associated species, in order to manage the commercial harvesting of Antarctic marine living resources in accordance with the 'ecosystem approach'. "Dependent species" are those species that feed on the target species or are impacted by the removal of the target species from the food web. "Associated species" are typically those that are impacted directly by the action of fishing e.g. through by-catch or incidental mortality.

In order to provide information of the effects of fishing on dependent species, CCAMLR set up the CCAMLR Ecosystem Monitoring Program (CEMP) in 1989. The two aims of CEMP are to:

1. Detect and record significant changes in critical components of the marine ecosystem within the Convention Area, to serve as a basis for the conservation of Antarctic marine living resources;

2. Distinguish between changes due to harvesting of commercial species and changes due to environmental variability, both physical and biological.

CEMP's major function is to monitor the key life-history parameters of selected dependent species. Currently the focus is primarily on 'krill-dependent species' that are used in CEMP; these include land-based species such as seals and penguins. The indicator-species currently used in the CEMP program are:

Adélie penguin (*Pygoscelis adeliae*)
Chinstrap penguin (*P. antarctica*)
Gentoo penguin (*P. papua*)
Macaroni penguin (*Eudyptes chrysolophus*)
Black-browed albatross (*Thallasarche melanophrys*)
Antarctic petrel (*Thalassoica antarctica*)
Cape petrel (*Daption capense*)
Antarctic fur seal (*Arctocephalus gazella*).
The parameters monitored fall into four groups:
Parameters of reproduction;
Growth and condition;
Feeding ecology and behaviour; and
Abundance and distribution (CCAMLR, 2016).

In order to ensure comparability between sites and over time, CCAMLR has agreed a set of CCAMLR Ecosystem Monitoring Program Standard Methods that include details of how data should be collected, formats for submission of the data to the CCAMLR Secretariat and procedures for data analysis.

Approach for integration of ecological information and assessment

The Working Group on Ecosystem Monitoring and Management (WG-EMM) oversees the analyses of the CEMP data and production of CEMP indices. The CEMP indices are standardized data indices provided annually by several Members States that measure various parameters across the 4 groups mentioned above such as growth, population size, reproductive success, diet and survival of penguins, flying birds, seals and Antarctic Shags. Indices also exist for environmental parameters.

The WG-EMM provides advice to the SC on the information resulting from CEMP indices, as well as various other issues that may arise (e.g., VMEs, IUU fishing). This is firstly captured in the Report of the WG -EMM working, which is produced annually. Recent annual reports present updated values of each of the indicators for the latest year and compare it with previous years to illustrate change (see example in Table 1) (WG-EMM-17/17).

Table 1. Values of indicators A3 (total number of average nests) and A6a (total average number of chicks) for different subareas, data collection sites and species (example from WG-EMM-17/17, https://www.ccamlr.org/en/wg-emm-17/17).

Subarea/Division	Site	Parameter	Species	2016 data	2017 data
48.1	ESP	A3	PYD	4500	3370
48.1	SPS	A3	PYD	447.3	289.67
48.1	SPS	A6a	PYD	429	227.67
48.1	NPT	A3	PYN	2850	2918
48.1	NPT	A3	PYP	2112	2604
48.1	LRP	A3	PYD	5782	3972

Graphs are also used to present trends in the indicator values for either single indicators or multivariate indices. An example of the former for the indicator "population size" is shown in Figure 5. For the latter, several sets of data for different ecosystem parameters will be combined into a single index (Combined Standardised index) as a way to bring different information into a single index (Reid *et al.*, 2005).

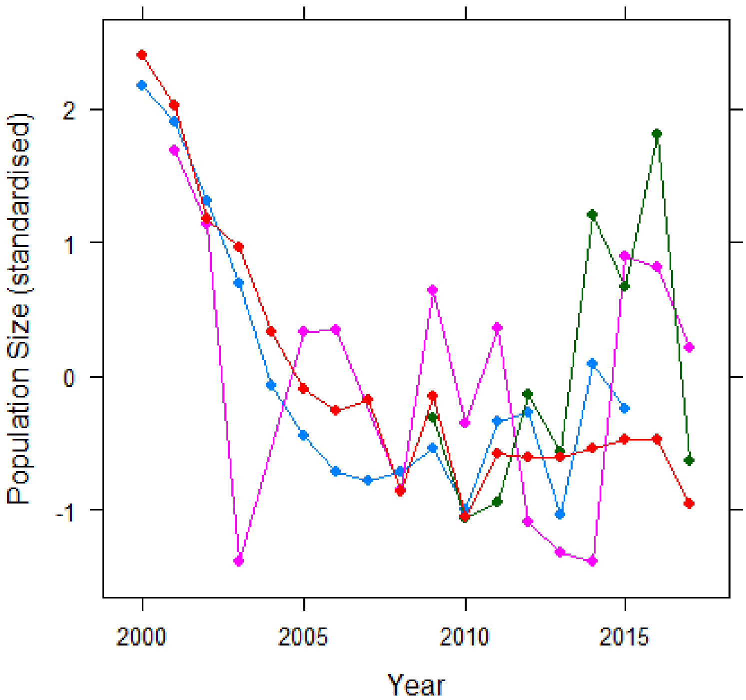


Figure 5. Standardised population size for adelie penguin. Each line represents a different area where monitoring takes place (WG-EMM-17/17).

The data from the CEMP programme has also been used to test links and correlations between those indices and the main fisheries targets (krill) (Figure 6). This is part of work to define the relationship of the monitored ecosystem indicators to fisheries related parameters and also describe the impact of fisheries on those indicators.

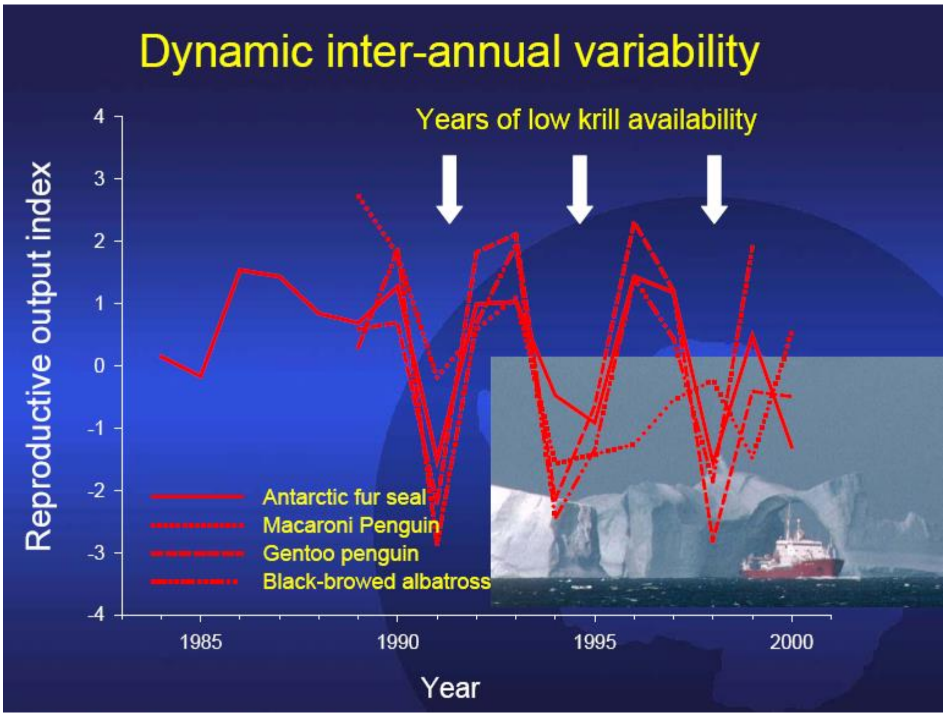


Figure 6. Annual variability of predators and availability of krill. Source: Keith Reid, "*The CCAMLR ecosystem monitoring programme: Application to the management of krill fisheries*", presented in the Monitor Workshop of the XII PICES Annual Meeting about *"Human dimensions of ecosystem variability".*

Other ecosystem related scientific information

In addition to trends in ecosystem parameters that WG–EMM produces, the Working Group on Incidental Mortality Arising from Fishing (WG-IMAF) also provides ecosystem related information and advice. Their advice focused on three major areas: avoidance of bycatch species, mitigation measures, and precautionary limits; to reduce the chance of over-exploitation of populations. This group met regularly until 2011. They provided updates on by-catch reduction and trends and focused on research and gear/fleet behavioral changes to reduce by-catch. In addition, they would advise the SC and Commission on measures required to achieve such reductions. They would also provide updates on trends in marine debris and mortality associated with the effect of fisheries and advise on further work needed. One of their recommendations was: "The Working Group recommended that observers be trained on how to identify seabirds with hydrocarbon soiling, and to report any sightings using the CCAMLR marine debris hydrocarbon soiling form (http://www.ccamlr.org/pu/e/sc/deb/forms-inst.htm) and submit this with their observer cruise report." Measures adopted led to significant reduction in by-catch mortality in the area and thus, since 2011, the WG-IMAF only meets to address specific issue(s) identified by the Scientific Committee. However, the report of the SC to the Commission still includes regular updates on incidental mortality and marine debris.

The Working Group on Fish Stock Assessment (WG-FSA) also provides ecosystem related advice in addition to standard fish assessments for harvested stock. Ecosystem-focused advice relates to identification and management of VMEs as well as fisheries-specific bycatch and incidental mortality. This information is captured in a fishery specific report, one for each target species/fishery, that the WG-FSA prepares or updates each year. This is another way to ensure that ecosystem considerations are part of decision-making.

Communication to stakeholders

Timing and procedural arrangement:

As mentioned already, ecosystem-related advice is provided to the Scientific Commission from different Groups to be then discussed and communicated to the Commission. There are a number of steps that are followed to develop the advice for the Commission, which follow the general standard procedures used by many international marine organisations. As an example, the process that will be followed for the CEMP data is described below. Similar steps are followed by other WG to provide management advice:

- Analysis of CEMP data by site, or across sites, is carried out during the intersessional period by Members States and the Secretariat, based on recommendations indicated in the reports of the Scientific Committee and Commission of preceding years, or by the National research programme objectives.

- Analysis/research on CEMP data and monitoring sites are summarised in working group papers submitted to the annual working group on Ecosystem Monitoring and Management held in July. The working group will review and discuss papers, research etc. during the course of the meeting, where there will be specific sub-groups focusing on specific aspects of CEMP or EMM.

- Recommendations made by WG EMM are discussed and reviewed/agreed during the annual Scientific Committee meeting held in October. If agreed by the SC, the recommendations are carried over into the SC meeting report. The report of the WG-EMM is also an Annex to the SC report.

• Recommendations made by the SC are then discussed and reviewed by the Commission in the annual meeting held directly after the SC meeting. The recommendations that are agreed by consensus at the Commission meeting are carried over into the Commission report and/or the relevant conservation measures for application by managers during the following CCAMLR season/intersessional period.

Management advice:

The CCAMLR convention recognises the need to account for ecosystem conservation, and therefore the management of its fisheries is based on 3 principles that need to be balanced. These principles? are 1) the existence of the fishery, 2) the krill stock status, and 3) the status of krill predators, that are used as indicators of the health of the whole ecosystem.

CCAMLR has tried to reflect those principles in its management from early on, and to do so, has adopted precautionary rules in defining the catches of krill. Simulation modelling is used to incorporate uncertainty in forecasting, and the rules require that long term krill biomass remains at 75% of its pre- exploitation levels to account for the needs of the predators. Trigger levels are also in place and if exceeded, will lead to the introduction of catch limits at a finer spatial scale to reduce the risk of local krill depletion and impacts on the ecosystem. This process offers a way to capture ecosystem considerations into management and allowed CCAMLR to adopt a more ecosystem focused approach to fisheries management despite limitations in knowledge about ecosystem processes and their links/response to fishing pressure.

Notwithstanding, the importance of such process in accounting for ecosystem impacts of fishing, the process is somehow arbitrary (e.g. there is no empirical evidence that the 75% escapement level is sufficient to meet the needs of predators). Similarly, although a trigger levels is in place to reduce the risk of depletion of krill, it is recognised that that level was established as the level that was considered not to affect predators regionally. This means that local effects on predators may still occur if the full trigger level was taken (CCAMLR, 2016). To address these issues CCAMLR has supported work to develop what is called a 'Krill Feedback Management procedure'. The information collected under CEMP contributes to CCAMLR’s efforts to develop such a procedure which is seen as a tool that could help decide how overall catch limits should be spatially distributed to minimize local depletion of krill and its predators. This procedure is primarily focusing on krill and will help inform decisions regarding acceptable total precautionary levels of krill harvest. Research supported by CCAMLR in this area aims to directly link ecosystem consideration with management. Specifically, it will help adapt management and produce area-specific catch limits that will vary depending on the status of krill and wider ecosystem in that area (SC-CAMLR, 2011).

Research on developing such feedback procedure is still on-going, but progress has been made mainly in developing risk frameworks that provide a better insight into the impacts of fishing at smaller spatial scale and in looking at type/combination of indicators that might better capture possible impacts of fishing on ecosystems.

Lessons learnt

Lesson 1. Sequential approach. CCAMLR has identified the key issues associated with the ecosystem approach and its fisheries (e.g. by-catch, food chain risks) and used that prioritisation to inform to minimise the main risks. This has allowed them to make significant progress on some key risks and then also focus on other emerging issues such as litter and vulnerable habitats.

Lesson 2. Ecosystem information as part of standard advice. Ecosystem considerations are part of the CCAMLR fisheries reports, which offer a quick summary of the main information relevant to each fishery, and that provides a way to mainstream such issues and increase the number of people (and managers) that are aware of them.

c. Ocean Health Index project

Introduction

The Ocean Health Index (Halpern *et al.*, 2012); http://www.oceanhealthindex.org/) is a tool for the assessment of ocean health that can be used to inform manager´s decisions that affect marine ecosystems. In this project more than 65 scientists/ocean experts have contributed as result of the partnerships between organizations like the National Center for Ecological Analysis and Synthesis, Sea Around Us, Conservation International, National Geographic, and the New England Aquarium.

The approach followed by the Ocean Health Index project stems from the need of new analytical approaches to guide in how to balance multiple competing and potentially conflicting public goals and connect human development with the ocean's capacity to sustain progress. Here, goals have to be understood as very general and broad components of ecosystem services that directly or indirectly will affect the society at the ecological, economic, health or life-quality levels.

This integrative approach is conducted through the so-called Ocean Health Index, which is a comprehensive index that simultaneously evaluate widely disparate metrics, allowing for an integrated assessment of changes in, for example, fish stocks, extinction risks, coastal jobs, water quality and habitat restoration. The Ocean Health Index incorporates in a quantitative way a wide range of existing ecosystem and socio-economic indicators developed and implemented a systematic approach for measuring overall condition of marine ecosystems that treats nature and people as integrated parts of a healthy system.

Each of ten goals (and their component parts, see next section) comprising the Ocean Health Index can be considered either separately or aggregated for a region, country, or the entire ocean, and compared across these scales. Tracking individual components of ecosystem health and benefits is useful when a more in-depth analysis of factors determining the index value is needed. However, combining them into a synthetic measure facilitates communication and allows direct comparison among management objectives.

Approach for the integration of ecological information and assessment

The approach developed measures the ocean health as a function of ten widely-held public goals or services for what the ocean can provide to people: food provision, artisanal fishing opportunities, natural products, carbon storage, coastal protection, coastal livelihoods and economies, tourism and recreation, sense of place, clean waters, and biodiversity (Figure 7). The Index therefore recognizes linkages between human societies and ocean ecosystems, and also that people are part of coastal and ocean systems. In turn, several goals have sub-goals. In these cases, the goal score is the average of the component sub-goals.

Each goal (or sub-goal) is assessed in relation to four dimensions: Status, Trend, Pressures and Resilience. These four dimensions are aspects of a goal that contributes to its current status or likelihood of being able to sustainably deliver that goal in the future. For each goal, each of these four dimensions is assessed based on various components, which in turn are defined by data layers that support the estimation of ecological or socio-economic indicators (see Figure 8). In Table 2, the Sub-goals, dimensions and components for the Food Provision goal are shown as an example of the structure behind the Ocean Health Index. For a complete list of combinations of goals, sub-goals, dimensions, components and layers check tables S22 and S23 in supplementary material of Halpern et al. (2012).

The ecological and socio-economic indicators and data layers were selected based in a set of criteria presented in section 2G (Halpern et al., 2012, suppl.mat.). Many of them were similar to the criteria followed to select indicators within this SC02 (see Task 2).

The method has a strong focus on sustainability and coupled human-natural systems, providing a score for each of the ten goals. Sustainability requires that both the current status and likely direction of change in status influence the score. Scenarios that maximize value today with no concern for future conditions are strongly penalized by the index. However, the main focus in the Ocean Health Index is in the near future (around 5 years) rather than longer term because near-term time frames are most relevant to policy makers and long-term future states are difficult to predict.

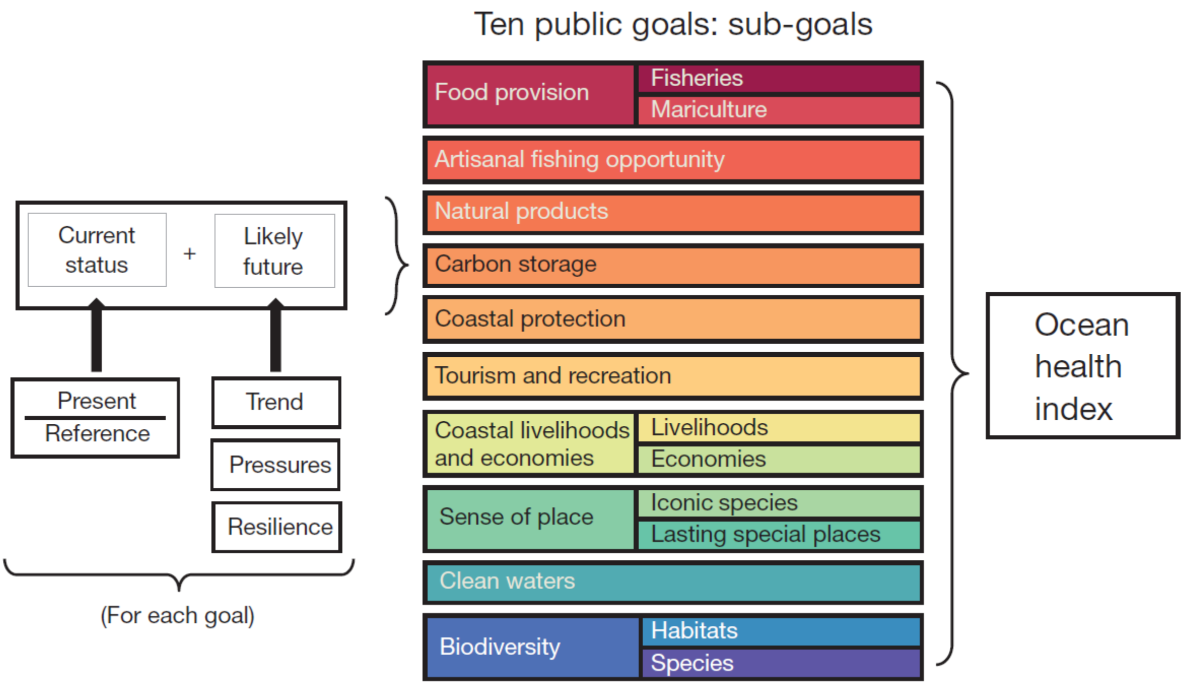


Figure 7. Conceptual framework for calculating the index. Each dimension (status, trend, pressures and resilience) is derived from a wide range of data. Dimensions combine to indicate the current status and likely future condition for each of ten goals (see equations in Methods Summary and equations (1) and (4) in Methods) (Modified from Halpern et al (2012)).

The objective (utility function) of the Index is to maximize its value (I), where I is determined as a linear weighted sum of the scores for each of the public goal indices (I1, I2, . . . , I10) and the appropriate weights for each of the goals (α1, α2, . . , α10), such that:

$$I = \propto_1 I_1 + \propto_2 I_2 + \cdots + \propto_{10} I_{10} = \sum_{i=1}^{N} \propto_i I_i$$

where $\sum_{i=1}^{N} \propto_i = 1$. The weights applied to each goal can be set based in previous knowledge, giving more importance in the final index score to one or another goal depending on the priorities, the reliability of the data, etc. As a first approach, weight can be set as 0.1 for all components or, alternatively, one of the four different sets of weights designed by Halpern et al (2012) to roughly represent three likely value sets (approximately values of preservationists, no-extractive users, and extractive users) and a fourth set of values more disparately-weighted based on a 'market first' scenario (values presented in Table 3).

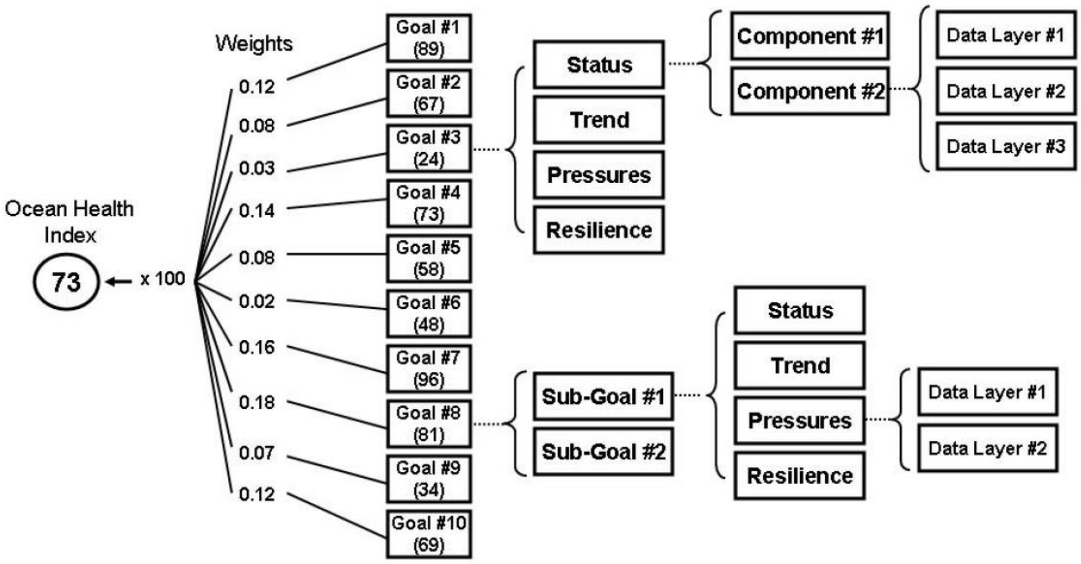


Figure 8. Flow diagram of how the Index is constructed. Goal scores are calculated by 1) combining values for the 4 dimensions, which may have more than one component, which in turn are comprised of one to several data layers (top example), or 2) averaging sub-goal scores which are each calculated by combining the 4 dimensions, which are made up of one to several data layers (bottom example). Goal scores are combined as a weighted average and multiplied by 100 to create the Index score between 0-100. (Modified from Halpern et al, 2012, suppl.mat.).

Table 2. Data layers used in each dimension for the food provision goal (Modified from Halpern et al, 2012. Supplementary material).

Goal	Sub-Goal	Status	Trend	Pressures	Resilience
Food Provision	Fisheries	Multispecies maximum sustainable yield (mMSY)	Change in Status over time	Chemical pollution	CBD habitat
		Taxonomic reporting quality		Nutrient pollution	Marine protected areas, EEZ
				Habitat destruction: subtidal hard bottom	Fisheries management effectiveness
				Habitat destruction: subtidal soft bottom	Access to artisanal fishing
				Habitat destruction: intertidal	Ecological integrity
				Alien species	Worldwide Governance Indicators
				Genetic escapes	
				Commercial fishing: high bycatch	
				Commercial fishing: low bycatch	
				Artisanal fishing: high bycatch	
				Artisanal fishing: low bycatch	
				Social pressure	
	Mariculture	Mariculture yield	Change in Status over time	Chemical pollution	CBD water
		Degree of sustainability of culture		Nutrient pollution	CBD mariculture
				Social pressure	Mariculture regulations
					Worldwide Governance Indicators

Table 3. Weights used for each goal when combining scores into the single Index under different potential value sets (Modified from Halpern et al, 2012. Supplementary material).

Goal	Preservationist	Extractive Use	Non-extractive Use	Strongly Extractive Use
Food Provision	0.05	0.15	0.10	0.18
Artisanal Opportunity	0.05	0.15	0.05	0.18
Natural Products	0.05	0.15	0.05	0.18
Carbon Storage	0.15	0.05	0.05	0.03
Coastal Protection	0.15	0.10	0.10	0.09
Coastal Livelihoods & Economies	0.10	0.15	0.10	0.18
Tourism & Recreation	0.05	0.10	0.15	0.09
Sense of Place	0.10	0.05	0.15	0.03
Clean Waters	0.15	0.05	0.10	0.03
Biodiversity	0.15	0.05	0.15	0.03

Each goal score, I_i, is a function of its present status x_i and an indication of its likely near-term future status $\hat{x}_{i,F}$:

$$I_i = \frac{x_i + \hat{x}_{i,F}}{2} .$$

The present status of goal i, x_i, is its present status value, X_i, relative to a reference point, $X_{i,F}$, uniquely chosen for each goal and rescaled 0-100 such that:

$$x_i = \frac{X_i}{X_{i,F}} .$$

The reference point, $X_{i,F}$, can be determined in different ways (Defined under subtask 4.1), depending on the conceptual and data constraints for each goal. Reference points can be estimated mechanistically using a functional relationship (e.g. for fisheries: maximum sustainable yield, MSY; spatially, by means of comparison with another region; or temporally, using a past benchmark.

The estimate of a goal's likely near-term future status, $\hat{x}_{i,F}$ is a function of four dimensions: present status, recent trend (over the past ~5 years) normalized to a reference value, current cumulative pressures to the goal, and social and ecological resilience to negative pressures (measured as a function of governance and social institutions in place to protect or regulate the system and the ecological condition of locations). The role of the Resilience and Pressure dimensions is to modulate the likely near-term future condition by incorporating additional information beyond that provided by the recent trend. That additional information relates to factors that negatively affect a goal as Pressures and those that positively affect a goal as Resilience. The expectation of a likely future condition suggested by the Trend will become more or less optimistic depending on the effects of resilience and pressure.

Hence, all the four dimensions status, trend, pressure and resilience are assessed quantitatively for each goal (or subgoals). A detailed description of the exact models and equations used to estimate the score for each goal is presented in the supplementary material provided by Halpern et al. (2012).

Communication to stakeholders

The resulting Ocean Health Index is presented in a graphic and colorful way (Figure 9). This visual way of presenting the index is a very intuitive and easy approach to show the score obtained for the global Ocean Health Index for all the ten goals together, but also to present the score obtained for each of the goals separately. This provides to managers easily with an idea about the global state, but also about the areas (goals) identify the most problematic areas. In addition, the scores obtained for each of the data layers, components and dimensions, can also be presented in separate tables if required by the managers to identify specifically the dimensions (if current versus short-term status) and the components that needs more focus from the management perspective.

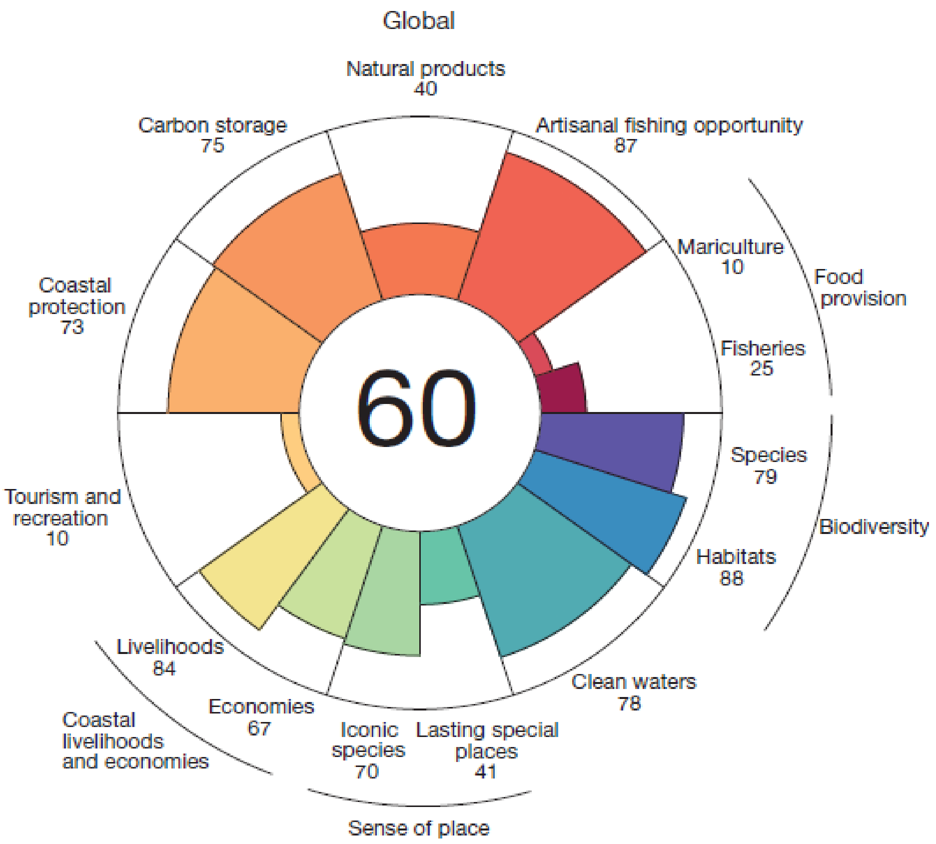


Figure 9. Index scores (inside circle) and individual goal scores (colored petals) for global area-weighted average. The outer ring is the maximum possible score for each goal, and a goal's score and weight (relative contribution) are represented by the petal's length and width, respectively (Modified from Halpern et al., 2012).

Lessons learnt

The methodology to estimate the Ocean Health Index implies a number of assumptions and caveats which are mostly related with the correlation in the information between 1) goals beyond what already considered within the calculations, 2) the assumption that the pressures and resilience measures will manifest their impacts within the near-term time frame, or 3) the fact that reference points for different goals are variably ambitious and variably realistic. The consequence is that some goals require a higher standard to achieve a perfect score than other goals. A more detailed list of assumptions is presented in section 2F in Halpern et al. (2012, suppl.mat.).

d. Nested Environmental status Assessment Tool (NEAT v.1.3)

Introduction

The Nested Environmental status Assessment Tool (NEAT) (Berg *et al.*, 2017; Borja *et al.*, 2017) is a flexible and user-friendly desktop application developed with the aim of supporting European Member States and Regional Sea Conventions in their commitment to assessing the environmental status of marine waters, so they can inform managers on where management measures are needed.

This software has been developed in the context of the DEVOTES project (http://www.devotes-project.eu/). Whereas the software, the concept and design has mainly been developed by three institutions (MARILIM, NIVA, and Aarhus University), more than 20 scientists have contributed to its development, providing inputs and testing the tool at ten different sites around Europe (Uusitalo *et al.*, 2017). In addition, there several anonymous contributors have contributed, through their participation in courses, by proposing improvements of the tool, that now is in the version 1.3.

The main principles of NEAT are:

Indicators: The assessment is based on indicators. The current version of NEAT integrates an indicator catalogue (Teixeira *et al.*, 2016) for predefined indicators for the biodiversity assessment. However, the tool is not limited to those indicators; it allows adding as many indicators as needed (not only biodiversity but indicators any kind of– specific to the assessment to be made).

Weighting and hierarchies: the central principle in the NEAT method is a hierarchical, nested structure of Spatial Assessment Units (SAU), habitats and ecosystem components. Each indicator is related to a specific ecosystem component (e.g. fish), which lives in a certain habitat (e.g. water column), and information has been collected for a specific area or SAU (e.g. all ICES zones). The contribution of the indicator is weighted by the area to which the indicator contributes. Thus, no bias is introduced into the assessment by the choice of the indicators or weightings.

Aggregation: in order to aggregate indicators, they are all normalized into a scale of 0 to 1. Specific boundaries of the indicators (e.g. boundary between moderate and good status) are also normalized. By default, aggregation is done across all indicators belonging to a SAU. However, NEAT is designed to do aggregations to any other entity. For example, the method can be used to aggregate all indicators of a SAU and show the status divided among the different ecosystem components of the SAU.

NEAT value: the outcomes of the aggregation are visualized into a number (the NEAT value) and a color, which corresponds to the status. This NEAT value is obtained for the whole assessed area but can be visualized in different manners. For example, it is possible to visualize how the information from the different ecosystem components (e.g. fish, birds, etc.) has contributed to the assessment.

Uncertainty: Each NEAT value is accompanied with its quantitative estimate of uncertainty. This estimate is performed using the standard error (entered at the same time as the indicator value), and performance of Monte Carlo simulations as means to understand how this error propagates throughout the assessment.

Although the driver for the development of NEAT was the biodiversity status assessment in European seas, NEAT capacity is much broader than that. In fact, recently, it has been applied to the Caspian Sea to assess the status of bathing waters (Nemati *et al.*, 2017). The assessment principles used in NEAT are universal and can easily be adapted to other assessment types such as pressure assessments, impact assessments, ecosystem service assessment, etc. Further details on the assessment method behind NEAT can be found in (Andersen *et al.*, 2017).

Approach for integration of ecological information and assessment

The following section is a summary of Berg et al. (2017). For further details, please consult this reference which contains the NEAT manual.

The main window of the NEAT software is kept very simple by design (Figure 10). It gives direct access to the main functions of the software.

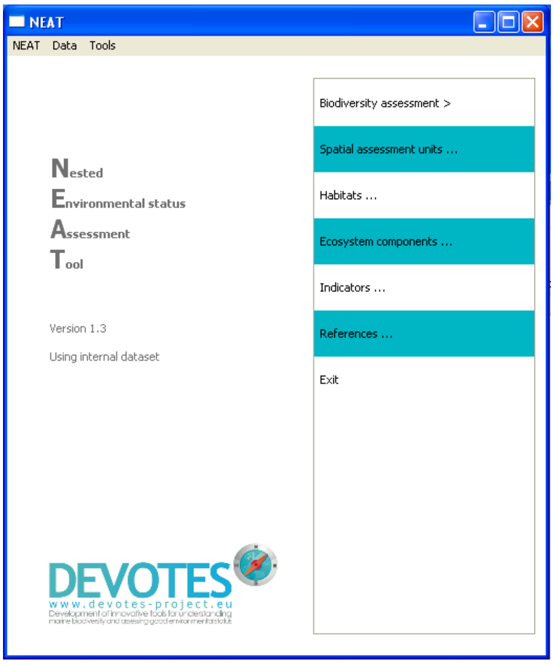


Figure 10. Main window of the NEAT application as visualized with Windows version (XP).

By clicking on the spatial assessment units or habitats bottoms, a set of predefined hierarchies appear. That is, it is possible to choose the spatial scale for which the assessment is to be performed. However, since not all possible options are available, these spatial assessment or habitat hierarchies can be designed according to the specificities of the assessment.

The ecosystem components menu brings the user to a set of predefined ecosystem components, where additional ones can be added. Although this menu is presented in a hierarchical format, this hierarchy does not play any role in the assessment.

The indicator menu contains a catalogue of more than 600 indicators with their associated metadata (e.g. who has entered the data, reference, targets, information on type of indicator (e.g. state or pressure indicator), etc.). Most indicators are related to marine biodiversity, since its assessment was the main focus for the NEAT development; however, any additional indicator can be added.

For performing an assessment, a set of predefined options are available. These are based on the hierarchies available for the spatial assessment units and habitats, and the pre-defined ecosystem components. However, it can also be used the "custom" option, so the spatial assessment unit for which the assessment wants to be performed, the specific habitats and ecosystem components can be defined.

Every assessment item is a combination of one indicator assigned to a combination of one SAU, one habitat and one ecosystem component. For each of these combinations, a value and its standard error must be given. This standard error reflects the value of the indicator in the specified SAU, habitat and ecosystem component.

The ecosystem indicators have to be classified based in the shape of its functional relationship. Once the classifications are ready, the indicators can be added to the assessment, for which the indicator values and error values need to be provided. Then, the assessment can be performed by clicking the "Do assessment" button. The assessment will be calculated with some default settings. The window shown is separated into two parts (Figure 11). The upper part contains the settings that influence how the NEAT calculations are done. The lower part presents the assessment results in a table. The assessment will automatically by re-calculated when a setting has been changed.

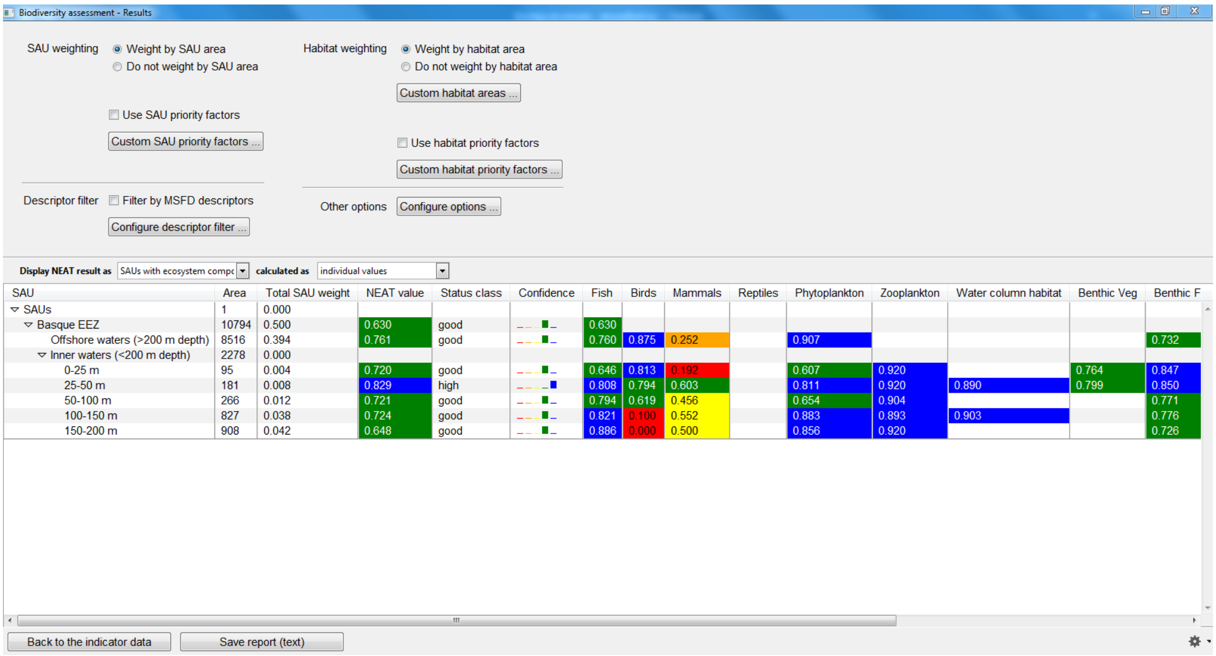


Figure 11. NEAT assessment outputs presented for the overall spatial scale (and its hierarchy) and visualized by ecosystem components. Colors are associated to different status levels. Bar figures present the confidence of the different assessment values.

The first block of settings influences the way in which the assessment does the weighting. That is, the weighting can be done taking into account the specific spatial coverage of the different spatial assessment units and/or habitats or not. Furthermore, a priority factor can be given to specific spatial assessment units or habitats (if that is thought to be appropriate (e.g. case example?).

The second block is used to filter the assessment by descriptor and to configure some auxiliary settings, such as the number of Monte Carlo permutations used for calculating the uncertainty of the assessment.

In addition, the other half of the screen presents different options for displaying the results and the results themselves. The assessment results are shown in a tabular format. Each row in the table represents an individual SAU and either its associated ecosystem components or habitat (for which indicators have been selected). This is determined by choosing either "SAUs with ecosystem components" or "SAUs with habitats" as NEAT values to display (listbox above the results table).

The displayed NEAT values can be calculated in two different ways. The default is "summarized values". This means NEAT values of a specific SAU include the assessment of all subordinate SAUs NEAT and these are aggregated into the final result. This fully utilizes the defined weightings. The second calculation mode is "individual values". In this mode all NEAT values are only representing the individual SAUs without aggregating their subordinate SAUs into the final value. This can e.g. be used to evaluate the individual contributions of the SAUs to the overall summarized NEAT result.

Communication to stakeholders

The NEAT outcomes are presented in an easy to interpret table with meaningful colors (Figure annex 8). On the one hand, it is possible to visualize the different NEAT scores, and it is possible to perform different visualizations of the outcomes. In addition to visualizing NEAT values of the different SAU (if existing), it is possible to see how different ecosystem components (e.g. fish, mammals) contribute to the NEAT value at each SAU and to the overall assessment. Similarly, this is also possible to present the output, so it allows assess the performance of the indicators in the different habitats. Furthermore, descriptors can be filtered, so only indicators that correspond to the descriptor of interests are considered in the assessment.

It is worth noting that since the NEAT software has been developed in the context of the Marine Strategy Framework Directive (MSFD), and as such, indicators are linked to the descriptors defined under the MSFD. However, this could be easily adapted, and one of the elements of the structure of NEAT used for a given descriptor may be used to describe any other quality that is of interest for assessment on course. As an example, descriptor 1 in NEAT originally designed to assess biodiversity could be used to assess the pressure indicators instead.

In addition to the NEAT values, the background of each number is set so it provides five possible colors, each color corresponding to 5 different types of assessment quality (i.e. bad, poor, moderate, good, high).

Finally, uncertainty is also visualized using a bar graph, in which the certainty for the assessment to be in any of the five "quality" assessment categories.

Lessons learnt

The methodology used to calculate the NEAT values is clear, transparent and straight forward. It is based on existing entities (SAUs, habitats, and ecosystem components), making outcomes more likely to be closer to reality, since extrapolations or assumptions are not needed.

Fortunately, most of the complexity of the algorithms and calculations are not visualized in the software, allowing for easy use and interpretation of outcomes.

The only requirement for using this software is the information availability of indicators, for which a value and standard error is needed. In addition, the reference value that defines the limit between moderate and good status, as well as "worse limit" and "best limit" are needed for being of used in the assessment.

Most features of the NEAT can be customized, from indicators, to ecosystem components, weighting and priority factors, and as well as visualization of output.

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18. APPENDIX 5.1. – PILOT ECOSYSTEM PLAN IN ICCAT

1 INTRODUCTION

Key message

- Effective operational plans are needed to link higher level policies into management actions.
- Ecosystem plans are driven by objectives centered on the ecosystem, and not on individual species or stocks.
- This ecosystem plan aims to guide the operationalization of an EAFM in the Tropical Ecoregion of the Atlantic Ocean.
- While the ecoregion has well-defined geographic boundaries, these boundaries should be relaxed when developing ecosystem analyses and assessments to allow understanding of the external pressures, impacts and ecosystem processes governing the ecoregion. However, the ecosystem-level management advice should be focused on the most pressing high priority issues and challenging needs of the ecoregion.

1.1 Main objectives and purpose of the ecosystem plan

The main purpose of this pilot ecosystem plan is to facilitate the implementation and operationalization of the Ecosystem Approach to Fisheries Management (EAFM) in the International Commission for the Conservation of Atlantic Tunas (ICCAT). While ICCAT has committed to operationalize the EAFM within its Convention Area, its ecosystem-based research and activities have been implemented in an *ad hoc* way, without having a long-term vision and a formalized plan to prescribe how fisheries will be managed from an ecosystem perspective (Juan-Jordá *et al.*, 2017). Here, a pilot ecosystem plan is developed for the Tropical Ecoregion of the Atlantic Ocean to guide the operationalization of an EAFM in this region. This ecosystem plan is based on objectives centered on the ecosystem and not on one individual species or stock targeted by ICCAT fisheries in this region. At this stage, this pilot ecosystem plan seeks to create awareness about the need for ecosystem planning, create discussion about what elements need to be part of a planning process, and intents to be the foundation for future participatory and consultative ecosystem plans in the ICCAT convention area.

The EAFM aims to balance the impacts of fisheries on the ecosystems and the ecosystem services derived from them (FAO, 2003). The EAFM should be treated as a process; a process that needs to get updated and adapted as new information and tools become available. This adaptive management requires effective planning. Therefore, ecosystem plans need to be operational and adaptive. Operational ecosystem plans are designed to translate higher level policies and objectives into actions (Staples *et al.*, 2014). Ecosystem plans are considered a tool that can serve as a framework to identify and formalize ecosystem goals and objectives, plan actions based on priorities, measure performance of the whole fishery system, address trade-offs, and incorporate them in fisheries management (Levin *et al.*, 2018). It is important that ecosystem plans are tailored to a well-defined region in order to focus on its priorities and singularities.

There are multiple purposes and benefits in developing an ecosystem plan, which ultimately aims to guide the implementation of an EAFM in a region (NPFMC, 2007; Staples *et al.*, 2014; Levin *et al.*, 2018), including:

(1) It creates a transparent process that may help the Commission to set ecosystem goals and management objectives;

(2) It provides a framework for strategic planning to guide and prioritize fishery and ecosystem research, modelling and monitoring needs;

(3) It facilitates the integration of information and knowledge from different fisheries operating in a region and their cumulative impact on the ecosystem;

(4) It provides a framework to document current and best practices in the region as well as the impediments hindering the operationalization of EAFM in the region;

(5) It provides a framework to identify key ecosystem components in the region, their interconnectedness, and their importance for specific management questions;

(6) It helps the Commission to understand the cumulative effects of fisheries and emergent trade-offs between multiple objectives;

(7) It serves as a communication tool to better link ecosystem science and policy and as a dialogue forum for managers, scientist and stakeholders;

1.2 Geographic area of the ecosystem plan

The geographic area of the ecosystem plan covers the Tropical Ecoregion of the Atlantic Ocean (Figure 1). Seven potential ecoregions within the convention area of ICCAT were proposed in the project *EASME/EMFF/2016/008 SC02 Selecting ecosystem indicators for fisheries targeting highly migratory species*. The boundaries of the ecoregions rest on three pillars of information: the existing knowledge of biogeographic classifications of the pelagic environment, the spatial dynamics of tuna and tuna-like species and communities they form, and the spatial distributions of the main fishing fleets targeting them (for more details on the delineation of ecoregions see Task 3 of SC02 final project report). Each ecoregion is characterized by greater similarity in biogeographic and oceanographic characteristics, in tuna and billfish communities and the type of fishing fleets exploiting them. The proposed ecoregions aim to focus fisheries management on a specified place and on priority issues facing the most challenging needs for each region.

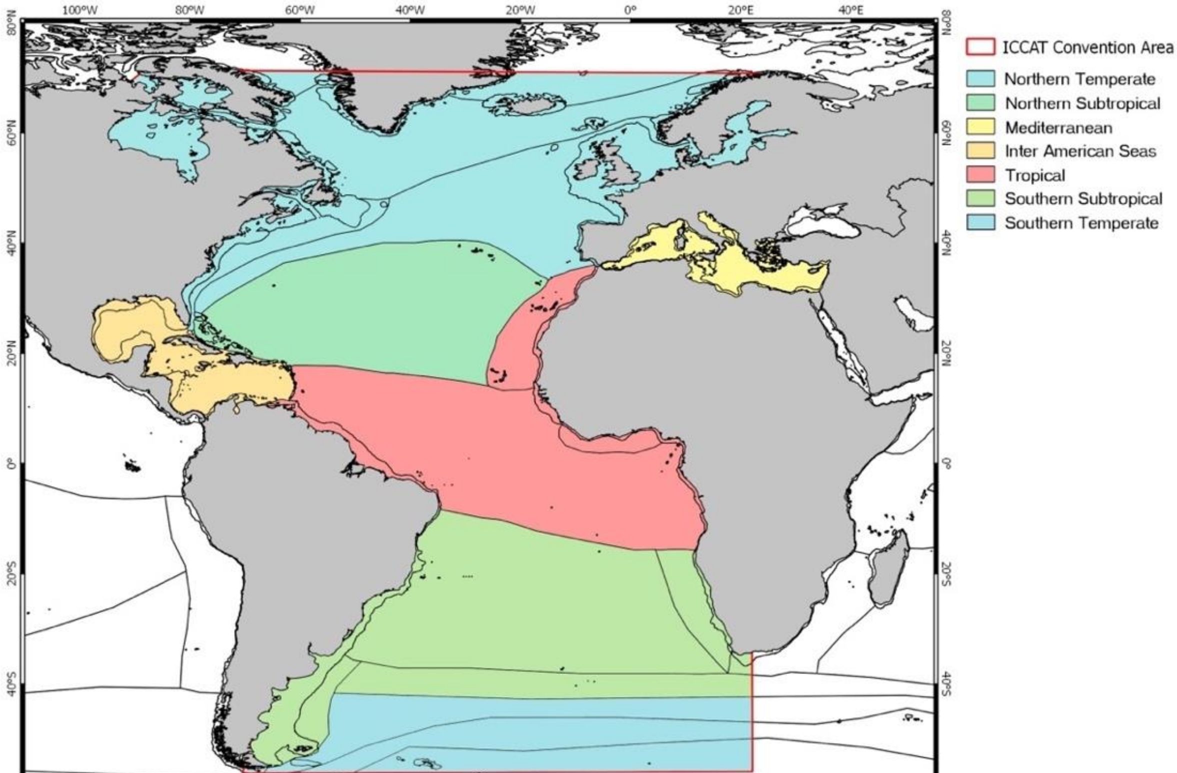


Figure 1. Proposal of ecoregions within the ICCAT Convention area. The Tropical Ecoregion is the core area of this ecosystem plan.

The Tropical Ecoregion is the result from combining several provinces of the Spalding biogeographic classification into one larger region (Spalding *et al.*, 2012). The provinces combined were the Guinea Current Province, the Equatorial Atlantic Current Province, and the Canary Current Province. The Tropical Ecoregion is characterized by several areas of coastal upwelling along the African coast, with increased biological productivity, and rich fishing grounds. It also features the seasonal equatorial upwelling (July – September) which creates environmental conditions quite different compared to adjacent oceanographic gyres. ICCAT is responsible to manage the tuna and tuna like species in this region. The species primarily targeted in this ecoregion are the tropical tuna species – skipjack, yellowfin, and bigeye tunas, and secondarily swordfish, but other billfishes, bony fishes and sharks are also caught as bycatch and retained for their commercial value. Industrial purse seiners, followed by industrial longliners are the main fisheries targeting tuna and tuna-like species in the Tropical Ecoregion (ICCAT, 2006). There are also artisanal baitboat and gillnets fisheries operating in the region (Riskas & Tiwari, 2013). The Tropical Ecoregion is, however, also home to a large diversity of species which depend on and support the populations of tuna and tuna-like species. Many of these species also interact and are caught accidentally by ICCAT fisheries, including some sharks, marine turtles, marine mammals and seabirds.

While the combined Spalding's provinces form the core geographic area of this plan, the geographic boundaries should be relaxed to allow understanding of the external pressures, impacts and drivers on the ecoregion. When operationalizing an ecosystem approach, the main interactions between ICCAT fisheries on the different ecosystem components in this region need to be identified and monitored to provide effective ecosystem advice. Effective ecosystem advice is crucial not only to ensure sustainable fisheries of tuna and tuna-like species but also to minimize their impacts on the ecosystem to avoid undesired ecosystem states.

1.3 A snapshot of the key elements of the ecosystem plan

The development of an ecosystem plan requires the use of multiple tools and the development of multiple elements and processes. Here, the pilot ecosystem plan developed for the Tropical Ecoregion includes the following main core elements which will be developed individually in the following sections (Figure 2). Each key element is briefly presented and described below:

6. **Strategic vision and goals –** An ecosystem plan needs clear statements of vision, goals and objectives. A vision is a top-level aspiration of the Commission, a long-term statement of the aspirations of the Commission of what the future

would look like if management is successful (Staples *et al.*, 2014). This vision should encapsulate key principles of the ecosystem approach such as the sustainable use of fish resources, the conservation of biodiversity and the maintenance of resilient ecosystems.

7. **Ecosystem overview** –The ecosystem overview aims to integrate and synthesize the current knowledge of the main pressures and drivers that contribute to the state, and changes in the state, of the different ecosystem components in the Ecoregion covered by the plan. It also allows identifying how the different ecosystem components interact and relate to each other, highlighting those emergent issues that need to be monitored. Ecosystem overviews also facilitate the identifications of data and research gaps in the region. It can be used as a tool to synthesize information to the Commission.

8. **Conceptual ecosystem models** – Conceptual ecosystem models are a tool that allows visualizing those relevant ecosystem components and their interconnection. It also allows identifying and raising a manageable number of issues that may need to be researched separately or as a whole and ensures that no critical components are missed. Conceptual ecosystem model can also help to identify trade-offs of management actions on different components of the ecosystem, which may lead to more informed decision making. In addition, the conceptual ecosystem models can also be used as a tool to synthesize information to the Commission (as well as the public). Therefore, it can be used as a communication tool for ecosystem science.

9. **Skeleton of indicator-based ecosystem assessments** - The ecosystem overview and conceptual ecosystem models for the Tropical Ecoregion allows to identify those issues that need to be addressed in the ecosystem plan, and those issues or ecosystem elements that would require monitoring or further research. Here, a general framework is designed where all relevant ecosystem interactions that need to be monitored and assessed by the Commission are listed. For each interaction, a list of ecosystem indicators is proposed as well as potential management objectives to track the state of each relevant interaction.

10. **Strategy for communication and provision of advice –** The pilot ecosystem plan needs to be shared and communicated to different audiences including the Standing Committee on Research and Statistics (SCRS) and the Commission. A communication strategy is proposed for sharing results in a logical and strategic

way. This ecosystem plan also identifies and proposes a series of products and activities that could be developed to better link ecosystem science and fisheries management advice.

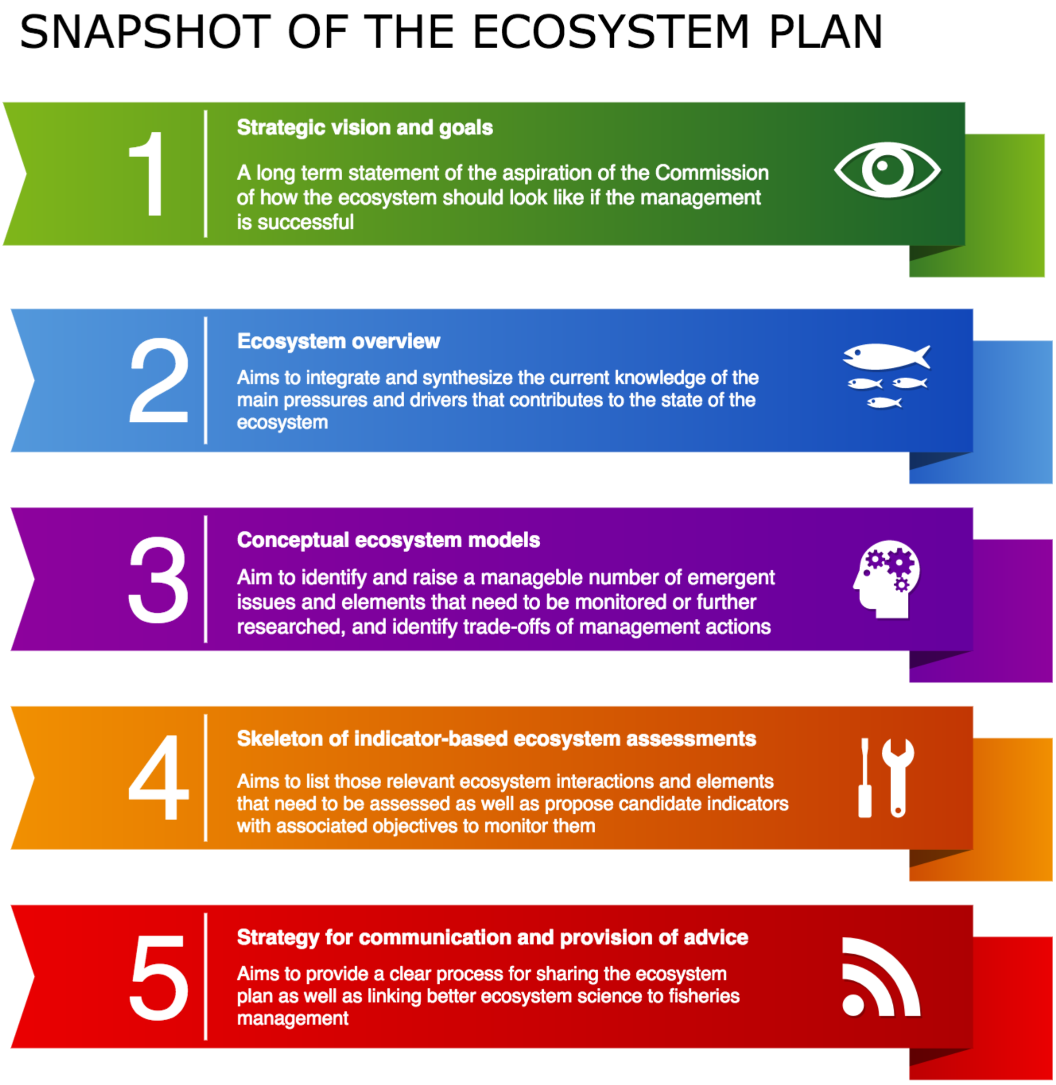


Figure 2. A snapshot of core elements of the pilot ecosystem plan for the Tropical Ecoregion.

The aforementioned elements are considered to be the first steps towards the development of a formal ecosystem plan in ICCAT. At present, the current state and formulation of elements included in the ecosystem plan should be seen as preliminary as they are still under development and need to be openly discussed with the SCRS and Commission. Furthermore, the elements developed under this plan should not be considered as a complete list. Future revisions of this pilot ecosystem plan could also envision to include additional elements. For example, it could include a section with management actions needed to meet each specific objective, a section on skills and capabilities to support the implementation of the plan, as well as identify continuous financial support for ensure its implementation, to name a few (see recommendations section).

1.4 Main scope of the ecosystem plan

This pilot ecosystem plan focuses on the operationalization of an ecosystem approach to “fisheries” management, by identifying and addressing issues that can only be dealt by the fisheries sector and by ICCAT fisheries. It does not cover other human sectors such as navigation, tourism or pollution as these are not under the manageable activities of ICCAT. However, this non-fishery derived pressures might also have an impact on marine ecosystems and ultimately the conservations and sustainable use of tuna and tuna-like species. Addressing them might require more cross sectoral management and coordination with other international and intergovernmental institutions. This plan does not address these cross sectoral interactions.

Furthermore, it is important to highlight that this plan only addresses the ecological component of an EAFM. While, an EAFM rests on the three pillars of sustainability including the ecological well-being, socio-economic well-being and good governance (FAO, 2003), this plan only focuses on developing the ecological aspects to be taken into account when providing ecosystem advice, and does not address the socio-economic and governance aspects of fisheries. Until the socio-economic considerations and governance are addressed properly, this pilot ecosystem plan will only be partially guiding the operationalization of EAFM in the Tropical Ecoregion.

2 STRATEGIC VISION, GOALS AND OBJECTIVES

Key message

- The Commission needs to agree on the vision for this (or any) ecosystem plan.
- This plan illustrates examples of ecosystem visions adopted by other organizations to guide the Commission to develop its own.

A vision is a top-level aspiration of the Commission, a long-term statement of the aspirations of the Commission of what the future would look like in the Tropical Ecoregion if fisheries management is successful (Staples *et al.*, 2014). Ideally a strategic vision should be discussed and agreed by the Commission. ICCAT has not developed and adopted its own ecosystem policy which should include a well-defined ecosystem vision statement, ecosystem goals and an implementation strategy to achieve them. This pilot ecosystem plan provides three examples of ecosystem vision statements adopted by other organizations and programs and highlights their commonalities to guide the Commission on what key principles should be included when developing its own.

Examples of vision statements:

The North Pacific Fisheries Management Council in the USA adopted in 2014 an ecosystem policy that expressed the Council aspiration to continue moving towards implementing the ecosystem approach to fisheries management. The policy included a value statement, vision statement, implementation strategy and ecosystem goals. Its ecosystem vision articulates:

> "The Council envisions sustainable fisheries that provide benefits for harvesters, processors, recreational and subsistence users, and fishing communities, which (1) are maintained by healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; (2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and (3) are managed using a precautionary, transparent, and inclusive process that allows for analyses of trade-offs, accounts for changing conditions, and mitigates threats."

The Mid-Atlantic Fishery Management Council in the USA approved its first strategic plan including a vision, a series of goals and strategies in 2013. Its vision statement articulates:

> "Healthy and productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders"

In Europe, the Marine Strategy Framework Directive (MSFD) adopted in 2008 is the main environmental policy for the marine domain, which main goal is to achieve Good Environmental Status (GES) of EU marine waters by 2020. The Directive defines GES as:

> *"The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive" Article 3"*

Also relevant for the European marine domain, the Common Fishery Policy (CFP), last updated in 2014, sets the rules for managing European fishing fleets and fish stocks, which objectives aligns with the main objective of the MSFD. The CFP overall objective is

> *".. shall ensure that fishing and aquaculture activities are environmental sustainable in the long-term and are managed in a way that is consistent with the objectives of achieving economic, social and employment benefits, and of contributing to the availability of food supplies."* and the CFP also articulates *"should contribute to the protection of the marine environment, to the sustainable management of all commercially exploited species, and in particular to the achievement of good environmental status by 2020…".*

These policy and vision statements encapsulate key principles of the ecosystem approach to fisheries management including (1) the sustainable use of fish resources, (2) the conservation of biodiversity and the maintenance of resilient and productive ecosystems, and (3) the provision of economic, social and employment benefits to stakeholders. These aforementioned principles should guide the Commission efforts to developing its own vision statement, strategic goals and objectives.

3 ECOSYSTEM OVERVIEW -UNDERSTANDING THE TROPICAL ECOSYSTEM IN THE ATLANTIC OCEAN

Key message

- The ecosystem overview was developed to facilitate the synthesis and integration of all relevant and available ecosystem information of the Tropical Ecoregion, so it can be better communicated to the Commission.
- The selective extraction of species by fishing and the production and dumping of marine debris derived from fishing activities are the main manageable pressures by ICCAT causing an effect on the state of the ecosystem. Natural environmental variability and climate change are the main pressures non-susceptible to ICCAT management.
- The state of the principal market tunas (and few billfish and shark species), which are the main targeted and retained species in ICCAT fisheries, are relatively well known and monitored. There remain a large number of retained fish species for which their state is unknown. Furthermore, the state of the large majority of non-retained species including sharks, marine turtles, seabirds and marine mammals are also poorly known and monitored.
- The impacts of ICCAT fisheries on the community structure and marine foodweb also remain poorly monitored and understood.
- Habitat of ecological significance, which might include areas used by species for spawning grounds and migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate in a particular time, are also poorly monitored and understood.

The ecosystem overview for the Tropical Ecoregion aims to integrate and synthesize the existing knowledge of the main pressures and drivers that contribute to the state, and changes in the state, of the different ecosystem components in the ecoregion. Therefore, it requires prior identification of the main pressures impacting the state of the marine ecosystem, and identification of what ecosystem components are being affected and impacted by these pressures (Figure 3). The ecosystem overview also aims to identify how the different ecosystem components interact and relate to each other, raising up those emergent issues that need to be monitored in the ecoregion and those research gaps that need to be addressed to have a complete view of the system.

A distinction is made between pressures that can be controlled by ICCAT management and those that cannot (Figure 3). The most important manageable pressure is commercial fishing, which selectively extracts a number of species but indirectly also impacts other marine species (incidental captures). The unquantified illegal, undeclared and unregulated (IUU) fishing occurring in the area, if any, should also be accounted for as an additional human activity exerting pressure on the species being extracted and the broader ecosystem as well as impacting the fisheries operating in the region. Another manageable pressure consists on the production and dumping of marine litter derived from the commercial fisheries. Finally, the changing oceanographic conditions of the region as well as climate change are the most important unmanageable pressures by ICCAT. Changing oceanographic conditions and climate change potentially can affect and impact the state of the ecosystem and all its components including the productivity of the system all the way to the upper trophic levels of the marine foodweb. While there is still a debate whether climate change is a driver or a pressure in the system. Here it is treated as a pressure following this definition: a pressure "is the result of a driver-initiated mechanisms (human activity/natural process) causing an effect on any part of an ecosystem that may alter the environmental state" (Oesterwind *et al.*, 2016). By following this definition, climate change can be attributed to pressure categories resulting from both anthropogenic and natural drivers (Figure 3).

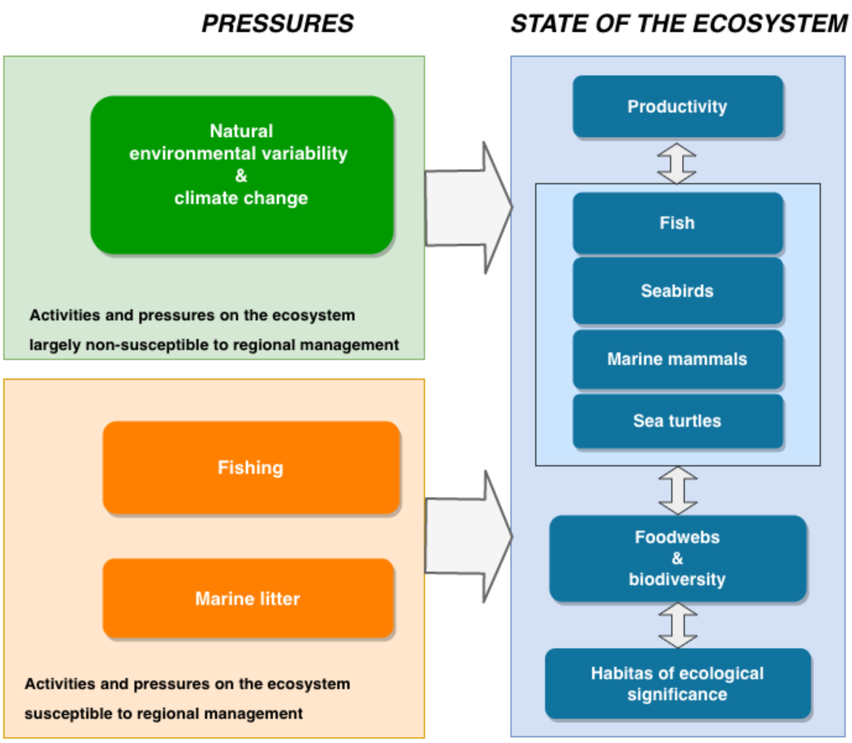


Figure 3. Atlantic Tropical Ecosystem overview with the major regional drivers, pressures affecting the state of the different ecosystem components.

The ecosystem overview in Figure 3 also describes the state and the changes in state of the different components of the ecosystems and describes the main interactions between the existing pressures and the different states of the ecosystem. The state of the main ecosystem components described are (1) the productivity of the system (plankton communities), (2) fishes, (3) megafauna including seabirds, sea turtles and marine mammals, as well as (4) how these species interact forming complex food webs and sustain marine biodiversity. Finally, the overview also describes how species (and the different stages of their life cycles) interact in space and time forming habitats of ecological significance. Furthermore, when describing the state of the different taxonomic groups, it is important to distinguish between species that are targeted as well as retained by the ICCAT fisheries from those species that are not necessarily targeted but that are either retained by ICCAT fisheries because of some commercial value or are not retained (and therefore discarded either death or alive) due to lack of no commercial value or non-retention measures in place (e.g. some sharks, seabirds, sea turtles).

3.1 Pressures susceptible to regional management

This section aims to provide an overview of the main manageable pressures causing an effect on the state of any part of the ecosystem. First, it describes the main commercial fisheries, including the main gears and flag states, operating in the region as well as the main fish species targeted and caught by these fisheries. It also presents our current knowledge on the IUU fishing occurring in this region. Last, it presents an overview on the current understanding of the production and dumping of marine debris derived from ICCAT fishing activities in the region.

3.1.1 Selective extraction of species through fishing

Three major gears operate in the Tropical Ecoregion including purse seine, longline, and baitboat fisheries (Figure 4). Other gears also catch tunas and tuna-like species in the Tropical Ecoregion, such as gillnets and harpoons, but these are poorly monitored and overseen in ICCAT (ICCAT, 2006; Riskas & Tiwari, 2013). Combining all the fisheries together, the reported landings of major commercial tuna and billfishes was around 325 thousand annual tonnes between 2010 and 2014 in the Tropical Ecoregion, a 18% decrease from 1991 (Figure 4). Landings increased since the 1950s rapidly until the early 1990s, then decreased by 43% until 2006 (driven mainly by the decrease in purse seiners operating in the area that moved to the Indian Ocean), and they have since increased reaching 323 thousand tonnes in 2014. Between 2010-2014, the majority of the landings were made of skipjack tuna (53%), followed by yellowfin (23%) and bigeye (19%) tunas (Figure 4.a). The catches of swordfish accounted for 2% and less than 1% for albacore of the total catch in the ecoregion. While these proportions provide an idea of the species composition in the area, the percentages could be in some extend affected by management regulations as, for example, swordfish have been managed with quotas (total allowable catch) over the last 20 years which limits the total cap on their landings.

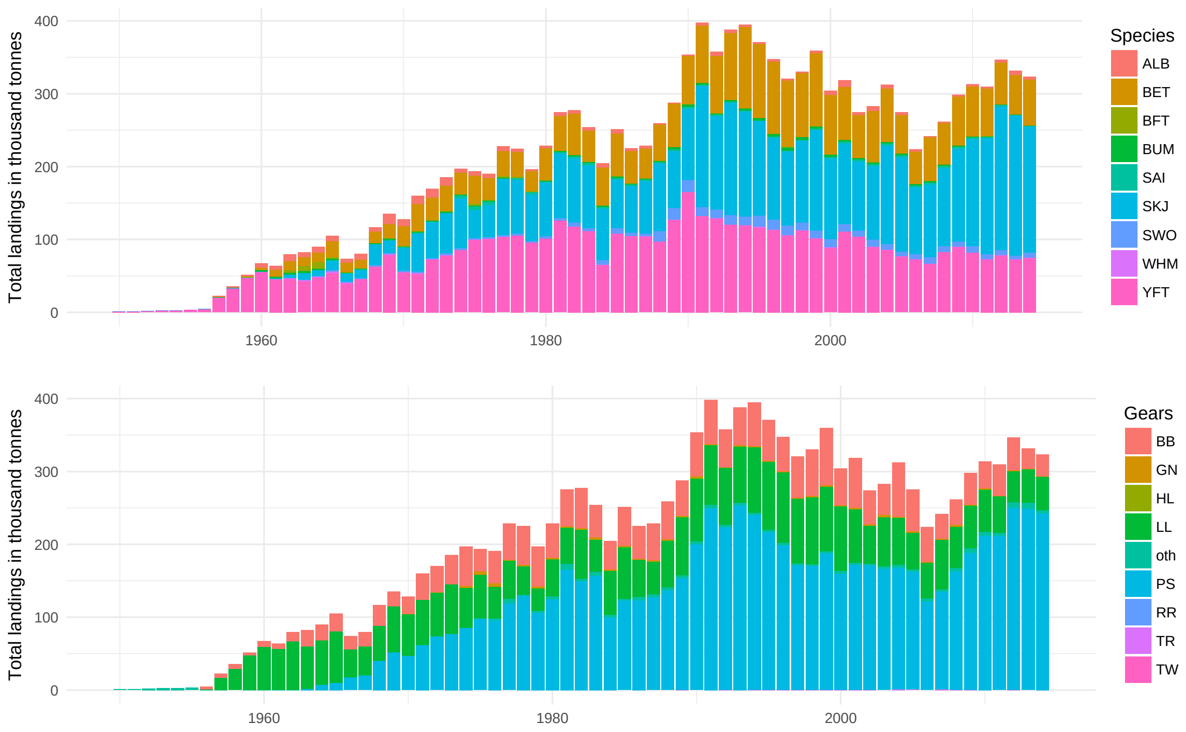


Figure 4. Total reported landings in the Tropical Ecoregion. (a) by species: albacore tuna (ALB), bigeye tuna (BET), Atlantic bluefin tuna (BFT), Atlantic blue marlin (BUM), Atlantic sailfish (SAI), skipjack (SKJ), swordfish (SWO), Atlantic white marling (WHM), and yellowfin tuna (YFT); (b) by main gear groups: bait boat (BB), gillnet (GN), handline (HL), harpoon (HP), longline (LL), oth (others), purse seine (PS), road & reel (RR), trap (TR), trawl (trawl). Data source: ICCAT Task I nominal catches database.

The large scale longline fishery started at the end of the 1950, declined in the late 1970s but then rose again and stabilized during the 1990s (Figure 4.b). The purse seine fishery started in the late 1960s and developed rapidly. In the mid 80s, the catches from purse seiners dropped as many of them moved to the new fishing grounds of the western

Indian Ocean (Majkowski, 2007). However, since the late 2000 purse seine catches rose again. In 1990s, purse seine associated with Fish Aggregating Devices (FADs) started to operate in the eastern tropical Atlantic. Baitboat fisheries mainly initiated near islands such as the Canary, Madeira and Azores Islands, and started to get expanded in the 1960s to the eastern tropical Atlantic and the catch has stayed quite steady since then. Average catches for the last five-year period (2010-2014) provide an indication of the performance of the fisheries in the ecoregion. Between 2010-2014, 71.7% of the landings in the Tropical Ecoregion were made by purse seine fisheries, followed by longline (15%) and baitboat fisheries (11%). While the landings made by purse seiners have increased in the region since 2006, the landings made by longliners have slightly decreased (Figure 4).

Since the 1980s, the most important flag states operating in the region have been EU.Spain, EU.France, Ghana and Japan (Figure 5). Between 2010-2014, the majority of the catches was made by EU.Spain (25%), followed by Ghana (19%), EU.France (11%), Curaçao and Panama (6% each) and Cape Verde, Chinese Taipei and Japan (4% each), which together made over 80% of the total catches in the Tropical Ecoregion (Figure 5.a). The Japanese longline fishery is the oldest, which started operating in the Equatorial Ecoregion in the 1950s targeting yellowfin tuna, but at the end of the 1970s it changed to target bigeye tuna until today (Figure 5.b). This resulted in the introduction of deep longline gears focusing on targeting bigeye tuna on the tropical eastern Atlantic. The EU French and EU.Spain purse seine fisheries also have a long history, which started in the 1960s and 1970s respectively, and now remain one the largest fishing flag states in the region. The EU.France and EU.Spain flags mainly target skipjack and yellowfin tuna with purse seiners (Figure 5.c).

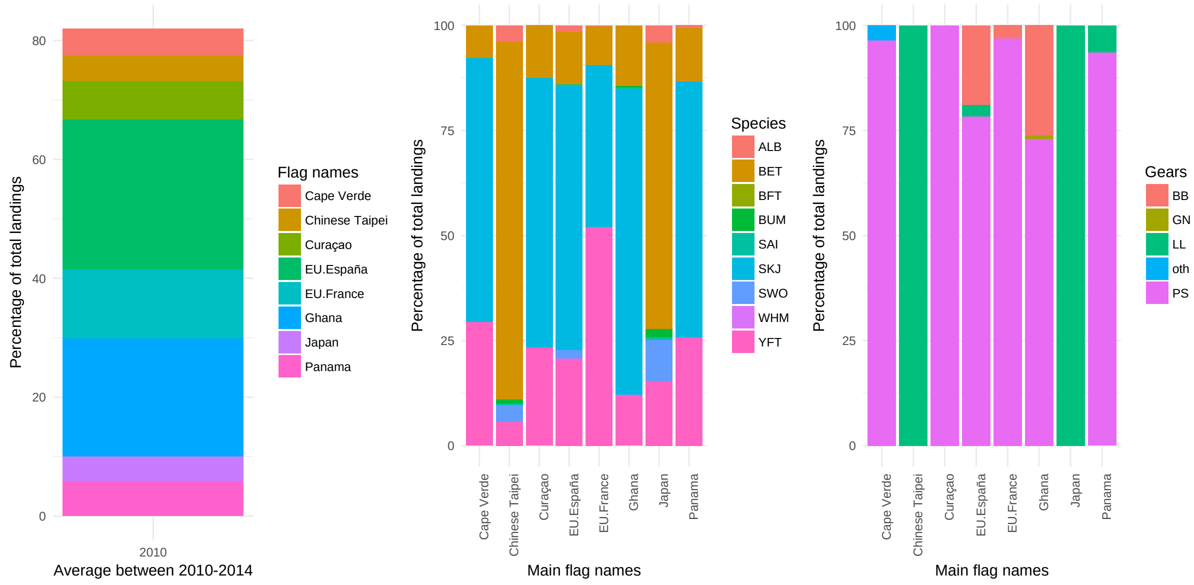


Figure 5. Main fishing nations or CPCs (Contracting Party or Cooperating non-Contracting Party, Entity or Fishing Entity) in ICCAT operating in the Tropical Ecoregion (a) Flag names making 82% of the total landings in the Tropical Ecoregion. (b) Percent of total landings by species for main CPCs. (c) Percent of total landings by gear for main CPCs. Data source: ICCAT Task I nominal catches database. For species and gear codes see Figure 4.

Between 2010 and 2014, the majority of the catches made by longliners was bigeye tuna (60%), followed by yellowfin (17%) and swordfish (14%) (Figure 6.a). Pelagic longline methods are very diverse, but they can be broadly divided into shallow/night and deep/day sets depending on the target species. When targeting swordfish, longliners generally set relatively shallow (30-70 m) between sunset and sunrise, taking advantage of the swordfish diel movement patterns, with near-surface feeding habits during the night (ICCAT, 2006)**.** When targeting tropical tunas, longliners set the hooks at greater depths (between 100-250+ m) typically during the day. The largest longline fleets (in terms of total catches) are the Japanese and Taiwanese fleets which mainly target bigeye tuna and yellowfin in subsurface waters during the day (typical hook depth ranging from 100 to 250+ meter depth), while the EU Spanish fleet target mostly swordfish in surface waters during the night (typical hook depth ranging from 30-70m). In purse fisheries, the majority of the catch is made of skipjack tuna (61%), followed by yellowfin (27%) and bigeye (11%) (Figure 6.b). The purse seine fisheries show a seine minimum depth of 120-150 meters (Santana J.C. *et al.*, 2002) and can be broken into two distinct fishing modes. The first one consists of purse seiners fishing on free swimming schools of fish which are not associated to any floating object (PS FS). Purse seines fishing on free schools catch predominantly yellowfin tuna (65%), followed by skipjack (23%) (Figure 6.b). The second mode consists of purse seiners fishing around floating objects, the majority of them artificial with satellite-tracked buoys attached to them, known as fish aggregating devices (FADs). Purse seine setting on FADs started to be used in the 1990s and this type of fishing catches predominantly skipjack (74%) but also catches yellowfin and bigeye tunas in smaller proportions, 13% and 12% respectively (Figure 6.b). The largest purse seine fishing nations are EU.Spain, EU.France and Ghana (Figure 5.c).

The extent and magnitude of the IUU fisheries capturing tuna and tuna like species is unknown or poorly known in the region. Yet there is some evidence of potential illegal practices involving reefer vessels and transshipments of tuna catches in the western Africa region as well as their mode of transportation for fish exports to the EU and other emergent markets (Daniels *et al.*, 2016). It is advisable to investigate whether this illegal activity might be exerting a significant additional pressure on tuna and tuna like species and associated ecosystem, which are currently unaccounted in fisheries assessments in ICCAT.

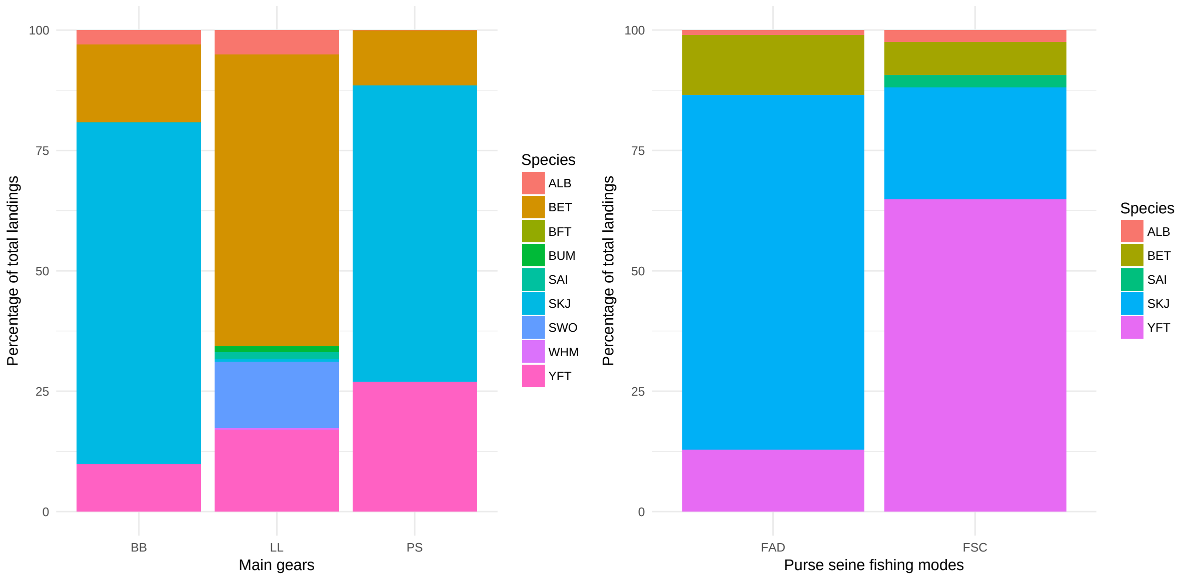


Figure 6. Percent of total landings of main gears. (a) Percent of total landings by species for the three main gear types, and (b) percent of total landings by purse seine fishing modes. Data source: ICCAT Task I nominal catches database. For species and gear codes see Figure 4.

3.1.2 Marine debris

Abandoned, lost and discarded fishing gear potentially can also cause ecological problems for marine species and sensitive habitats as well as socio-economic problems for the fishing fleets when lost unintentionally. One ecological problem derived from these abandoned, lost or discarded fishing gears is that lost floating gears may continue to catch organisms (known as ghost fishing). Not accounting for ghost fishing mortality in population and stock assessment models has the potential to make less effective the harvest strategies of managed species as well as affect the population viability of the most vulnerable species such as sea turtles, marine mammals, seabirds and some sharks and bony fishes (Coggins *et al.*, 2007; Gilman *et al.*, 2013). Furthermore, the abandoned, lost and discarded fishing gear (here referred as marine debris) can also end up stranded on beaches and sensitive coastal areas such as coral reefs (Maufroy *et al.*, 2015; Zudaire *et al.*, 2018).

Over the last decades the amount of these marine debris has increased substantially globally with the expansion of fishing effort and with the transition to more durable and more buoyant fishing materials (Gilman, 2015). Potentially fishing boats operating in the Tropical Ecoregion may lose gear (or associated), discard gear or abandon gear, yet the extent and magnitude of the marine debris derived by longliners, purse seiners or other fleets in the ecoregion is unknown or poorly known. For purse seiners, a recent large-scale examination of the spatio-temporal patterns of drifting FADs deployed by French purse seiners in the Atlantic and Indian Oceans during 2007-2011 provides some insights about the impacts of drifting FADs and GPS buoys lost on the pelagic environment (Maufroy *et al.*, 2015). Satellite-linked GPS buoys are deployed by fishing vessels to monitor the positions of drifting FADs in near real time. This study estimated that between 1500-2000 GPS buoys may have been lost onshore and stranded on the coast each year in both oceans combined contributing to coastal marine debris (Maufroy *et al.*, 2015). In the Atlantic Ocean, the beach buoys tend to concentrate in the Gulf of Guinea but some of them also end up stranding off the northern Brazilian coast (Figure 7). These beaching events may be occurring potentially in sensitive areas such as coral reefs and estuaries. These estimates of numbers of buoys lost are only from the French purse seiners, while there are more purse seine fleets operating in the Tropical Ecoregion.

Mitigating the impacts of lost drifting FADs is possible by avoiding deployment zones and time periods that increases the probability of losing leading to an increase in beaching events (Maufroy *et al.*, 2015).

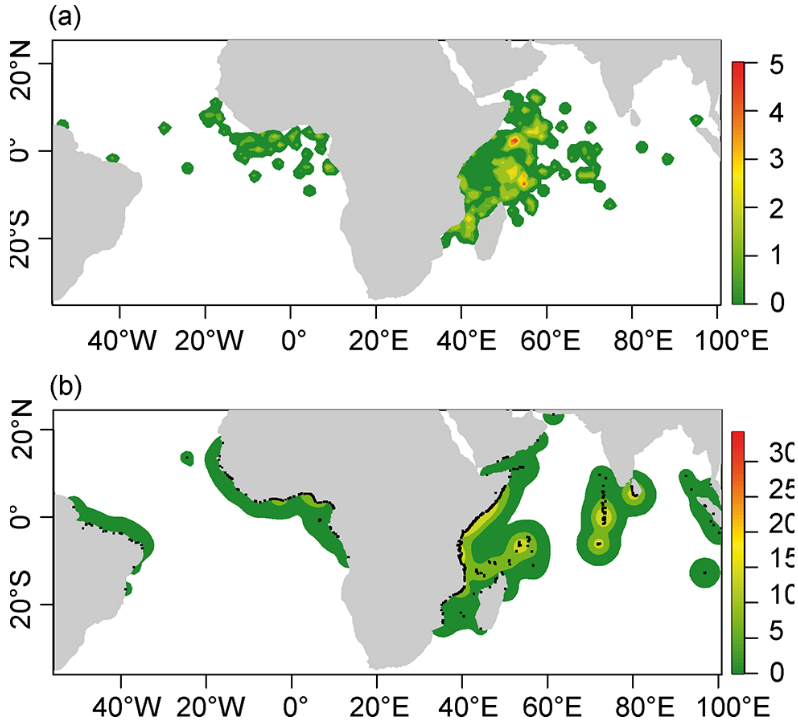


Figure 7. FAD beaching locations. (a) Deployment positions of FADs (b) Smooth densities of drifting FADs and black points correspond to individual beaching positions. Figure extracted from (Maufroy *et al.*, 2015).

3.2 Pressures non-susceptible to regional management

There are pressures that are impossible or difficult to be managed at a global and/or regional scale. In this section, two different types of non-manageable pressures are described:

a) Natural environmental variability, which is inherent to the geographical and oceanographical properties of the ecoregion. (see subsection 3.2.1).
b) Climate change, which has an intrinsic natural variability but is also affected by human activities (see subsection 3.2.2.).

3.2.1 Main oceanographic features of the Tropical Ecoregion

The Tropical Ecoregion is composed by three different pelagic provices as defined by Spalding *et al.* (2012), which conform the oceanic and coastal zones of this ecoregion: the Atlantic equatorial province (non-gyral but with an equatorial seasonal upwelling), the Canary current (part of a clockwise ocean current system, with an upwelling caused by offshore winds from the continent, and with a thermal mixing occuring as a consecuence of the heating effect from the Sahara which creates productive fishing grounds) and the Guinea current (characterized by areas of upwelling and increased biological productivity, with no clear correlation between sea surface temperature and wind patterns on a seasonal time scale).

Some of the most relevant physical processes that determine these oceanographic features are: i) the equatorial divergence, ii) the tropical instability waves, iii) the North and South Equatorial Counter Currents, iv) trade winds and v) the Angola and Guinea thermal Domes. All these condition the dynamics of the biotic components and the species diversity of this ecosystem producing, for example, well defined high productivity seasons and areas associated to the equatorial currents, zooplankton blooms in well-identified coastal areas, higher abundances of surface fishes as tropical tuna species (yellowfin and skypjack tunas) in the eastern oceanic zone and productive fishing grounds associated to the area influenced by the canary current (Longhurst, 2007; Lezama-Ochoa, 2016).

3.2.2 Climate change

Climate change has been characterized as a pressure that cannot be completely eliminated or effectively addressed by any short-term and regional management measure (Oesterwind *et al.*, 2016). Changes on environmental conditions will have direct and/or indirect impacts on the status of different components of the pelagic ecosystem in general and the highly migratory species in particular (Bromhead *et al.*, 2015). Potential changes caused by climate change have been long investigated in the Pacific Ocean (Lehodey *et al.*, 2010; Nye, 2010), but limited research has been carried out in the Atlantic ocean and in particular in the Tropical Ecoregion (any?). Better understanding of all these processes is needed for allowing a rapid response from managers and decision makers.

A recent study from the IUCN highlights that there is high uncertainty of how individual tuna populations will respond to rising ocean temperatures and synergistic effects of other climate change outcomes such as O_2 concentrations, pH, direction and speed of currents, vertical mixing and changes in eddies (Gilman *et al.*, 2016). In general, oceanic tunas and billfishes are expected to respond to this changes by 1) adopting new cooler subtropical areas for spawning, either replacing or in addition to existing tropical spawning sites, due to expected changes in temperature; 2) altering their migration phenology, including changing the timing of spawning and truncating the spawning season altering the distributions and survival rates of larvae and young age classes, reducing recruitment and biomass in existing spawning grounds, but increasing recruitment and biomass at new spawning grounds; 3) altering their foraging distributions to higher latitudes and to different longitudes, and alter their vertical depth distributions.

Gilman et al. (2016) also highlight that there is high uncertainty of how these effects on oceanic tunas and billfishes will affect pelagic ecosystem structure, processes and stability, and in turn how these broad changes will directly and indirectly affect the population dynamics of tunas and billfishes. For example, effects of climate change outcomes on the productivity of lower- and mid-trophic levels in tuna food chains, as well as changes in vertical and horizontal distributions, and changes in tuna access to prey at depth due to increased stratification and decreased O_2 concentrations may test the resistance and resilience of tunas to climate change.

3.3 State of the main ecosystem components

This section aims to describe the state and the changes in state of the different components of the ecosystems in the Tropical Ecoregion, as well as the main links and interactions between the existing pressures and the state of the ecosystem components shown in Figure 3. While the ecosystem overview aims to describe the state of productivity, fishes including sharks, marine mammals, seabirds and sea turtles as key components of the ecosystem, for practical reasons, when describing the state of the different taxonomic groups, it is important to distinguish between those species retained and non-retained by ICCAT fisheries. Therefore, for practical reasons, the state component of the ecosystem overview is divided in the following major sections (Figure 8):

- ***State of retained species:*** it includes a description of the state of the main fish species retained by ICCAT fisheries and how the main manageable pressures are impacting their state. The retained species include the main commercial tunas, billfishes and sharks as well as the small tunas and other bony fish species caught and retained by ICCAT fisheries because of their commercial value. Each fishery preferentially targets and retains a set of species but may also catch other fish species, that although not primarily targeted, are also retained for commercial reasons.

- ***State of non-retained species:*** it includes a description of the state of the main species (fish and non-fish) incidentally caught by ICCAT fisheries and non-retained either because of their low commercial value or the non-retention measures in place. This also includes some shark species, sea turtles, seabirds, and marine mammals. It also summarizes the current knowledge on the extent of ICCAT fisheries interactions on these species in the ecoregion.

- ***State of food-web and biodiversity:*** it includes a brief description of our state of knowledge about the ecosystem structure and functioning in the Tropical Ecoregion. Key trophic relationships are detailed and the potential impacts of the fishing activity on the dynamics of the ecosystem are assessed, based on the existing knowledge from the Tropical Ecoregion.

- ***State of habitats of ecological significance:*** it includes a description of our state of knowledge on habitats of ecological significance for the species in the area interacting with ICCAT fisheries and how these fisheries might be impacting them. Habitat of ecological significance might include areas used by species for spawning grounds and migration corridors, productive areas for feeding, or areas of with a large aggregation of species and high biodiversity.

- ***State of productivity:*** it includes a small description of the productivity of the region and main spatio-temporal patterns.

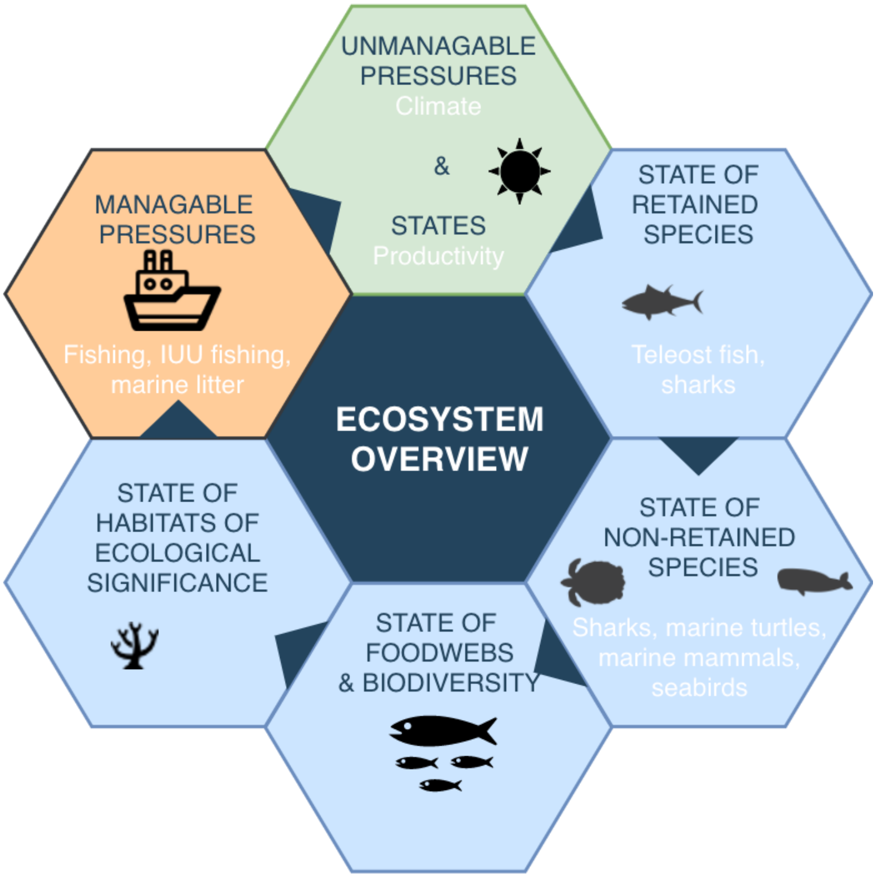


Figure 8- Main ecosystem components to be described in the ecosystem overview.

3.3.1 Retained species including bony fishes and sharks

ICCAT fisheries retain a large number of fish species. However, it is important to distinguish between those fish species that are part of ICCAT convention mandate, for which ICCAT has responsibility to assess and manage to ensure their sustainable use and conservation, from those species that are not covered by ICCAT convention mandate. For those species not formally included in the Convention mandate, ICCAT still has the responsibility to monitor the interaction of its fisheries on those fish species.

The species covered by the ICCAT Convention mandate are those included under the term "tuna and tuna-like fishes". The mandate defines this term as those species in the Scombriformes Order with the exception of the families Trichiuridae and Gempylidae and the genus Scomber within the family Scombridae. Thus, the Convention mandate covers species of the family Scombridae (17 species including the principal market tunas, small tunas, bonitos, and Spanish mackerels), family Istiophoridae (6 species including marlins, spearfishes and sailfish) and Xiphidae (1 species, Swordfish) distributed in the ICCAT Convention Area. Therefore, ICCAT has the responsibility to assess on principle the state of 24 species (Table 1) and manage them. To this list of fish species, dolphinfish (Family Coryphaenidae) also needs to be added, that although not covered in the current mandate, the ICCAT Small tuna Working Group included it under their species of interest. In addition, several sharks species also need to be added to the list since they are currently assessed and managed in ICCAT. These include the three main shark ICCAT species, i.e., blue shark, shortfin mako and porbeagle. Consequently, there are 28 species of fishes ICCAT is responsible to assess, manage and ensure sustainable exploitation (Table 1).

Aside those 28 species for which ICCAT is responsible for, there are a larger pool of fish species that interact with ICCAT fisheries and that are also retained for commercial use. There are a total of 181 fish species (bony fish and sharks) reported in the ICCAT Task I data sets (Hanke & P., 2018) for which ICCAT CPCs have reported some landings between 1950 to 2016. However, the ICCAT Sub-Committee on Ecosystems (SUBECO) notes that this list needs to be revised for a number of reasons (1) errors in the species names (e.g. some species not found in the Atlantic Ocean), (2) changes in the taxonomic classifications of the species, (3) some species interact very rarely with ICCAT fisheries which does not justify their monitoring. The ICCAT SUBECO has therefore recommended the revision of this list to produce a coherent and consistent list of retained species for monitoring purposes based on established criteria. The impacts of ICCAT fisheries on the state of these species in this list remains unknown or poorly known as they are not formally monitored or assessed in ICCAT.

Of these 28 species, 23 are found in the Tropical Ecoregion (Table 1). The current exploitation status for these 23 species and stocks are summarized in Figure 9. ICCAT has conducted fishery stock assessments for 5 species (8 stocks) of principal market tunas, for 4 (6 stocks) of billfishes, and for the 2 shark species (4 stocks) (ICCAT, 2018). Overall, the exploitation status is known for 19 stocks of 11 species under ICCAT convention mandate (Figure 9). Five stocks are currently overfished and experiencing overfishing (bigeye tuna, blue marlin, eastern sailfish, and Northern and southern shortfin mako sharks), four stocks are overfished but not experiencing overfishing (western Atlantic bluefin tuna, yellowfin tuna, white marlin, south Atlantic swordfish), seven stocks are not overfished and not experiencing overfishing (Eastern and western skipjack tuna stocks, northern and southern albacore tuna stocks, sailfish, northern Atlantic swordfish and northern Atlantic blue shark), and finally two stocks have been assessed but their status was undetermined (eastern Atlantic bluefin tuna and southern Atlantic blue shark).

Table 1. ICCAT species for which ICCAT has management responsibility, whether they are assessed in ICCAT and found in the Tropical Ecoregion.

Whether formally covered in ICCAT mandate	Family	Taxonomic groupings	Common name	Scientificname	Assessed in ICCAT	Found in Tropical Ecoregion
ICCAT mandate	Scombridae	Principal market tunas	Atlantic bluefin tuna	*Thunnus thynnus*	Yes	Yes
ICCAT mandate	Scombridae	Principal market tunas	Yellowfin tuna	*Thunnus albacares*	Yes	Yes
ICCAT mandate	Scombridae	Principal market tunas	Skipjack	*Katsuwonus pela mis*	Yes	Yes
ICCAT mandate	Scombridae	Principal market tunas	Bigeye tuna	*Thunnus obesus*	Yes	Yes
ICCAT mandate	Scombridae	Principal market tunas	Albacore tuna	*Thunnus alalunga*	Yes	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Blackfin tuna	*Thunnus atlanticus*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Spotted Spanish mackerel	*Scomberomorus maculatus*	No	No
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Cero mackerel	*Scomberomorus regalis*	No	No
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	King mackerel	*Scomberomorus cavalla*	No	No

ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	West African Spanish mackerel	*Scomberomorus tritor*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Serra Spanish mackerel	*Scomberomorus brasiliensis*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Bullet tuna	*Auxis rochei*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Frigate tuna	*Auxis thazard*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Little tunny	*Euthynnus alleteratus*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Atlantic bonito	*Sarda sarda*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Plain bonito	*Orcynopsis unicorlor*	No	Yes
ICCAT mandate	Scombridae	Small tunas and Spanish mackerels	Wahoo	*Acanthocybium solandri*	No	Yes
ICCAT mandate	Istiophoridae	Billfishes	White marlin	*Tetrapturus albidus*	Yes	Yes
ICCAT mandate	Istiophoridae	Billfishes	Roundscale georgii	*Tetrapturus georgii*	No	Yes
ICCAT mandate	Istiophoridae	Billfishes	Mediterranen shortbill spearfish	*Tetrapturus belone*	No	No
ICCAT mandate	Istiophoridae	Billfishes	Blue marlin	*Makaira nigricans*	Yes	Yes
ICCAT mandate	Istiophoridae	Billfishes	Sailfish	*Istiophorus*	Yes	Yes

				albicans		
ICCAT mandate	Istiophoridae	Billfishes	Spearfish	*Tetrapturus pfluegeri*		Yes
ICCAT mandate	Xiphidae	Billfishes	Swordfish	*Xiphias gladius*	Yes	Yes
Not in ICCAT mandate but a focus species	Carcharhinidae	Sharks	Blue shark	*Prionace glauca*	Yes	Yes
Not in ICCAT mandate but a focus species	Lamnidae	Sharks	Shortfin mako	*Isurus oxyrinchus*	Yes	Yes
Not in ICCAT mandate but a focus species	Lamnidae	Sharks	Porbeagle	*Lamna nasus*	Yes	No
Not in ICCAT mandate but a focus species	Coryphaenidae	Other fishes	Dolphinfish	*Coryphaena hippurus*	No	Yes

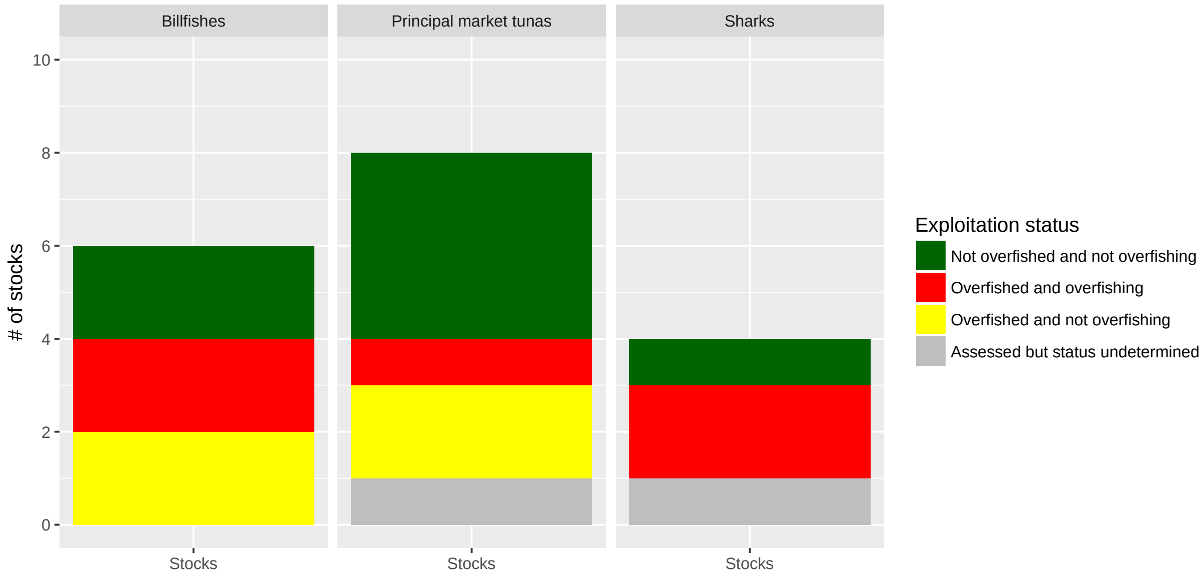


Figure 9. Stock status for assessed species found in the Tropical Ecoregion as December 2017 (ICCAT, 2018).

ICCAT has not conducted fisheries assessment for any of the small tuna and Spanish mackerels (9 species) or for the dolphinfish (Table 1). These species are generally considered fast growing, short lived and with early maturation, which makes them more resilient to exploitation. Therefore, the main concern is that if they are discarded in good conditions, which depends on the fishery, these species are underutilized. However, many of these species are caught and sold in local markets in western Africa as a product called "faux poisson". Therefore, it is important to monitor and quantify these catches. The SCRS with the assistance of the Small Tuna Working Group has the task to conduct assessments for these species. However, the Small tuna Working Group has recognized that there is little information available to determine the stock structure and to carry quantitative assessments of stock status for the small tunas and Spanish mackerel species. Although ICCAT has not carried quantitative stock assessment for the small tunas and spanish mackerels, there are some local assessments available for some species which have been carried by some ICCAT CPCs (e.g. *Scomberomorus* spp. in the United States). The SCRS has recommended in many occasions that countries should submit all available data to ICCAT in order to carry assessments using data poor assessment methods. The SCRS has also developed some size-based indicators for these species, however, their robustness still need to be evaluated before they can be used to provide management advice to the Commission (ICCAT, 2018). Additionally, the Small tuna Working Group has conducted an Ecological Risk Assessment (ERA, last updated in

2017) for teleost fishes (other than the principal market tunas and billfishes) caught by longline and purse seine fisheries in the Atlantic Ocean. This ERA found that the top three species most at risk in the Atlantic ocean and that should have priority assessments were Little tunny *Euthynnus alletteratus*, Wahoo *Acanthocybium solandri*, and King mackerel *Scomberomorus cavalla (Lucena Frédou et al., 2016)*. Given the social and economic importance of the Atlantic bonito (*Sarda sarda*), the Small tuna Working Group has also recommended Atlantic bonito as a priority assessment (ICCAT, 2018). Of these species, *E. Alletteratus* and *A. solandri* is found in the Tropical Ecoregion and *S. sarda* in smaller proportions because it has a more subtropical and temperate distributions.

While the fishery impacts on the state of small tunas and other bony fish species is poorly known or unknown, some CPCs report their interactions with these species. For example, the European purse seine fishery mainly targeting skipjack and yellowfin tuna species, which operates largely in the Tropical Ecoregion, has reported bycatch estimates for fish species bycaught during the period 2003 and 2007 (Amande´ *et al.*, 2010). Among the fish species bycatch, some are retained and sold in the local markets in West Africa as "faux poisson", including Little tunny (*Euthynnus alletteratus*) which was caught in large proportions (36% of all the small tunas), as well as Triggerfish sp, Rainbow-runner (*Elagatis bipinnulata*) and wahoo (*Acanthocybium solandri*) which made also 31%, 31% and 17%, respectively, of all the other bony fish caught by purse seiners (Amande´ *et al.*, 2010). Atlantic bonito *Sarda sarda* was not caught by the EU purse fishery during this period, suggesting very few interactions with this fishery and therefore became a low research priority species in this area. Billfishes while targeted in some fisheries, are also caught as bycatch in the purse seine fisheries, some of which are also retained. A total of 581 billfish (27 tonnes, six species) were observed in the EU purse seine fishery between 2003-2007 (Amande´ *et al.*, 2010). While some billfish species are of concern because they are thought to be below B_{MSY} (e.g. blue marlin, eastern sailfish) and some other species remain unassessed (e.g black marlin and shortbill marlin), catches of billfishes are relatively small in purse seine fisheries compared to other gears such as longliners.

Sharks are not covered by ICCAT convention, yet the SCRS has conducted assessments for some sharks species targeted or that represent important bycatches by ICCAT fisheries (blue shark, shortfin mako shark and porbeagle shark) and a larger number of shark species are known to interact with ICCAT fisheries, some of which are retained by some fleets due to their commercial value and others release following the non-retention measures (See section 3.3.2). For example, observers on Portuguese longliners targeting swordfish in the Atlantic Ocean reported interactions with 21 different shark species (Coelho *et al.*, 2012). Similarly, 19 species of shark are known to be caught as bycatch and landed by the Spanish surface longline fleet targeting swordfish in the Atlantic ocean (Mejuto *et al.*, 2009). The SCRS conducted in 2012 an ERA for 16 shark species (20 stocks) interacting with longline fisheries (Cortés *et al.*, 2015). The ecological risk assessment provided a stock- level index of vulnerability to longline fisheries, which allowed the identification of those species most vulnerable to pelagic longline fisheries. Based on this ERA, the bigeye thresher, longfin and shortfin mako, porbeagle and night sharks have been identified as being the most vulnerable species to longline fisheries. Of these species, there is a non-retention measure for bigeye thresher shark in ICCAT (see section 3.3.2). This ERA has been used to prioritize research and management measures for shark species in ICCAT.

An ERA has not been conducted to identify those shark species most vulnerable to other ICCAT fisheries such as purse seiners or gillnet fisheries. Yet, there is a clear recommendation from the SCRS to conduct these ERAs as well as to conduct more research on the magnitude of shark entanglements in purse seiners, and in particular those associated with FADs (ICCAT, 2018). This type of information is available and has been reported by some ICCAT CPCs. For example, the European purse seine has reported bycatch estimates for shark species for the period 2003 and 2007 (Amande ́ *et al.*, 2010). Over this period, 10 tonnes of sharks (341 sharks) were recorded by observers and the large majority of them, 90%, were caught by purse seine associated to FADs. The main species caught were silky sharks (*Carcharhinus falciformis*) which represented 72% of the catch in numbers. Smooth hammerhead *Sphyraena zygaena* and Scalloped hammerhead *S. lewini* also represented 7% of the shark bycatch in numbers, and Oceanic whitetip shark *Carcharhinus longimanus* and Shortfin mako *Isurus oxyrinchus* were also caught occasionally, representing less than 1% of the bycatch. Also, 17.6% of the sharks caught in number were unidentified. All the shark species, except shortfin mako, have non-retaining measures in ICCAT and cannot be retained on board (see section 3.3.2). Since 2014 the European purse seine fleet has progressively used non-entangling FADs (and by 2016 in all its fleet), with the objective of reducing its bycatch rates (Grande M. *et al.*, 2018).

Except for the main retained shark species (blue shark and shortfin mako), the fisheries stock status is unknown in the large majority of all other sharks bycaught and the impacts of fisheries on these shark species remains largely unknown. Those other species, that interact and are captured by ICCAT fisheries but now are mainly discarded due to regulations, would include species like the bigeye thresher, oceanic whitetip, silky shark and hammerheads (Covered in section 3.3.2). Other species, like the crocodile shark and pelagic stingray are also captured, but discarded mainly due to lack of commercial value. Furthermore, the fisheries data reported to ICCAT (task I or task II data) are very incomplete and underestimate the true catches for these species which make it hard to apply data-poor methods to quantify their status (Cortés *et al.*, 2015).

3.3.2 Non-retained fish and non-fish species including sharks, seabirds, marine turtles and marine mammals

Non-retained bony fish

The quantity of fish non-retained, and therefore discarded at sea, dead or alive is poorly monitored, as these species are poorly, or non-reported at all, in logbooks. Yet these data are collected by some fleets via logbooks or as part of the observer programs. This information is crucial to determine the extent of bycatch and discarding practices in the fisheries and to inform the assessments of the effects of fishing on ecosystems (Garcia *et al.*, 2003). According to the observers of the European purse seine fishery during the period 2003-2007 largely operating in the Tropical Ecoregion, extrapolated values of the bycatch fate showed that small tuna bycatch was mostly discarded at sea (91% of small tuna caught), while 52% of other bony fishes and 33 % of billfishes were discarded at sea (Amande´ *et al.*, 2010). In 2017, ICCAT adopted a measure (Rec. 17/01) to prohibit the discards of tropical tuna species on the purse seine fisheries. While this measure can help improve the reliability of catch statistics for the main target tunas, as well as improve regional food security, the bycatch fate for the other fish species remains still poorly quantified. Similarly, the bycatch fate and discarding practices of fishes in longline fisheries remain poorly known.

Non-retained sharks and rays

There are at least 26 sharks species which are known to interact with ICCAT fisheries (Mejuto *et al.*, 2009; Amande´ *et al.*, 2010; Coelho *et al.*, 2012; Capietto *et al.*, 2014; Cortés *et al.*, 2015). Of these, the porbeagle (Lamna nasus), oceanic whitetip (*Carcharhinus longimanus)*, silky shark (*C. falciformis)*, bigeye thresher shark (*Alopias superciliosus*), and hammerhead sharks (except *S. tiburo*) are non-retained shark species in the ICCAT convention area due to specific ICCAT recommendations (Rec. 15/06 for porbeagle, Rec.09-07 for bigeye thresher, Rec 10-07 for oceanic white tip, Rec 11-08 for silky and Rec 10-08 for hammerheads). All those species occur and interact with ICCAT fisheries within the Tropical Ecoregion. The non-retained hammerhead sharks are scalloped hammerhead (*Sphyrna lewini*), smooth hammerhead (*Sphyrna zygaena*) and great hammerhead (*Sphyrna mokarran*). Rec 10-06 also dictates that ICCAT CPCs that do not report catch data for Atlantic shortfin mako should be prohibited from retaining this species. Additionally, there are other pelagic sharks and rays that may also be captured by ICCAT fisheries and although they have non-retention measures are mostly discarded due to low or no commercial value, such as the crocodile shark, tiger shark, whale shark or pelagic stingray (Capietto *et al.*, 2014; Cortés *et al.*, 2018). These species are also found in the Tropical Ecoregion. Finally, some countries have no-retaining measures for some shark species. Other species such as blue shark may be retained by some fleets and discarded by other due to their fishing practices and preferences (Cortés *et al.*, 2018).

The ERA of shark species to ICCAT longline fisheries conducted in 2015 by the SCRS included the six non-retained shark species. This risk assessment revealed that the bigeye thresher was the most vulnerable species to longline fisheries. Bigeye thresher had the lowest productivity of all shark species, as well as ranked as the most susceptible to longline gear. Meanwhile, the vulnerability of silky and oceanic whitetip to longliners ranked medium, and the vulnerability of the three hammerheads (scalloped, smooth and great hammerheads) ranked relatively low driven by their relatively high productivity values and low susceptibility to longline gears (Cortés *et al.*, 2015). An ERA has not been conducted to identify those shark species most vulnerable to other ICCAT fisheries such as purse seiners or gillnets. However, individual studies conducted by different ICCAT CPCs suggest that silky shark is the most frequently species encountered by purse seiners setting on FADs (Amande´ *et al.*, 2010). In the EU purse seine tuna fishery setting on FADs, the silky shark was the one with the largest number of interactions with purse seine associated to FADs. The numbers and biomass of silky sharks captured was 59 percent in weight and 75 percent in numbers of the total sharks during the 2003-2007 period (Amande´ *et al.*, 2010). Hammerhead sharks were the most numerous sharks in purse seiners setting on free schools, followed by oceanic whitetip sharks, and these were less commonly caught in purse seiners associated with FAD objects (Amande´ *et al.*, 2010). The number of bycatch interactions of the purse seine fishery setting on free schools with smooth and scalloped hammerheads was 37% and 23% in weight, respectively of the total catch, and with oceanic white tip shark were 8% in weight of the total sharks. 37 of these sharks (in weight) were discarded at sea dead or alive. Among rays, mobula species (*Mobula coilloti, M. mobular and M. birostris*) were the most numerous rays in purse seine setting on free schools, as well as the cownose rays. 94% of them (in weight) were discarded at sea dead or alive (Amande´ *et al.*, 2010). Whale sharks are also known to interact with purse seine fisheries and gillnet fisheries. Purse seine fisheries might detect tuna schools by locating and fishing close to whale sharks. Data from the European tropical tuna fishery between 1980s and 1995 suggest the incidence of apparent whale mortality due to fishery interaction is extremely low. One of the 107 whale sharks encircled by the net between 1980s and 1995 died in the Atlantic Ocean (Capietto *et al.*, 2014). A post-capture survival of whale sharks encircled in tuna purse seine nets suggest that whale sharks have a good chance of survival when released (Escalle *et al.*, 2016). Finally, the number of interactions of sharks and rays with gillnets is poorly known and poorly monitored in the ICCAT convention area. The extent of bycatch and discarding practices in these fisheries are poorly known.

The reported number of interactions of sharks with ICCAT fisheries does not necessarily mean that all reported number of sharks die. The post-release mortality for these non-retained sharks species after being caught by ICCAT fisheries is poorly known for most species, as well as their overall effect on the populations are not well understood (Coelho *et al.*, 2012).

The fisheries population status is unknown in all the non-retained sharks. ICCAT has not conducted fisheries assessment for these species. The fisheries data reported to ICCAT (task I or task II data) are very incomplete and underestimate the true catches for these species (Cortés *et al.*, 2018). In addition, very few ICCAT CPCs report dead discard estimates for the non-retained sharks. This hinders the possibility for quantitative assessment to determine the status of these species. Without concerned collaborative efforts by all CPCs to report all catches and dead discard rates, as well as to estimate total dead discard rates based on information collected in scientific observer programs of their fleets, quantifying total mortality for non-retained sharks seems unachievable (Cortés *et al.*, 2018).

All the non-retained sharks are listed as threatened on the IUCN Red list as either Vulnerable (oceanic whitetip, silky, bigeye thresher, smooth hammerhead and whale shark) or Endangered (scalloped and great hammerhead). Additionally, there are several non-retained shark species that have been listed under Appendix II of the Convention on International Trade in Endangered Species (CITES). Smooth hammerhead (*Sphyrna zygaena*), scalloped hammerhead (*Sphyrna lewini*), oceanic whitetip sharks (*Carcharhinus longimanus*) and whale shark (*Rhincodon typus*) were listed under Appendix II of CITES 2013. Porbeagle and manta rays were also listed under Appendix II in CITES 2013. In 2016, the threshers (*Alopias spp.*), silky sharks (*Carcharhinus falciformis*) and the remaining mobulids (*Mobula spp.*) were also added to the Appendix

II of CITES. CITES Appendix II carries a requirement that Parties issue export permits based on finding that take is legal and sustainable.

Non-retained seabirds

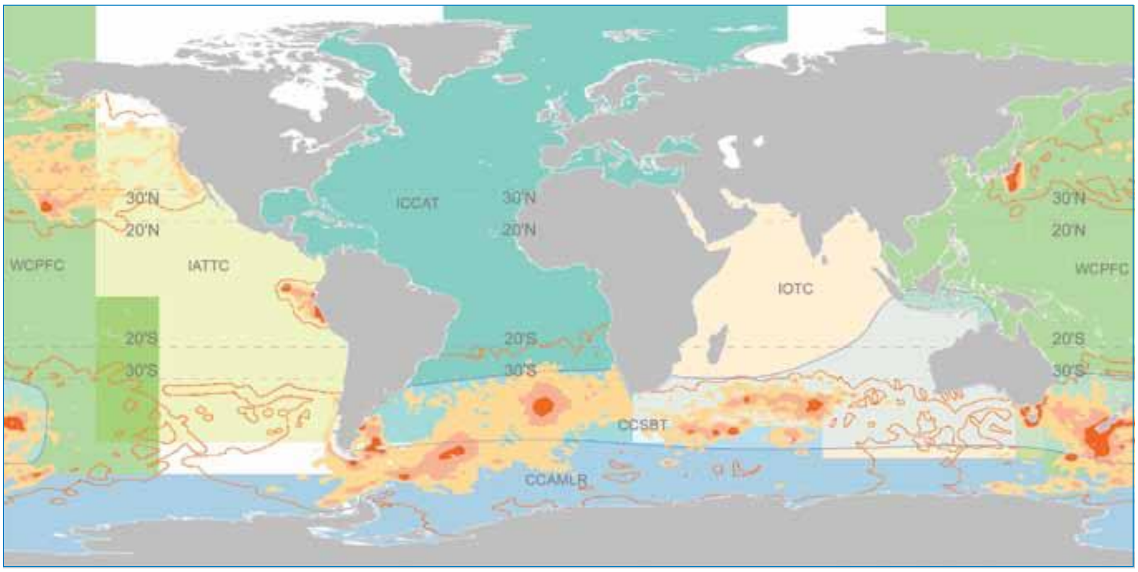
Seabirds live partly in a terrestrial environment for reproduction strategies and partly in the marine littoral and oceanic habitats for foraging or feeding. Multiple anthropogenic threats affect seabirds included bycatch mortality rates, habitat degradation and loss, overexploitation for their meat, bioaccumulation and pollution and sea level rise (Lascelles *et al.*, 2015). It is often difficult to disentangle these pressures, yet incidental capture in longline fisheries as well as gillnet fisheries is the primary threat to seabirds at sea, particularly impacting albatrosses (family Diomedeidae) and petrels (family Procellariidae) (Alderman *et al.*, 2011; Croxall *et al.*, 2012; Clarke *et al.*, 2014). The incidental captures of seabirds in purse seine fisheries are low to negligible.

Fifteen of the 22 albatross species found around the globe are listed as threatened on the IUCN Red List, and declines of albatross and petrels have been severe in the South Atlantic Ocean (Carneiro *et al.*, 2017). The overlap between the albatross and petrels and longline fisheries is highest in higher latitudes, south of 30 degrees (Figure 10) in the Atlantic Ocean, with some tropical and subtropical exceptions including the waters offshore from Brazil and Namibia (Carneiro *et al.*, 2017). Therefore, in the Tropical Ecoregion, the overlap between the albatross and petrel distributions and ICCAT tuna and swordfish longline fisheries is negligible during the seabird breeding season as well as non-breading seasons (Gilman, 2011).

While the tropical Atlantic is considered an area with low bycatch risk for seabirds, there are some migratory seabirds and breeding colonies of seabirds on the islands in the Gulf of Guinea. Eleven species of seabirds were identified as offshore species or migrant to the Gulf of Guinean through the British Ornithologists Union checklist for the birds of the Gulf of Guinea (Forrestal, 2016). The eleven species are *Calonectris diomedea* and *Ardenna gravis* (petrels and sheerwaters, Family Procellariidae), *Oceanites oceanicus* , *Hydrobates pelagicus*, *Oceanites oceanicus* , *H. castro* and *H. leucorhous* (storm petrels, family Hydrobatidae), *Sula leucogaster* (boobies, Family Sulidae) and *Onychoprion fuscatus, Anous stolidus* and *Anous minutus* (gulls, Laridae). Of these species, only *Calonectris diomedea*, the Scopoli's shearwater, is known to interact with longline fisheries in the Atlantic Ocean, and although the level of interactions is unknown, this species is listed as Least Concern on the IUCN Red List.

It is also expected that the low densities of seabird species found at the tropics would make this species to be less susceptible to gillnet fisheries in this region than in the most temperate and subpolar regions. Yet, no information about seabird bycatch in gillnets is available for the Tropical Atlantic (Zydelis *et al.*, 2013).

BREEDING SEASON



NON BREEDING SEASON

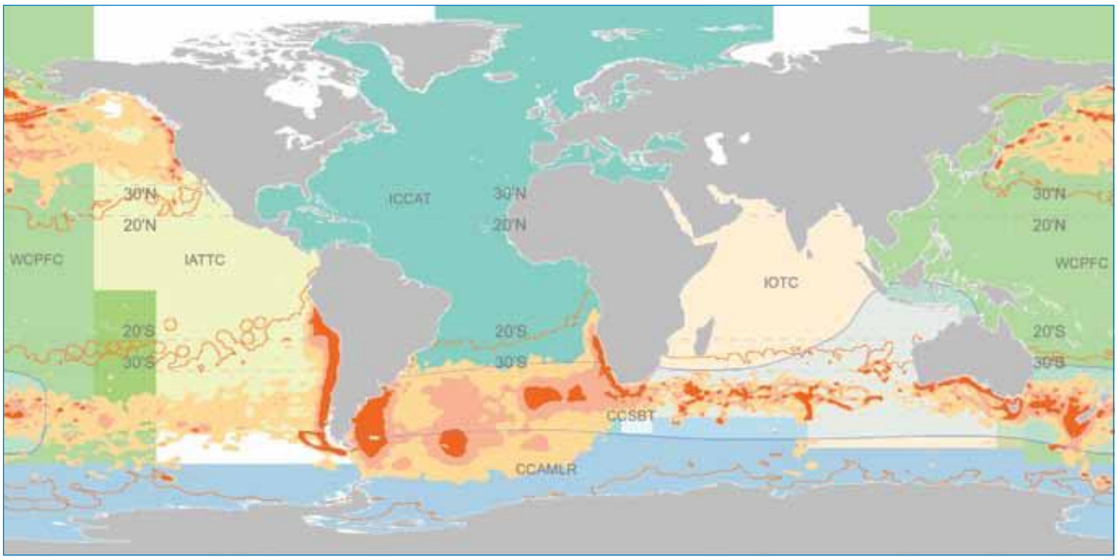


Figure 10. Global density distribution of albatrosses and giant petrels during their breeding seasons (top figure) and non-breeding seasons (bottom figure) in relation to the areas managed by the tuna RFMOs. Figures extracted from (Alderman *et al.*, 2011). Red, pink and orange shaded areas indicate the 50, 75, and 95% probability contours of albatross and gian-petrel distributions, and the single line indicates the full range based on dta available to these analyses.

Non-retained marine turtles

Globally there are seven species of sea turtles, all of which are known to interact with tuna and tuna-like fisheries through their distribution (Clarke *et al.*, 2014). These species are green turtle (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), flatback (*Natator depressus*), loggerhead (*Caretta caretta*), Kemp's ridley (*Lepidochelys kempii*),olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*). All the sea turtles are listed on the IUCN Red List as either Vulnerable (leatherback and olive ridley), Endangered (loggerhead and green turtle), or Critically Engendered (Kemp's ridley and hawksbill). Flatback turtles were listed as data deficient. In the Atlantic Ocean, all turtles are found except the flatback turtle. The hawksbill turtle is the most tropical species, but the leatherback, loggerhead, green, olive and Kemp's ridley are also widely distributed and found in the tropics.

In addition to fishing, sea turtles are also known to be threatened by a number of other threats, including utilization of their eggs, meat and other turtle products, coastal development, pollution and pathogens, and climate change (Wallace *et al.*, 2011) (Wallace *et al.*, 2013). However, it is widely recognized that sea turtle interactions with fishing gear is among the most important threat to sea turtles, followed by climate change (Wallace *et al.*, 2011). Therefore, it is important to estimate the total number of interactions and mortality from bycatch in the ICCAT fisheries.

In the Atlantic Ocean, turtles are caught incidentally by fishery operations targeting tuna and tuna-like species with longlines and purse seiners mostly in the open ocean, and gillnets in the more coastal areas. Fisheries bycatch of sea turtles are considered one of the major causes of decline of the species (Clarke *et al.*, 2014). The seven species are known to interact with longline fisheries worldwide. There are many factors underlying species-specific differences in the interactions rates with the different gear types, including sea turtle morphology, distribution and feeding behavior, as well as their oceanographic preferences, and configurations of the gears relative to the habitat utilization of the species (Clarke *et al.*, 2014), however some generalities can be made. An ERA of sea turtles to tuna fishing with longliners and purse seiners in the ICCAT convention area shows longline fishing poses greater threat to turtles than purse seiners (Angel *et al.*, 2014). Gillnet fisheries were not included in the ecological risk assessment of sea turtles because catch and effort data from gillnet fisheries are considered extremely poor in the ICCAT convention area. According to this ecological risk assessment, the olive ridley, leatherhead and hawksbill are the most vulnerable species to both gear types, longliners and purse seiners in the Tropical Ecoregion, but all of the turtles found in the Tropical Ecoregion appear to be vulnerable to being capture by both longliners and purse seine gears.

Purse seiners pose negligible threats to turtles relative to longliners. However, in purse seiners the turtles are attracted to floating objects, and are captured in sets of FADs or logs. While sea turtles are caught in small numbers by purse seiners and they can be released alive relatively easily, they may die if entangled and not released (Hall & Roman, 2013). Although purse seine fishing operations appear to be minor in comparison to the impacts from longlines, the overlapping areas of highly concentrated purse seine and longline effort in the tropical Atlantic Ocean makes this area of high risk to sea turtles (Angel *et al.*, 2014).

A recent meta-analysis of longline bycatch rates estimated the total number of sea turtles interactions (all species combined) with pelagic longline gear in the ICCAT convention area (McKee Gray & Diaz, 2017). The total estimated number of sea turtles interactions with pelagic longline gear, which included 16 fleets, ranged from 30,612 to 47,315 during 2012-214 in the entire convention area. This study also identified areas of potential conservation concern for each species with the identification of hotspot areas where high intensity of sea turtle interactions occurs with pelagic longline gear, which allows to identify what sea turtles interact the most with longline fisheries in the Tropical Ecoregion (McKee Gray & Diaz, 2017). This study showed high number of interactions of the olive ridley, green turtle and leatherback interacting with longline fisheries in the Tropical Ecoregion and suggested this area was a hotspot area for these three species, while the number of interactions of the loggerhead and hawksbill turtles was smaller and not considered a hotspot in the Tropical Ecoregion (McKee Gray & Diaz, 2017). While this meta-analysis provides the first estimate of sea turtles interactions with pelagic longline gear in the ICCAT convention, it is not known what fraction of these interactions result in mortality, since it remains largely unassessed.

The total number of sea turtles interactions with purse seine gear have not been estimated and it is not known in the ICCAT convention area. Yet the bycatch rates of sea turtles of longliners is known for some fleets (e.g. EU.Portugal longline fleet, EU.Spain and France fleet) (Santos *et al.*, 2012; Bourjea *et al.*, 2014; Coelho *et al.*, 2015). On the EU.Portugal longline fleet, in the tropical Atlantic region, most interactions with sea-turtles were with loggerheads, olive ridley and leatherback turtles (Santos *et al.*, 2012; Coelho *et al.*, 2015). The Spanish purse seine fishery, which operates entirely in the Tropical Ecoregion, reported that the olive ridley had the largest number of interactions with purse seiners both setting on free schools and FADs (Sarralde *et al.*, 2004; Sarralde *et al.*, 2007). A more recent study shows the European Spanish and France purse seine fishery operating in the Atlantic Ocean incidentally caught annually 218 (standard deviation 150) individuals between 1995 and 2011, with more than 75% released alive (Bourjea *et al.*, 2014). The total mortality of sea turtles interacting with all ICCAT gears in the regions is largely unassessed and unknown.

Understanding the spatio-temporal characteristics of sea turtle bycatch by the different gears as well as the cumulative effects of the multiple gears and fleets remains a challenge (Bourjea *et al.*, 2014). While the bycatch rate by industrial longliners and purse seiners is relatively better understood, the artisanal and coastal gears such as gillnets remains largely unassessed.

Turtles are listed by the IUCN Red List as threatened, which align with current efforts in ICCAT to develop and implement mitigation measures in purse seine and longline fisheries that would avoid their incidental capture and entanglement.

Non-retained marine mammals

Marine mammals consist of cetaceans (whales, dolphins and porpoises), pinnipeds (seals, sea lions and walruses), sirenians (dudongs and manateers), mustelids (sea otters and marine otters) and the polar bear. This section only focuses on cetaceans interactions (here referred as marine mammals) with ICCAT fisheries in the Tropical Ecoregion. Marine mammals have broad ocean-wide distributions and are known to interact widely with ICCAT longline, purse seine and gillnet fisheries (ICCAT, 2006). The list of marine mammal species that interact with ICCAT fisheries include 25 species (14 whales and 11 dolphins and porpoises) (ICCAT, 2006). Purse seine and gillnet operations interact with a larger number of marine mammals (15 spp. and 17 spp. respectively) than longline operations (6 spp.) (Table 2). The presence of these interactions does not imply these species are caught in significant quantities or that individuals die after being caught. However, the magnitude and regional extent of these mammal interactions with the different gears and post-mortalities is poorly known. These mammal species were included in a taxonomically comprehensive ecological risk assessment for ICCAT fisheries which assess the relative risk of both target and bycatch species being impacted by longline, purse seine and gillnet fisheries (Arrizabalaga *et al.*, 2011). However, due to the low frequency of interactions of marine mammals with longline and purse gears, it was not possible to compute a susceptibility scores for any of the marine mammals, and therefore they were not included in the final risk assessment (Arrizabalaga *et al.*, 2011). Yet, their intrinsic vulnerabilities to population decline were among the highest. Historically, industrial harvesting of marine mammals has reduced the abundance of many species and populations and there have been local extinctions of whales recorded (Smith *et al.*, 2015). Some whale populations have been reduced to remnant status, becoming functional extinct as they no longer play a significant role in the ecosystem (e.g. right whales from the northeastern Atlantic). The impact of biodiversity loss of marine mammal due to local and functional extinctions on marine ecosystems has been documented at local and ocean basin wide scales (Estes J.A. *et al.*, 2006). Therefore, it is important to monitor the number of interactions (and mortalities) of marine mammals with ICCAT fisheries since even a small number of them can have disproportionally a large effect on populations that have already been depleted to low levels (Smith *et al.*, 2015).

The distribution of 20 of these species (11 whales and 9 dolphins) are known to overlap with the Tropical Ecoregion (Table 2), yet it is poorly known the level of interactions of these species with the different gears operating in this area. Some ICCAT CPCs report marine mammal fisheries interactions, but these data have been insufficient and virtually non-existent to calculate species-specific gear interactions and mortality rates at the temporal and spatial scales relevant to provide management advice (Arrizabalaga *et al.*, 2011). Thus, there is a general need to improve the monitoring of the interactions to determine if they are significant and propose effective mitigation techniques to reduce incidental mortalities if those areas and gears needed. Mammal interactions, if collected and reported by CPCs, is done via logbooks and/or on-board by observers. However, the current observer data reporting formats, called the ST09 form, that national observer programs use to report their data to ICCAT has been recently revised, and it does not include detailed operational (set by set) level details anymore. Further, it is not clear if marine mammals should or should not be reported by this form, as some interactions refer to sightings of marine mammals around the vessels and the longline gear, often related with depredation events, but do not necessarily mean that the specimens were captured or entangled by the fishing gear. These two very distinct types of interactions (capture *vs* sightings/depredation) are not clearly distinguished and there is no clear way to report this in the ST09 forms. Therefore, the information on marine mammal interaction with ICCAT fisheries is limited not only due to poor monitoring and underreporting (as is the case for the other species groups discussed in this sections), but also by the more cryptic nature of the interactions (Clarke *et al.*, 2014).

While estimates of the total number of marine mammal interactions with longliners, purse seiners or gillnets are not available for the Tropical Ecoregion, or any region within the ICCAT convection area, estimates from some fleets and gears, which are relevant to the Tropical Ecoregion, are available. A study using captain’s logbook information (1980-

2011) and observers' data (1995 to 2011) from the EU purse seine tuna fishery operating in the eastern tropical Atlantic estimated the percentage of cetaceans associated fishing sets was around 3.6%, where 0.74% of sets had cetaceans encircled. Of the 155 cetaceans encircled in a purse seine sets (93 baleen whales, 62 delphinids, 0 sperm whales) between 1995 and 2011, the immediate apparent survival rate was high (92%) (Escalle *et al.*, 2015).

Table 2. List of marine mammal species (only cetaceans) found in the Tropical Ecoregion known to interact with ICCAT fisheries. Their conservation status is also presented. (Extracted from ICCAT manual need to cite).

Scientific name	Common name	Code	LL	GILL	PS	IUCN Red List	CITES
Balaenoptera acutorostrata	Minke whale	MIW		x	x	LC	I
Balaenoptera borealis	Sei Whale	SIW			x	EN	I
Balaenoptera edeni	Bryde's whale	BRW			x	DD	I
Delphinus delphis	Common dolphin	DC0		x	x	LC	II
Globicephala macrorhynchus	Shortfin pilot whale	SHW			x	DD	II
Grampus griseus	Risso's dolphin	DRR		x		LC	II
Kogia breviceps	Pygmy sperm whale	PYW		x		DD	II
Megaptera novaeangliae	Humpback whale	HUW		x		LC	I
Mesoplodon spp	Beaked whake	MEP		x		DD	II
Orcinus orca	Killer whale	KIW			x	DD	II
Physeter macrocephalus	Sperm whale	SPW		x	x	VU	I
Pseudorca crassidens	False killer whale	FAW			x	DD	II
Stenella attenuata	Pantropical spotted dolphin	DPN			x	LC	II
Stenella clymene	Shortsnouted spinner dolphin	DCL			x	DD	II
Stenella	Striped dolphin	DST	x	x	x	LC	II

coeruleoalba							
Stenella frontalis	Atlantic spottted dolphin	DSA		x		DD	II
Stenella longirostris	Spinner dolphin	DSI			x	DD	II
Steno bredanensis	Rough-toothed dolphin	RTD			x	LC	II
Tursiops truncatus	Bottlenose dolphin	DBO	x	x	x	LC	II
Ziphius cavirostris	Goosebeaked whale	BCW	x	x		LC	II

There are also few studies reporting longline fleet interactions with marine mammals in the Atlantic Ocean, including the USA longline fleet (Garrison & Stokes, 2012), the EU Spanish longline fleet (Ramos-Cartelle & Mejuto, 2008) and Uruguay longline fleet (Passadore *et al.*, 2015). Of these studies, only the EU Spanish longline fleets targeting swordfish operates within the Tropical Ecoregions and has reported its number of interactions with the false killer whale between 1993 and 2006 (Ramos-Cartelle & Mejuto, 2008). The incidental catch rate of the false killer whale by the Spanish longline fishery has been estimated to be 1.46 individuals per million hooks for the entire Atlantic (based on observer and logbook data), and the tropical area presented the largest number of interactions with the swordfish fishery. Most of the catches are due to the whale getting hooked by flipper or tangled up in the longlines. Of all the specimens caught only two were dead. The resulting incidental mortality rate of the false killer whale was estimated to be 0.36 individuals per million hooks in the Atlantic.

There are no known studies estimating gillnet interactions with marine mammals in the Atlantic Ocean. Although coastal gillnets are also used to catch tunas in the ICCAT convention area and are known to interact with marine mammals, these gillnet fisheries are not closely monitored by ICCAT. Mortality of marine mammals in gillnets is unknown, but thought to be high due to entanglement of the mammals with the gillnets and consequent most likely drowning.

Two of the 20 species known to interact with ICCAT fisheries in the Tropical Ecoregion have been listed as threatened in the IUCN Red List, Sperm whale (*Physeter microcephalus)* as Vulnerable and Sei whale (*Balaenoptera borealis)* as Endangered. Nine species were listed as Data Deficient, which means that their Red List Status category was not possible to determine given the data available and the rest of the species were listed as Least Concern under the IUCN Red List (Table 2). Additionally, all the 20 species have been listed under Appendix I or II of the Convention on International Trade in Endangered Species (CITES) (Table 2).

3.3.3 Community structure, foodwebs and biodiversity

The available information about the dynamics of this tropical ecosystem in terms of energy flows, trophic relationships and biodiversity of its food web is limited. The information provided in this section is based on three recent studies (Forrestal, 2016; Lezama-Ochoa, 2016; Olson *et al.*, 2016) that have been developed in the study area, though might not be completely representing the whole Tropical Ecoregion. These studies concluded that further research is required to better understand the dynamic of this pelagic ecosystem and move towards the implementation of the EBFM.

A food web model was constructed by Forrestal (2016) aiming at assessing the effects of the purse-seine fishery of the Gulf of Guinea ecosystem, for which both information coming from inside and outside the study area was used (Figure 11). The quality of this ecosystem model (in terms of pedigree index) was not enough to be used for management, as recommended by (Lassalle *et al.*, 2014) and recognized by Forrestal (2016). Getting a better ecosystem model in terms of quality of information (data used to feed that model) would provide the opportunity to derive different ecosystem indicators (species and trophic level biomasses, fishing and predation mortalities, trophic level of the catch). However, this ecosystem model serves as a first preliminary analysis on the ecosystem structure and functioning in the Tropical ecoregion. Figure 11 shows the trophic flow diagram with the connections between all the functional groups in the ecosystem model, from which existing predator-prey relationships can be inferred.

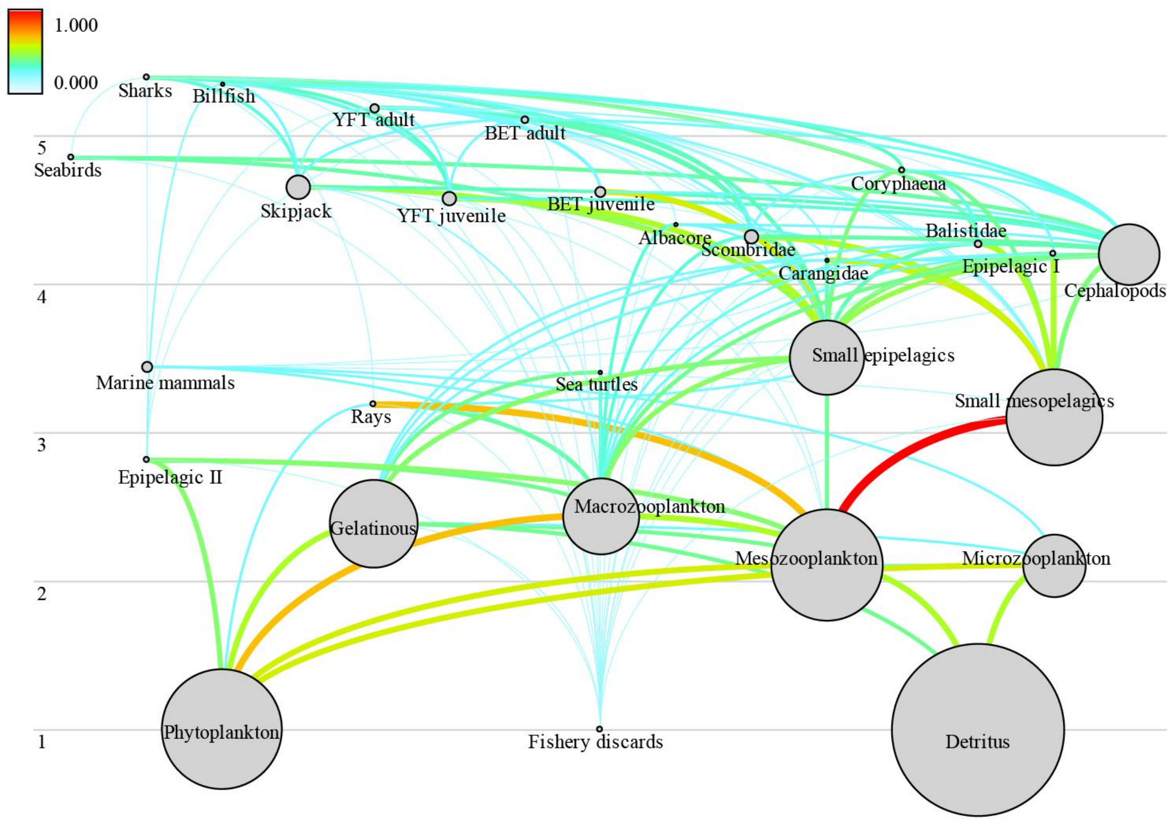


Figure 11. Trophic flow diagram showing the connections between the functional groups of the Gulf of Guinea model. Colored lines denote the relative proportion of each predator's diet and the size of the nodes is relative to the biomass of each functional group. Extracted from Forrestal (2016).

In the same period, Olson *et al.* (2016) summarized the existing knowledge about the trophic ecology of tuna species in the Atlantic Ocean, and in the Eastern tropical area in particular, containing the Gulf of Guinea. Three species of Thunnini are found in these waters: yellowfin (*Thunnus Albacares*), bigeye (*T. obesus*) and skypjack (*Katsuwonus pelamis*). They mainly prey on fishes, cephalopods and crustacean, following this order of preference, though these preferences depend not only on the predator species, but also on the season, the bathymetry and the distance from the coast. In general, the contribution of crustaceans to their diet was limited to the most coastal areas, whereas fish and cephalopod species where relevant in both coastal and oceanic areas. Mesopelagic fish are reported to be a relevant prey for young and adult individuals of yellowfin, skypjack and bigeye tuna.

Biodiversity in terms of alpha and beta diversity (number of species and change in species composition respectively) and evenness (relative abundance of species) have been investigated in the Tropical Atlantic in a recent study developed by Lezama-Ochoa *et al.* (2018). This study was based on the information obtained from the observer programs on the European purse seine fleets and specially focused on by-catch diversity. They showed that not only the environment, but also the different fishing types of purse seiners determine differences in species composition. However, no clear pattern was found to explain the differences in species composition between areas and modes of fishing, probably due to low observation coverage during the period analyzed. This type of studies are relevant for providing a better understanding of the ecosystem processes (Lezama-Ochoa *et al.*, 2018).

3.3.4 Productivity

The Tropical Ecoregion is a low productivity area compared with the most poleward areas in the Atlantic Ocean. But there are higher productivity areas associated with both, the equatorial and the coastal upwellings and the thermal domes in the ecoregion (Figure 12) (Siegel *et al.*, 2013).

All the high-productive systems of the Eastern tropical Atlantic between 20°N and 15°S are partly controlled by the sub-superficial equatorial countercurrent system, which feeds all of them with Southern Atlantic Central Water. However, the enrichment processes in the systems are quite different, and thus the structures differ from one another. The Longhurst biogeographic provinces provide more specific details about the complex spatial and temporal phytoplankton dynamics in the study area, in relation to the complex oceanographic features that characterize this ecoregion such as the equatorial divergence, currents and countercurrents, instabilities, etc. (Longhurst, 2007).

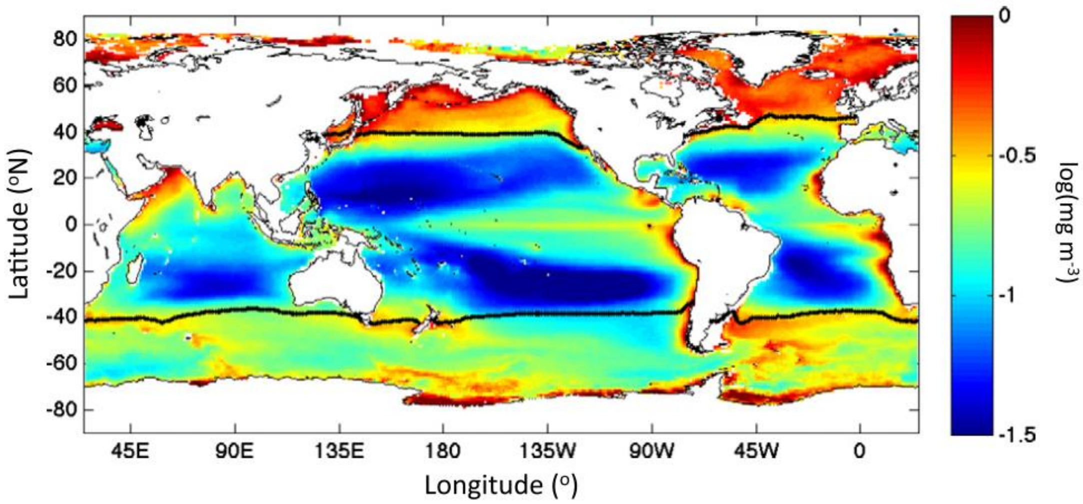


Figure 12. Mean Chl-a concentration from SeaWiFS Mission, from August 1, 1997 to December 14, 2010. Extracted from Siegel et al 2013.

3.3.5 Habitats of ecological significance

Identifying habitats of ecological significance for the species interacting with ICCAT fisheries is also an important tool for the management and conservations of species. Habitat of ecological significance might include areas used by species for spawning grounds and migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate in a particular time. Consequently, understanding the environmental preferences of species and how they change temporally and spatially, as well as what other biotic factor such as prey preferences, determine the spatial patterns of species, is important to inform the management and conservation of species (Harrison *et al.*, 2017). In particular, when this knowledge is available for multiple species, mapping areas of ecological significance for multiple taxa and their degree of overlap can be used to inform cross taxa area-based management by allocating the spatial and temporal distribution of fishing activities to minimize their impacts.

Some studies have been conducted to document habitat preferences and identify most important variables driving the spatio-temporal distributions of some ICCAT target species (Arrizabalaga *et al.*, 2015a; Druon *et al.*, 2016). There is also an increasing use of ecosystem and habitat models such as SEAPODYM and APESCOM to investigate the dynamics and spatial distributions of target species and their responses to natural climate variations and climate change in the ICCAT area (Schirripa *et al.*, 2011; Lefort *et* *al.*, 2014; Lehodey *et al.*, 2014). Habitat research focused on the habitat utilization and preferences of bycatch species has been more scant. Within the Tropical Ecoregion, the spatio-temporal environmental preferences of silky sharks have been mapped, which provides critical information of the dynamics and hotspots of silky sharks as well as the most significant habitat preferences of this species (Lopez *et al.*, 2016). Hotspot areas where high intensity of sea turtle interactions occur with pelagic longline gear have also been estimated in the Tropical Ecoregion (McKee Gray & Diaz, 2017). Coelho et al. (2018) mapped habitat use of various stages of blue shark using detailed fishery observer data from multiple ICCAT longline fleets. In that study, it was noted that adult blue sharks and pregnant females were predominant in the Tropical Regions, with those regions being most likely important mating grounds for the species. More research is needed to understand the spatio-temporal environmental preferences of species, as well as mapping these areas for multiple taxa to inform cross taxa area management.

A relevant process to follow is the Convention on Biological Diversity process to describe Ecologically Biologically Significant Marine Areas (EBSAs) in the world's oceans. This process, which started in 2008 has identified several EBSAs within the Tropical Ecoregion. The EBSAs have been chosen based on a criteria for identifying ecologically or biologically significant marine areas in need of protection in open-ocean waters and deep-sea habitat (Dunn *et al.*, 2014). These criteria accounts for (1) uniqueness or rarity (2) special importance for life history stages of species, (3) importance for threatened, endangered or declining species and/or habitats (4) vulnerability, fragility, sensitivity, or slow recovery (5) biological productivity, (6) biological diversity and (7) naturalness. These EBSA process (and the areas chosen) provide a strong basis and a rich source of information to support marine spatial planning and ecosystem based management within national jurisdictions and areas beyond national jurisdictions (Dunstan *et al.*, 2016). ICCAT fisheries is one potential pressure in these areas, and by committing to implement the ecosystem approach, the overlap and extent of ICCAT fisheries on these areas needs to be monitored and quantified.

4 CONCEPTUAL ECOSYSTEM MODELS – UNDESTANDING THE KEY ECOLOGICAL INTERACTIONS IN THE TROPICAL ATLANTIC ECOSYSTEM

Key message

- The conceptual ecosystem models developed have exposed 14 ecological interactions to be monitored by ICCAT in the Tropical Atlantic ecoregion in order to ensure the conservation and management of all its fisheries and avoid undesired changes of ecosystem state.
- At this stage, all the ecological interactions identified are treated as equally important to monitor changes in the state of the ecosystem and avoid undesired ecosystem states, however, some interactions might be more relevant than others.
- A future ecological risk assessment should determine the relative importance of these interactions, so the Commission can prioritize research, management actions and make choices between different risks.
- Regulatory and socio-economic interactions should also be identified in future revised ecosystem plans.

4.1 Conceptual ecosystem models of the Tropical Ecoregion

While the ecosystem overview developed in section 3 integrates the existing knowledge of the main pressures and drivers that contribute to the state of the different ecosystem components in the ecoregion, it also allows to identify how the different ecosystem components interact and relate to each other, raising up those emergent issues that ICCAT may need to monitor closely in order to ensure the conservation and management of all its fisheries and avoid undesired changes of ecosystem state. For any ecosystem plan it is important to identify key interactions between the different ecosystem components to ensure a more holistic and integrative view of how the different pressures may be affecting species and the structure and functions of the ecosystem they rely. In doing so, we built several conceptual ecosystem models at different scales of detail based on the information gathered in the ecosystem overview (Figure 13 general conceptual model, Figure 14-18 - individual fisheries models, Figures 19-multifisheries model). In these conceptual ecosystem models, an "interaction" is defined as a component (or group of components) that has an impact on another component (or group of components). The lines indicate links or interactions between components, where an arrow indicates a positive effect on the terminal group, a dot indicates a negative effect on the terminal group, a stripe indicates a neutral effect on the terminal group and a diamond indicates an unknown effect on the terminal group. Furthermore, a solid line indicates direct interactions between components, while a broken line indicates indirect interaction between components driven by a third component. At the end, conceptual ecosystem models are tools that allow visualizing those relevant ecosystem components and their interconnection. They also allow identifying and raising manageable number of issues that may need to be research separately or as a whole and ensures that no critical components are missed. Conceptual ecosystem model can also help to identify trade-offs of management actions on different components of the ecosystem, which may lead to more informed decision-making. In addition, the conceptual ecosystem models can also be used as a tool to synthesize information to the Commission (as well as the public), through the inclusion in glossy educational material and presentations. Therefore, it can be used as a communication tool for ecosystem science.

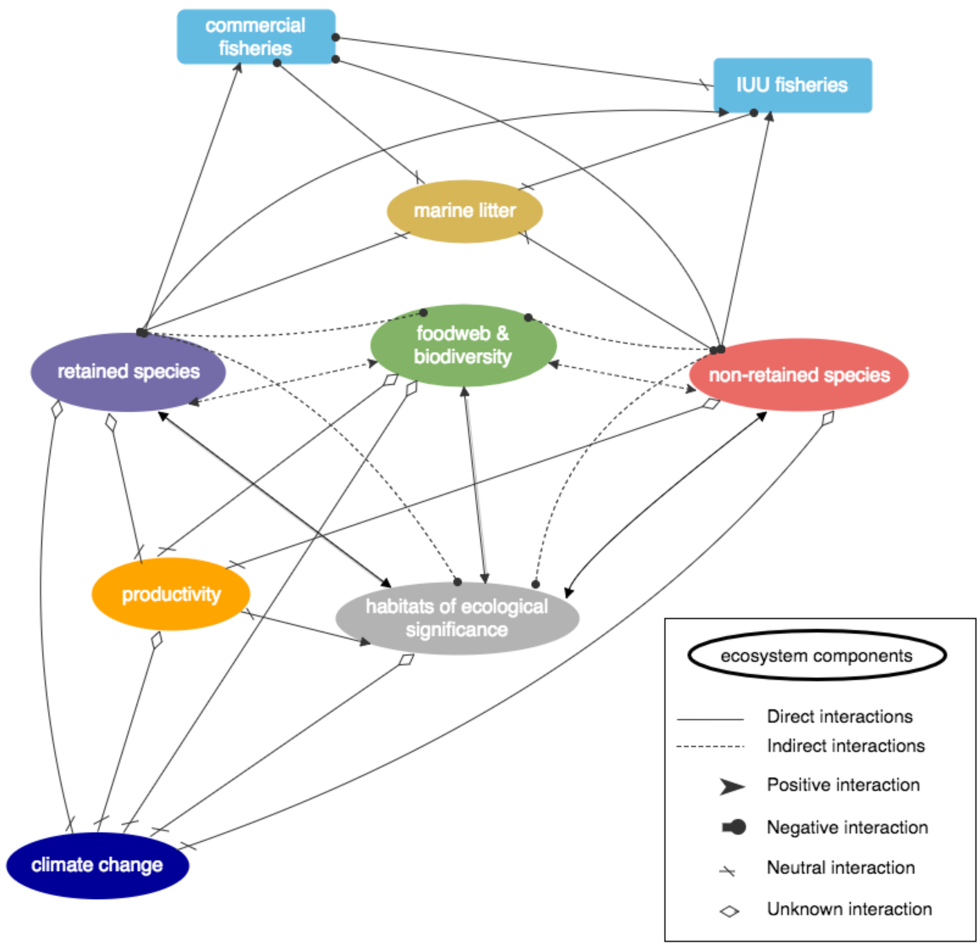


Figure 13 . General conceptual ecosystem model of the Tropical Ecoregion.

The general conceptual ecosystem model of the Tropical Ecoregion elucidates multiple and complex interactions between ecosystem components (Figure 13). *Commercial fisheries*, here seen as one stakeholder, has a negative link to *Retained species,* by decreasing their biomass and altering their size and age structure, while *Retained species* have a positive link to the *Commercial fisheries* stakeholders through the provision of catch and revenue. *Commercial fisheries* have a negative link to *Non-Retained species* by taking them accidentally and releasing them alive, injured or dead, which might have an impact on these populations. In return, *Non-retained species* have a negative link on *commercial fishery* stakeholders by producing them extra costs, for example, the time lost when handling accidental catches, the cost of applying mitigation measures, etc. Similarly, *Illegal, Unreported, Unregulated (IUU) fisheries* have a negative link to *Retained* and *Non-Retained species,* as these fisheries poses additional impacts on fish species and bycatch species which are not accounted in fisheries evaluations, while IUU fisheries benefit from these illegal catches (positive link from *Retained species and Non-retained species to* IUU fisheries). Thus, IUU fishing is also negatively linked to *Commercial fisheries* since such type of activities impact negatively *Commercial fisheries*. *Retained and Non-Retained species* interact with each other through reciprocal positive links and these positive links represent the reliance of these species on each other through trophic interactions such as the provision of food (predatory-pray interactions)*. Commercial and IUU fisheries,* by having a negative impact on Retained and Non-Retained species, might also have an indirect negative link with *Foodwebs and Biodiversity*, which might impact the structure and function of ecosystems making them less resilience to exploitation and climate change.

Abandoned, lost and discarded fishing gear produced by fishing boats, here renamed as *Marine debris*, also can have a negative effect on the ecosystem (Figure 13). *Marine debris* has a direct interaction with *Retained and Non-retained species*, since the lost gears might continue catching and killing species (known as ghost fishing) which also can cause indirect impacts on *Foodwebs and Biodiversity*. At the same time, lost gear can also impact negatively fisheries.

Habitats of ecological significance have a positive direct link to *Retained and Non-retained species* through the provisions of necessary habitat for feeding, spawning, migration corridors, etc. as well as *Foodwebs and Biodiverity. Commercial fisheries* might indirectly impact *Habitats of Ecological Significance* by impacting species and reducing biodiversity (Figure 13).

General environmental impacts of *Climate change* were also included, but their impacts on *Productivity, Retained and Non-Retained Species, Habitats and Foodwebs* were deemed unknown, in part because there is very little research documenting its effect on the Tropical Ecoregion, and also because environmental impacts of climate change could be translated into multiple perturbations and impacts on the different components of the ecosystem in a number of ways (Figure 13). Similarly, *productivity,* producing bottom up changes in the ecosystem, may impact species all the way to the structure and functions of the ecosystem, and this was also considered as "unknown interactions" since it could also perturb and impact the system in multiple ways depending on the regime state of the system.

While the general conceptual ecosystem model presents the main ecosystem components and its main interactions relevant to the Tropical Ecoregion, due to its generality, it also obscures the more detailed interactions between the main fisheries operating in the area and its interactions with species, foodwebs and habitats of ecological significance. Therefore, based on the information gathered in the ecosystem overview, we also constucted more detailed conceptual ecological models which focused on the interactions of each fisheries with the rest of the ecosystem components to identify and list those fishery-dependent ecological interactions that ICCAT may wish to monitor and well as to identify fishery to fishery interactions. First, we constructed a conceptual model for each main fishery (surface longliners, deep setting longliners, purse seiners setting on free schools, purse seiners setting on FADs and baitboats) (Figure 14-18). Second we constructed a conceptual model where all the fisheries level conceptual models in Figure 14-18 were merged together to understand fishery to fishery interactions as well as the cumulative effect of multiple fisheries on the state of the ecosystem components (Figure 19).

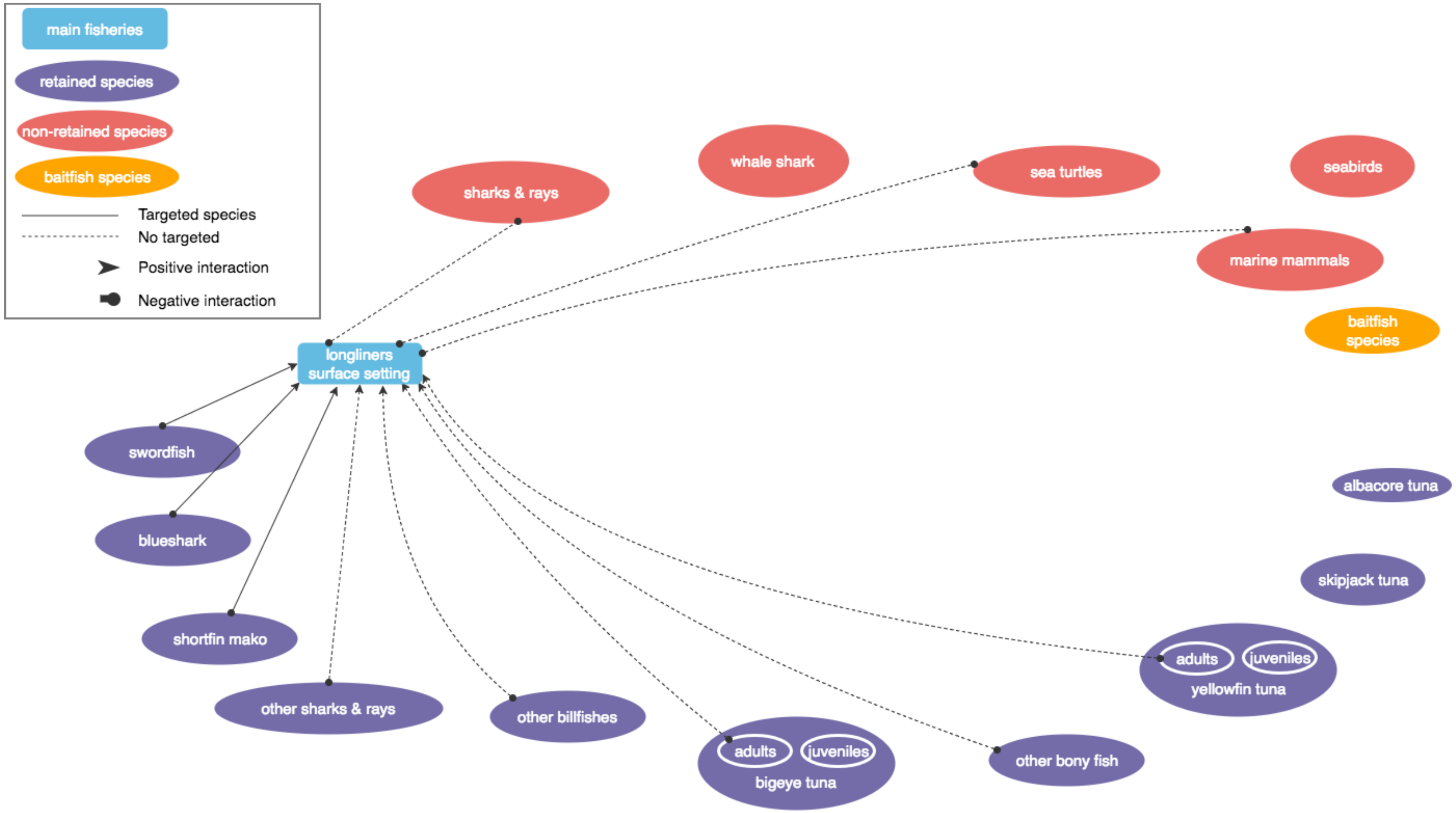


Figure 14. Conceptual ecosystem model of the surface setting longline fisheries operating in the Tropical Ecoregion.

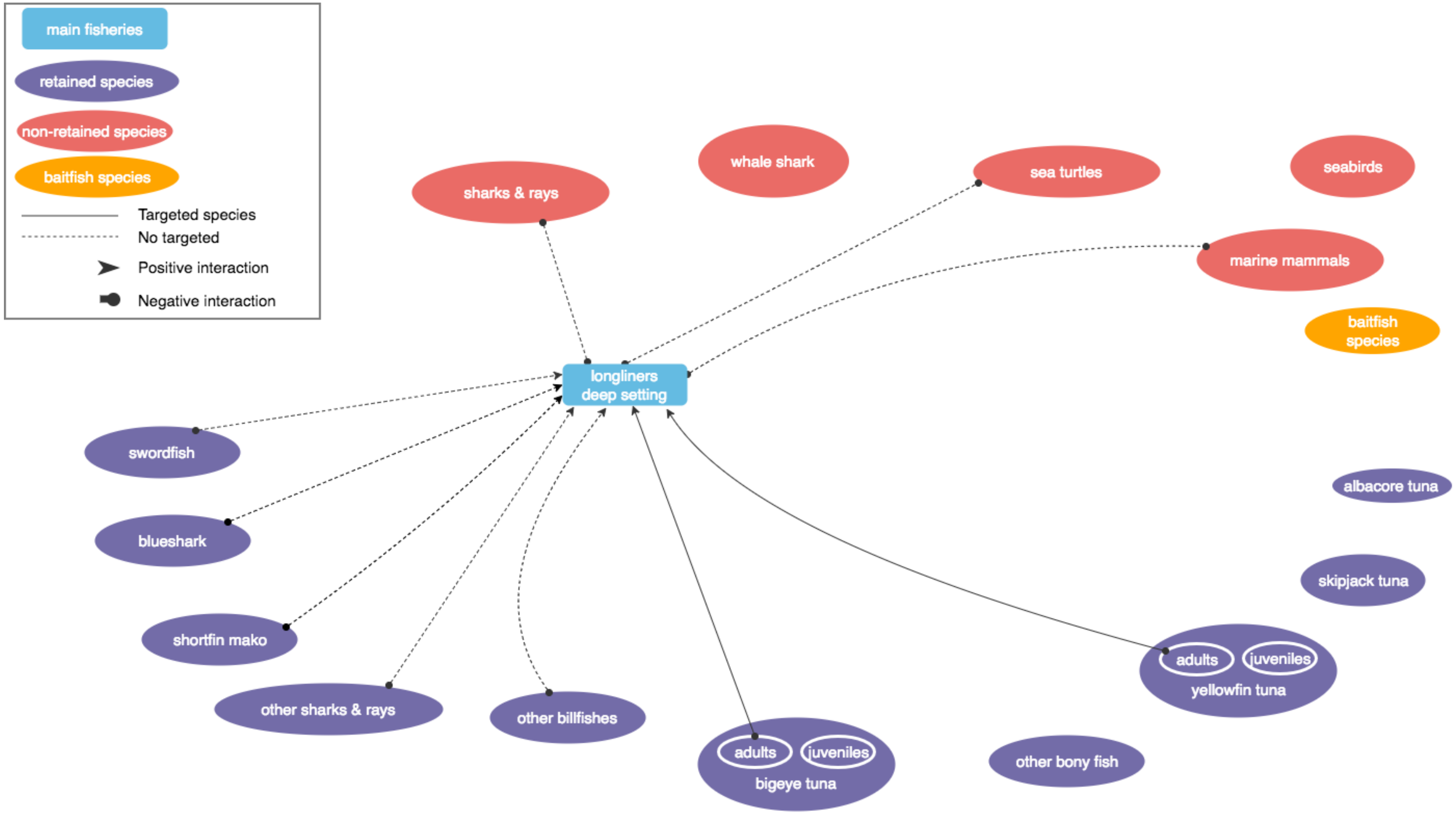


Figure 15. Conceptual ecosystem model of the deep setting longline fisheries operating in the Tropical Ecoregion.

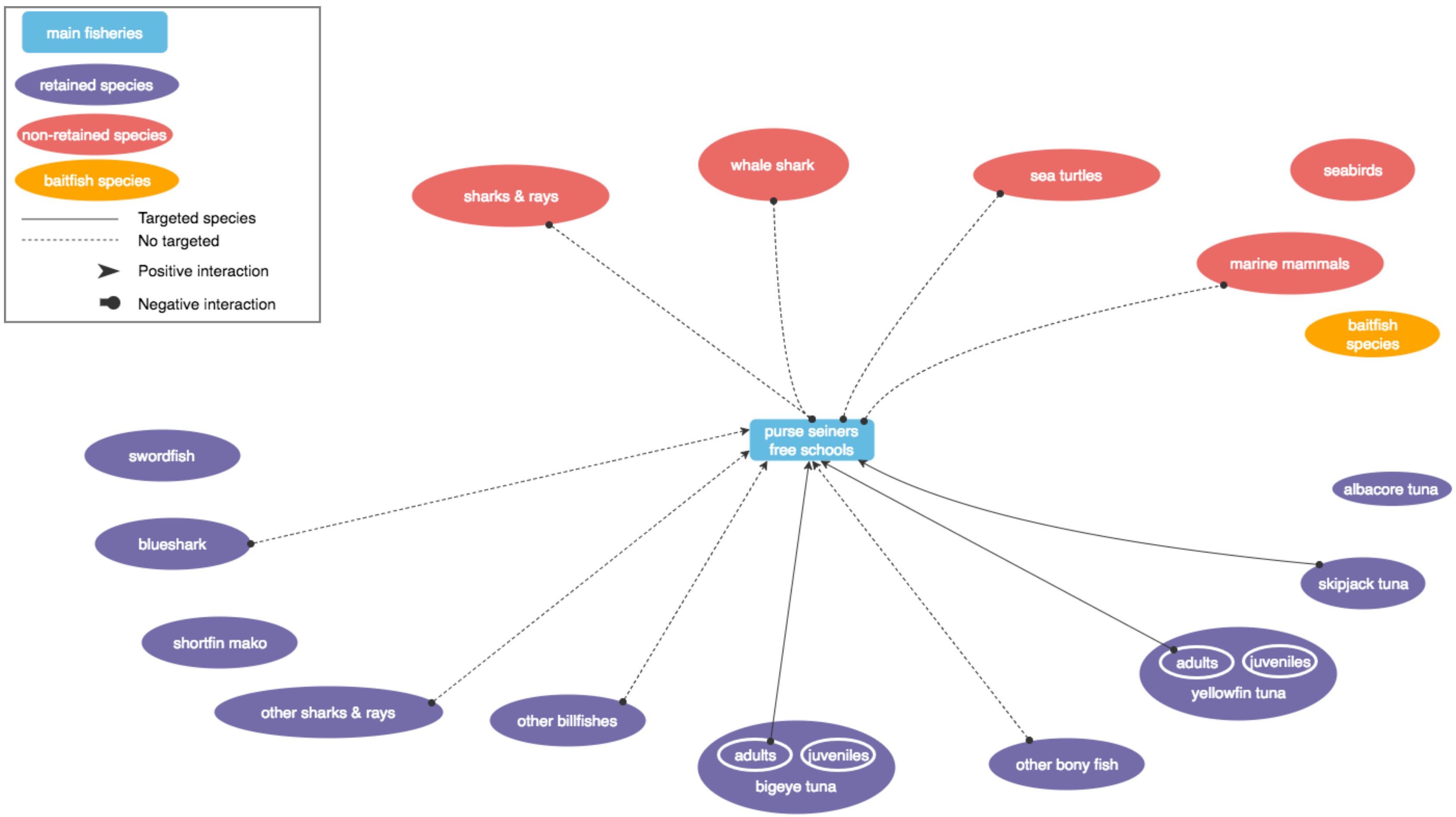


Figure 16 . Conceptual ecosystem model of the purse seine fisheries setting on free schools operating in the Tropical Ecoregion.

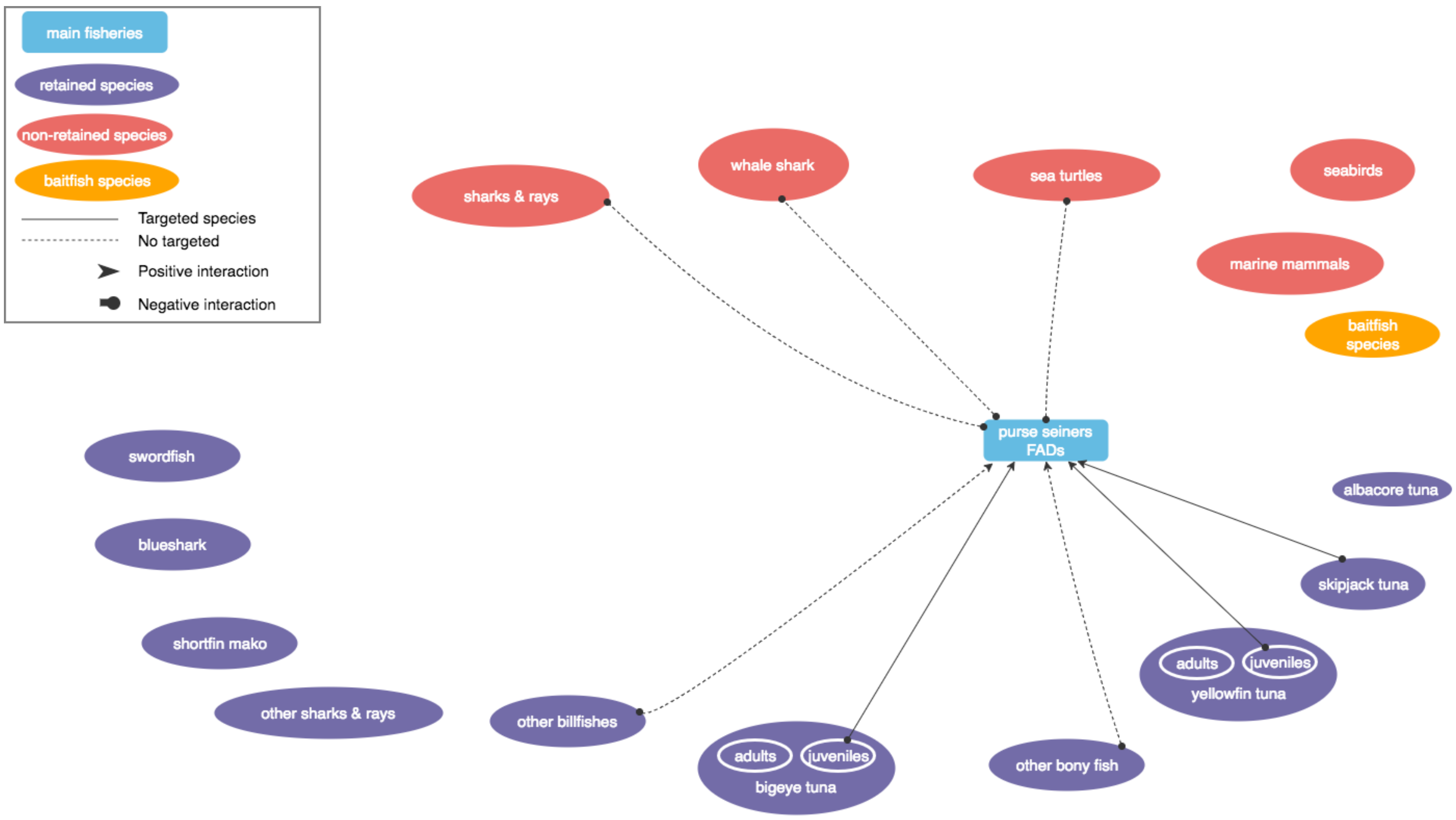


Figure 17. Conceptual ecosystem model of the purse seine fisheries setting on FADs operating in the Tropical Ecoregion.

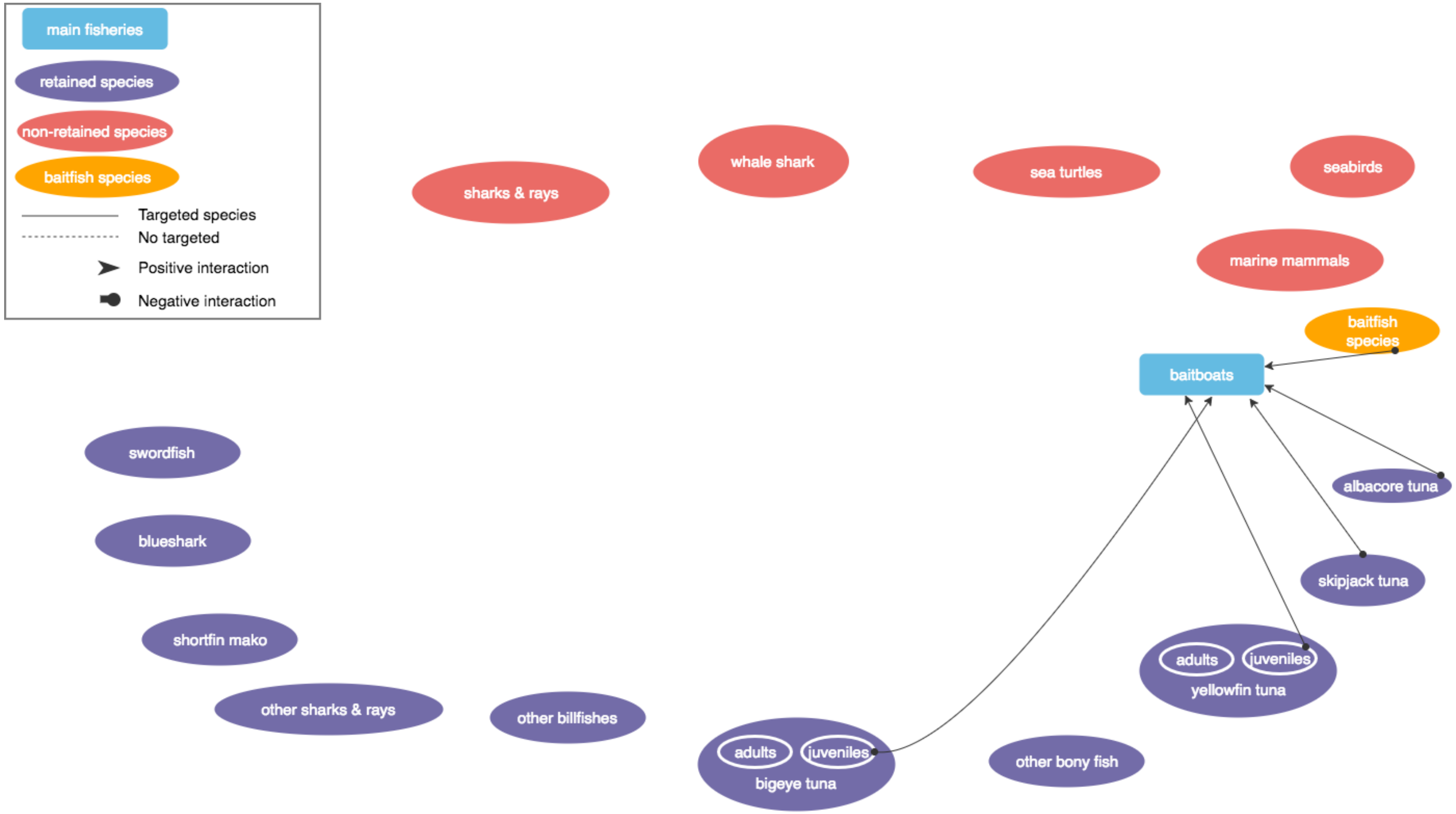


Figure 18. Conceptual ecosystem model of baitboat fisheries operating in the Tropical Ecoregion.

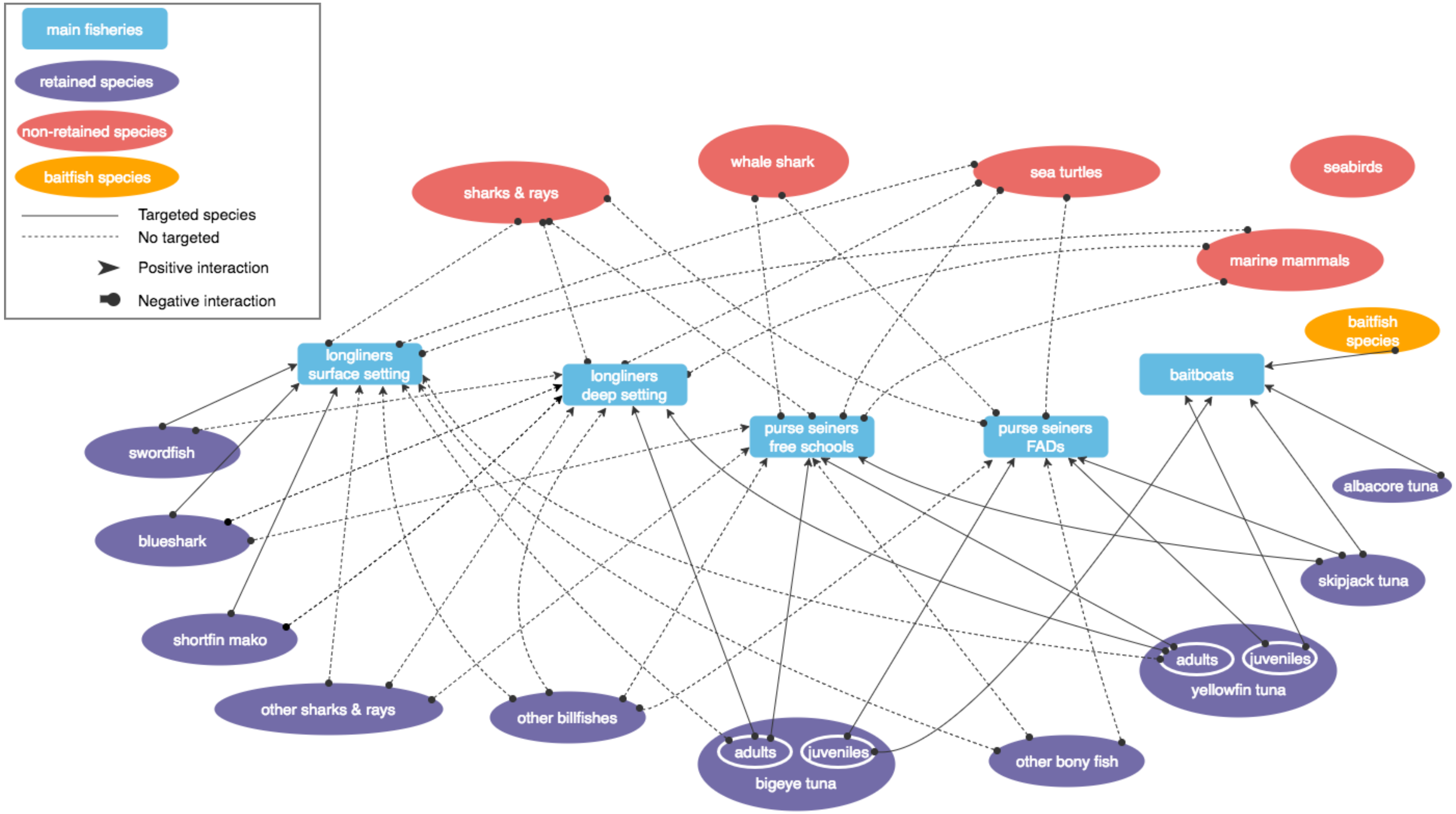


Figure 19 . General multifishery conceptual ecosystem model of the Tropical Ecoregion.

4.2 Key ecological interactions to be monitored in the Tropical Ecoregion

The conceptual ecosystem models presented in section 4.1 were used to identify broad interactions categories and key ecological interactions within each broad category (Figure 20) which are deem relevant to be monitored in the Tropical Atlantic ecosystem.

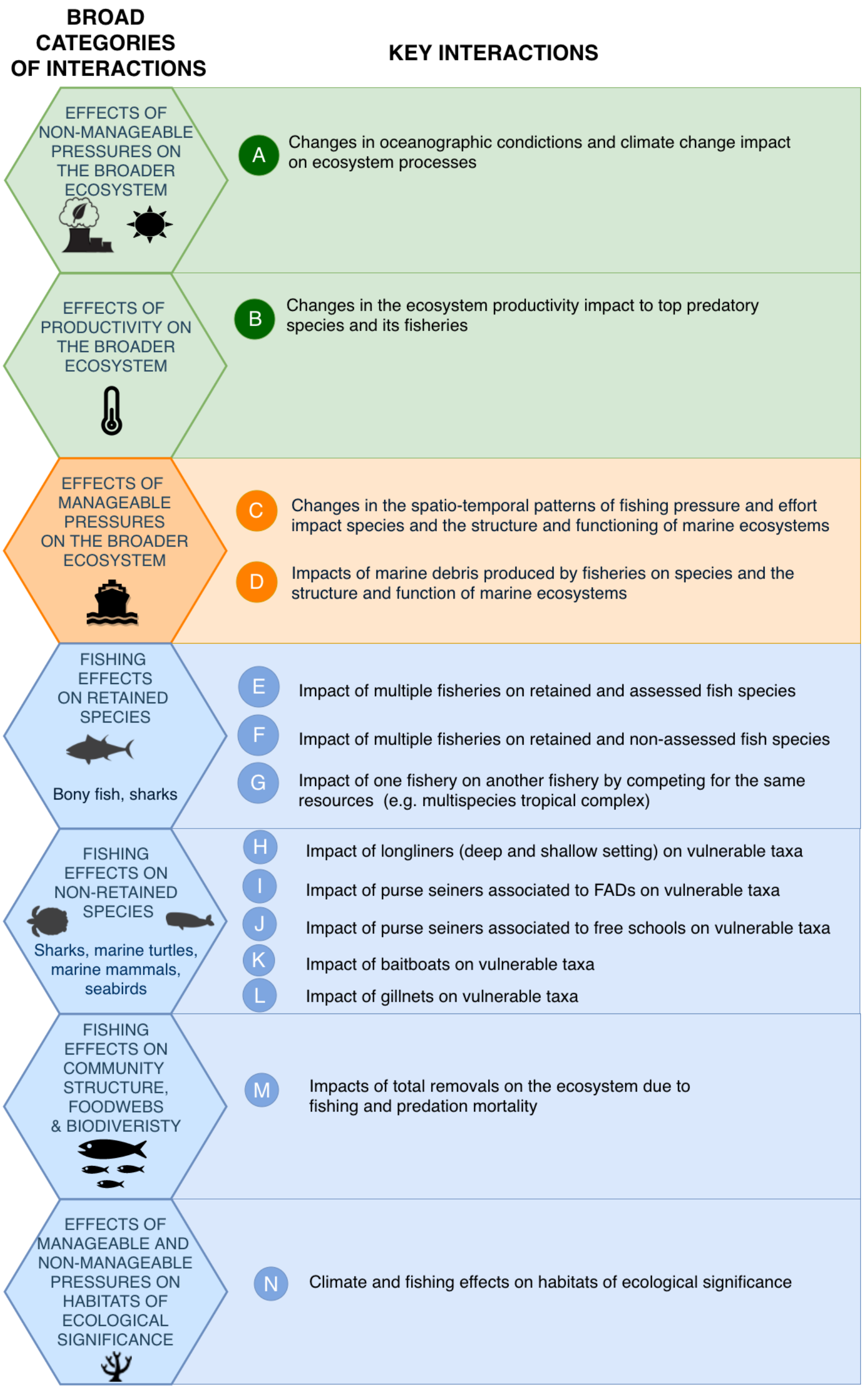


Figure 20. Key interactions considered relevant in the Tropical Ecoregion to be monitored by the Commission.

It is recognized that there are many more ecological interactions operating in the ecosystem within each of the main broad interaction categories identified. It is expected that the importance of these and complementary interactions will be re-evaluated in future updates to this ecosystem plan. At this stage, we are only identifying and defining the relevant ecological interactions in the Tropical Ecoregion and we are considering them as equally relevant to monitor changes in the ecosystem and avoid undesired ecosystem states. However, some interactions might be more relevant than others, either because they are more prevalent and have a higher probability to occur or because their level of impact might be relatively higher which might be imposing a high cost to the fishery or the ecosystem. Therefore, it is not only important to identify the existing ecological interactions, but also their importance to assess their relative risks (NPFMC, 2007). In the future, an ecosystem risk assessment should be conducted to determine the degree of importance of each interaction to the Commission. An ecosystem risk assessment aims to quantify the strength of each interaction, its risk, based on two sources of information, their probability of occurrence as well as the level of impact to the current ecosystem state. Defining these interactions and their relative importance and risk in the system, can provide the Commission with a tool to prioritize potential issues, make choices between different risks and trade-offs or take actions to avoid unwanted risk through appropriate management actions (NPFMC, 2007).

4.3 Matching key ecological interactions with management objectives

Monitoring the key interactions with ecosystem indicators allows to provide feedback to ICCAT about the state of each interactions, as well as identify the research and data gaps than hinders the monitoring of specific interactions. Ecosystem indicators as well as management objectives are key to monitor key interactions as well as to determine how a well an interaction is managed (or simply monitored by surveillance indicators) in relation to management objectives. Consequently, next we propose a series of candidate objectives which can be used to measure the performance of indicators (proposed in section 5) towards achieving specific goals within each broad interactions categories (Figure 21).

The management goals for each broad interaction category ideally should be discussed and agreed by the Commission. The management goals should encapsulate key principles of the ecosystem approach such as the sustainable use of fish resources, the conservation of biodiversity and the maintenance of resilient ecosystems. Until the Commission defines and adopts specific management goals for each broad interaction category, this pilot ecosystem plan will be based on the proposed management goals which intends to express ICCAT aspirations reflected in its Convention mandate, on-going negotiations for a Convention Amendment, and adopted recommendations and resolutions as well as relevant internationally agreed standards (Garcia *et al.*, 2018).

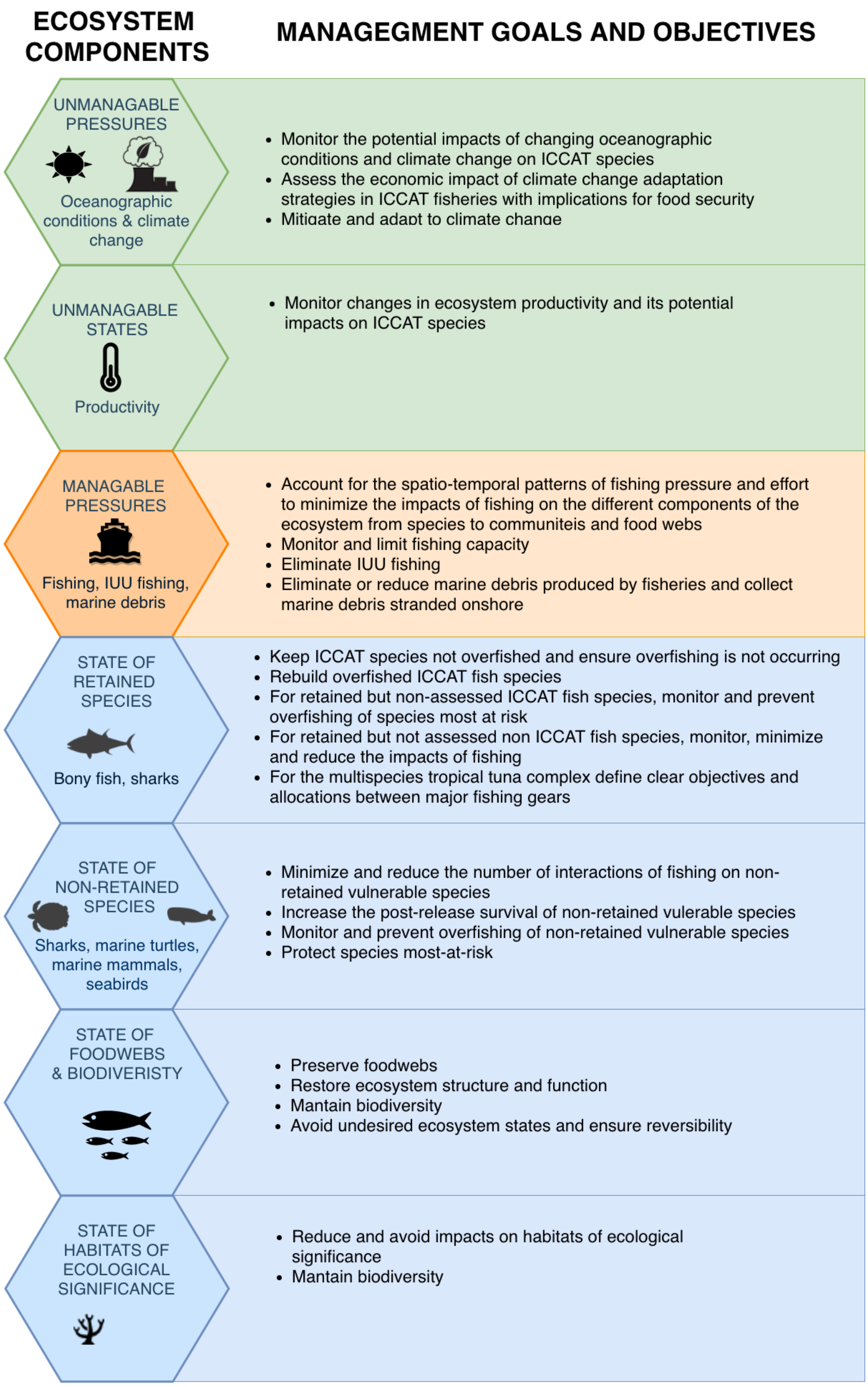


Figure 21. Ecosystem components linked to management goals.

5 SKELETON OF AN INDICATOR BASED ASSESSMENT FOR MONITORING ECOSYSTEM INTERACTIONS

Key message

- For each of the ecological interaction identified, we list candidate management objectives and ecosystem indicators with their potential data sources and research needs, expose the risks of not monitoring these interactions, and how the commission is (or should be) addressing the risks.
- Of the proposed ecosystem indicators, only a small number are routinely monitored by ICCAT. Many indicators could potentially be developed in the short term using the data available in ICCAT, the data collected from the observer programs, and data from external sources. Ecosystem indicators ,for which data are not currently and readily available for their estimation, are still included in the proposal, to guide future data collection and research efforts.
- The identified interactions and proposed indicators intend to be an interim step towards developing a comprehensive ecosystem status assessment in the Tropical ecoregion to provide the Commission with an integrated overview of the health ecosystem, and provide early signals that might warrant management interventions.

5.1 Tracking ecosystem indicators between ecosystem components and implications for management, priorities and considerations for the Commission

Ecosystem indicators can be used to monitor ecological interactions between ecosystem components which can be used to inform the Commission about ecological processes and the linkages between human pressures and the state of ecosystem components. Monitoring key interactions with ecosystem indicators provides feedback to the Commission about the state of each interaction and the research and data gaps. Therefore, the ecosystem indicators proposed in this section can have two main purposes under this ecosystem plan: (1) to help assess the state of the ecosystem components and their relevant interactions, and (2) to assess how well a fishery is managed in relation to objectives (NPFMC, 2007).

Next, for each broad category and interaction identified (Figure 20), we describe each interaction and the risk of not monitoring it. We also present management objectives and a series of candidate indicators to track the state of the interaction. The proposed indicators are divided into three categories depending on the on-going work in ICCAT and data availability to estimate them: (1) Indicators currently estimated and/or monitored in ICCAT; (2) Indicators for which data is potentially available (or partially available), but are not currently estimated and/or monitored by ICCAT; (3) Indicators for which data is not currently and readily available for their estimation, but are included to guide future data collection and research efforts. Notice that we merely propose a list of candidate indicators and we do not go through the process of estimating them or describing the time frame, mechanisms and costs for monitoring these indicators. However, for each interaction and candidate indicators, we discuss their data sources, data gaps and research needs, if relevant, in order to provide qualitative guidance about their feasibility to be used in the future for monitoring purposes. In the future, when some of these indicators are estimated, their performance also should be monitored against some reference points (or thresholds). The determination of critical thresholds to achieve management target is fundamental as well as determining the appropriate management actions that should take place. While these elements are not covered in the present pilot ecosystem plan, we refer to the guidelines developed as part of this SC02 project for setting reference points for a wide range of ecosystem indicators (See Task 4 of SC02 final report).

Last, we also provide a synopsis of what the Commission is doing to monitor (and potentially address the potential risks) for each of the interactions. We also identify actions that the Commission may need to initiate to monitor and address the potential risks associated with the interactions. Recommendations actions include suggestions of research needs to fill data and analysis gaps as well as specific Commission level analysis and actions (NPFMC, 2007).

5.2 Effects of non-manageable pressures on the broader ecosystem

5.2.1 Changes in oceanographic conditions/climate change impact ecosystem processes

Description

There are well known relationships between environmental variables such as temperature, pH, current speed and O2 concentration on the biological rates (growth, feeding, spawning, migration, etc.) of marine species (Dell'Apa *et al.*, 2018). Some of them have proven direct impacts on primary productivity and thus the forage base (Brown *et al.*, 2010). Given this, strong direct (exotherms and their habitat) and indirect (shift in distribution and abundance of species) dependency on oceanographic conditions, it is clear that environmental variability may greatly affect the dynamics of ICCAT species and ecosystem processes in general, both in the short-medium- and the long-term.

What is the risk of not monitoring this interaction

The abundance/biomass, horizontal and vertical distribution and reproductive capacity of species most vulnerable to environmental variability might change due to natural variability in the marine environment, which can be aggravated by climate change. This might lead to a dangerous decrease of ICCAT species abundance and/or a horizontal migration of tropical species to more temperate waters, that could end up having socio-economic impacts for ICCAT fisheries as well as mismanagement based on current knowledge.

Management objectives

-Monitor the potential impacts of changing oceanographic conditions and climate change on ICCAT species.

-Assess the economic impact of climate change adaptation strategies in ICCAT fisheries with implications for food security.

-Mitigate and adapt to climate change.

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are potentially available	Indicators currently not monitored in ICCAT for which data are not available
• Sea surface temperature (SST)* • Water column descriptions (e.g. mixed layer depth-MLD)*	• Sea surface temperature (SST) • Water column descriptions (e.g. mixed layer depth-MLD) • Chlorophyll concentrations/primary production • Chlorophyll concentration and seas surface temperature gradients (Fronts) • Sea level anomaly • Eddie Kinetic Energy • Dissolved oxygen concentration • Tropicalization index for a community of species	

*Collected in some observer's programs but not widely used.

Data sources, data gaps and research needs

Some environmental data is collected by some CPCs as part of their observers programs in the ICCAT area (mainly SST and wind speed from which MLD can be derived). Current speed and direction may also be measured in each fishing operation. However, all these variables are not being currently processed and used widely, and it is not known the extent of their existence and their quality. Alternatively, the proposed environmental indicators can be estimated based on data derived from existing remote/in situ sensing and model products from open-access data bases, such as the Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/), the NOAA Environmental Research Division's Data Access Program (ERDDAP) (http://coastwatch.pfeg.noaa.gov/erddap/) and Bio-ORACLE - Marine data layers for ecological modelling (http://www.bio-oracle.org/).

More research is required in investigating how potential changes in current oceanographic condition might directly and indirectly affect the dynamic of ICCAT species. Identifying most vulnerable species to these environmental changes is fundamental. Using habitat modelling and forecasting approaches as in other tuna RFMO areas (mainly in the WCPFC and IATTC) could help forecasting these effects and providing some scientific advice for a more precautionary management of these species (Lehodey *et al.*, 2010; Lehodey *et al.*, 2011; Arrizabalaga *et al.*, 2015b).

Recommendation for indicator development

- Identify and monitor those species most vulnerable to environmental changes and climate change.
- Identify and prioritize those environmental indicators that could more likely cause relevant effect on the dynamics of ICCAT species.
- Explore the potential of using data derived from observer programs.
- Identify remote sensing real time environment monitoring systems to collect the environmental data.

Relevance and implications for management

(a) How is the Commission addressing the risk now?

- The Commission is not monitoring or accounting for the effects of the environmental variability on ICCAT fisheries and species, though some research has been conducted and accounted in some individual species assessments.

(b) What other actions might the Commission put in place to address and mitigate the risk?

- Conduct a series of ecological risk assessments to identify those fish species most-vulnerable to changes in oceanographic conditions and climate change.
- Produce a coherent and revised list of species that are vulnerable to oceanographic conditions and climate change for monitoring purposes.
- Identify and monitor environmental variables that could more likely cause relevant effect on the dynamics of ICCAT species.
- Model and forecast the potential impacts of climate change on most vulnerable species to climate change.
- Assess the economic impact of climate change and climate change adaptation strategies for ICCAT fisheries and its implications for food security.

5.3 Effects of productivity on the broader ecosystem

5.3.1 Changes in ecosystem productivity impact top predatory species and its fisheries

Description

The amount of biomass of primary producers, and so, the energy at low trophic levels in an ecosystem, limits and controls the productivity of the systems in terms of the biomass of higher trophic level predators that are mainly caught in ICCAT fisheries. These bottom-up changes are often linked to the climate and physical interactions. In addition, some external stressors (for example, nutrient runoff fertilizing freshwater systems) may also cause changes in energy pathways from lower to higher trophic level triggering other ecosystem processes that might result in changes in species biomass and trophic relationships. Reductions in energy flow from lower trophic levels may lead to precipitate competition for scarce resources at higher trophic levels; and increases in energy flow on the contrary, could favor certain higher trophic level species in one pathway, allowing them to outcompete predators relying on another pathway.

What is the risk of not monitoring this interaction

A reduction in primary production may negatively affect the production of the commercially important ICCAT species and might contribute to a non-intended overfishing of stocks before the signal is completely clear. Bottom-up changes are likely to favor some species over others in competition for shared resources, potentially resulting in economic tradeoffs.

Management objectives

-Monitor changes in ecosystem productivity and its potential impacts on ICCAT species

Candidate Indicators to evaluate whether objectives are met:

Indicators which are currently estimated and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are potentially available	Indicators currently not monitored in ICCAT for which data are not available
None	• Primary production • Zooplankton biomass and/or abundance • Zooplankton biomass and size structure • Low trophic level biomass (e.g. small pelagic fishes biomass)	

Data sources, data gaps and research needs

There are different data sources that provide this type of information to different users worldwide. The most effective and widely used way of measuring primary production is by measuring *Chl-a* concentrations with remote sensing (see final report Task 2.3). But there are also other sources, such as the Continuous Plankton Recorder (CPR) that would provide information about phyto- and zooplankton biomass and size structure. However, the data obtained with the CPR is mostly concentrated in North Atlantic area. Consequently, the potential use of this type of data should be considered and similar programs could be promoted in the Tropical Ecoregion.

Recommendation for indicator development

-Make use of existing databases (for example, remote sensing products and CPR) to monitor ecosystem productivity.

-Develop ecosystem models that are able to include these low trophic levels in the system and analyze their evolution in time and space, linking them with the dynamic of the higher trophic levels of that system.

Relevance and implications for management

(a) How is the Commission addressing the risk now?

- There is no action taken by the Commission to address this issue at the moment.

(b) What other actions might the Commission put in place to address and mitigate the risk?

- Integrate the remote sensing and low trophic level information available in public data sources with the information collected by ICCAT, both from the fisheries and also from the observers programs, to analyze potential links between system productivity and productivity of ICCAT species.
- Explore the interaction between primary and secondary production and non-ICCAT species (e.g. small pelagics) and ICCAT species dynamics on this tropical Atlantic area.
- Develop ecosystem models and integrated methods to produce scenarios of low and high productivity for forecasting potential effects of changes in ocean productivity on top predators (ICCAT fisheries).

5.4 Effects of manageable pressures on the broader ecosystem

5.4.1 Changes in the spatio-temporal patterns of fishing pressure and effort impact species and the structure and functioning of marine ecosystems.

Description

The overall extent of fishing pressure and effort and the associated spatio-temporal patters of fishing are important to be monitored in order to draw sounds conclusions regarding the impacts of fishing on the different components of the ecosystems as well as inform management strategies to minimize and avoid impacts. It is essential to consider the spatial extent and patchiness of the fishing activity, as well as to have information about the consistency with which areas are fished in the same regions from year to year. Furthermore, it is important to monitor fishing capacity. Excess capacity might contribute to overfishing, declines in food production potential as well as economic waste.

What is the risk of not monitoring this interaction

Not taking into account the spatio-temporal patterns of fishing activity limits the potential of defining area-based plans to minimize regional impacts of fishing on main target species, as well as protect vulnerable taxa (e.g. avoid localized depletions).

Management objectives

-Account for the spatio-temporal patterns of fishing pressure and effort to minimize the impacts of fishing on the different components of the ecosystem from species to communities to foodwebs.

-Monitor and limit fishing capacity.

Candidate Indicators to evaluate whether objectives are met:

Indicators which are currently estimated and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are potentially available	Indicators currently not monitored in ICCAT for which data are not available
• Number of active ICCAT vessels operating in the area annually • Total catch spatially and over time • Total catch and effort (and size) distribution spatially and over time for all gears • Number of hooks deployed by longliners spatially and over time • Number and density of FADs for purse seiners spatially and over time.	• Total fishing activity as hours fished per square km by vessels with AIS or VMS systems • Vessel track intensity measured with AIS or VMS systems • Mean Trophic Level Indicators (catch data)	

Data sources, data gaps and research needs

The submission of Task I (nominal catches) for all species by flag and gear and Task II (catch and effort and catch at size) for all species by flag and gear by month and strata (5 by 5º degrees for LL and 1 by 1º degrees for surface fisheries) for all ICCAT and other species is mandatory for each ICCAT CPC. However, the compliance by CPC, especially with Task II submission, is far to be completed and most of the cases Task II data is not submitted for the complete fleet covering all the nominal catch reported by CPC in task I.

ICCAT also maintains a database of catch distribution by gear raised to total landings by time-area strata (5x5 degrees squares, quarter and gear), which is known as CATDIS. While this is the most reliable source to monitor the total catch extracted spatially and within the last 60-70 years in the ICCAT Convention Area, it only covers nine species of tunas and billfishes. It does not cover all ICCAT assessed species like blue shark or shortfin mako shark or other small tuna species under the ICCAT mandate. The limited species coverage of this data set may limit its usefulness to estimate some of the proposed indicators such as the mean trophic level indicator based in catch data. Instead this indicator could potentially be estimated using datasets derived from the observer programs held by the CPCs.

ICCAT also maintains a database of effort and catches distributed by time-area strata, which is known as EFFDIS. Using this data, ICCAT has estimated the overall Atlantic longline- and purse seine effort by time area strata (5x5 degrees squares and quarter), which is maintained by the Secretariat. There are several issues related to the estimation of total effort for both of these gears which are well known and discussed by the SCRS (ICCAT, 2014). There are some methodological issues that need to be resolved to better characterize uncertainty using different substitutions of catch rates, raising ratios to total effort and dealing with the proportion of unclassified fleets (ICCAT, 2014). It is also not clear what measure of overall effort should be used to monitor efforts of purse seiners and track changes in purse seine effort over time. Regarding the spatial scale and temporal level of aggregation (5 degrees squares and months for longline estimates), there are ongoing discussions about the adequacy of these scales to inform any type of area-based management responses fit to specific issues for its broad spatial and temporal resolutions (ICCAT, 2014). Furthermore, the SCRS has raised in many occasions the need for further resources to improve these data sets.

The total number of active ICCAT vessels operating in the area annually is being monitored by ICCAT since 2014, together with basic fishing vessels attributes. Before 2014, the vessels monitored by ICCAT included active and non-active vessels which made it difficult to use this type of information to monitor fishing pressure. The recent expansion of the automatic identification system (AIS) presents an opportunity to monitor fishing activity at fine spatio-temporal scales to quantify the behavior of global fishing fleets, including fleets targeting tuna and tuna-like species, down to the individual vessels (Kroodsman *et al.*, 2018). However, not all of the vessels, both large and small, has AIS and, thus, before using this potential information an analysis of the strengths and weaknesses of the tool by gear and CPCs should be carried out. Similarly, VMS systems have been implemented in ICCAT vessels for since 2003 for all commercial fishing vessels exceeding 20 meters between perpendiculars or 24 meters length overall (Rec. 03-14). But it is mostly a compliance tool and the data belong to the CPCs, so it is not shared for scientific purposes at ICCAT SCRS level (at least on a region wide scale). In fact, VMS has actually been implemented for much longer than AIS and could also be very useful for monitoring the spatio-temporal dynamics of fishing fleets.

Recommendation for indicator development

- Develop a CATDIS (Catch distribution) and EFFDIS (effort distribution) for all ICCAT species, gears and countries.
- Determine the best unit of effort for all gears including PS FAD and free school fishery.

- Develop a complete Task II database raised to total catch by gear/country.
- Develop a complete database for active ICCAT vessels and its characteristics.
- Explore the utility of AIS and VMS to monitor the spatio-temporal dynamics of ICCAT fishing fleets.

Relevance and implications for management

(a) How is the Commission addressing the risk now?

- It has developed, and maintains, the CATDIS and EFFDIS database with estimations of total catches and total effort of longliners and purse seiners on different time and area strata, but it remains incomplete.
- In 2014 it started to monitor the number of active vessels (and its main characteristics) operating in the Atlantic Ocean.

(b) What other actions might the Commission put in place to address and mitigate the risk?

- Improve compliance with Task I and II submission.
- Continue updating and improving the CATDIS and EFFDIS databases by improving the estimations as well as the spatio-temporal resolutions of these estimates for all ICCAT species and major gears.
- Continue updating the database of active vessels with the associated fishing-vessels attributes.
- Request countries to make available VMS data for SCRS and scientific use.
- Explore the AIS and VMS data to estimate indicators and monitor fishing activity at finer spatio-temporal scales in ICCAT fisheries.

5.4.2 Impacts of marine debris produced by fisheries on species and the structure and function of marine ecosystems

Description

Abandoned, lost and discarded fishing gear, here referred as marine debris, can cause ecological problems for marine species when floating gears continue catching and killing organisms (known as ghost fishing). It can also have an impact on sensitive habitats when stranded offshore as well as cause socio-economic problems for the fishing fleets by increasing costs when lost unintentionally.

What is the risk of not monitoring this interaction

Not accounting for the mortality due to ghost fishing in population and stock assessment models has the potential to make less effective the harvest strategies of managed species as well as affect the state of the most vulnerable species such as sea turtles, marine mammals, seabirds and some sharks and bony fishes (Coggins *et al.*, 2007; Gilman *et al.*, 2013). Accumulation of marine debris produced by fisheries along the coast can also impacts the health of coastal ecosystems and their utilizations by coastal communities.

Management objectives

-Eliminate or reduce marine debris produced by fisheries

-Collect marine debris stranded onshore

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are potentially available	Indicators currently not monitored in ICCAT for which data are not available
• FAD losses	• Number of drifting FADs lost outside fishing grounds • Number of FADs/GPS buoys stranded on the coast	

Data sources, data gaps and research needs

ICCAT does not hold a database with the number of drifting FADs lost outside fishing grounds or number of FAD/GPS buoys stranded on the coast for the different gears and fleets operation in the Tropical Ecoregion. Instead, individual CPCs might have access to this type of information for their individual fleets, as show but the EU French purse seine fleet operating in the ecoregion (Maufroy *et al.*, 2015; Zudaire *et al.*, 2018). More large-scale examinations of the spatio-temporal patterns of drifting FADs deployed by the different purse seine fleets operating in the ecoregion will be crucial to understand the cumulative effects and impacts of drifting FADs-GPS lost on the pelagic environment. It would be more challenging to examine the spatio-temporal patters of gear abandon, lost or discarded by longliners in the Ecoregion.

Recommendation for indicator development

- Calculate the number of purse seine FAD lost and recovered for major fleets.
- Calculate the number of FAD beaching events for major fleets.
- Calculate the number of lost gear events for major fleets.

Relevance and implications for management

(a) How is the Commission addressing the risk now?

- It does not monitor or maintain a database with the extent and magnitude of marine debris produced by ICCAT fisheries, however, it has a requirement to mark fishing gear to identify ownership (Recommendation 03-12[54]), and the purse seine FAD management plans need to include information on FAD marking and identifiers as well as FAD losses (Recommendation 17-01[55]) (Gilman, 2015) .
- Some CPCs have their own agreements and protocols to monitor and control lost, abandoned and discarded fishing gear (Gilman, 2015).
- Resolution 17-01 request CPCs to undertake research to gradually replace existing FADs with fully biodegradable and non-entangling FADs, with a view to phase out non-biodegradable FADs to reduce their contributions to marine debris and reduce mortality of entangling marine life.

(b) What other actions might the Commission put in place to address and mitigate the risk?

- Encourage all CPCs to establish protocols for data collection and monitoring for the lost fishing gear of its fleets and report to ICCAT to facilitate the quantification of cumulative effects across all gears and fleets.
- Promote preventive measures such as the use of technology to track gear position for their retrieval and reduce the incidence of gear loss.
- Implement measures to reduce the abandonment and discarding of fishing gear at sea
- Establish port reception facilities for recycling unwanted gears.

5.5 Fishing effects on retained fish species

This broad interaction aims to monitor the impacts of fishing on the fish species retained by ICCAT fisheries. Each fleet preferentially targets a species or set of species but also catches incidentally other fish species that may be retained because of their commercial value (Figure 15-19). ICCAT fisheries retain a large number of fish species, including the

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[54] Recommendation by ICCAT Concerning the Duties of Contracting Parties and Cooperating Non-contracting Parties, Entities or Fishing Entities in Relation to Their Vessels Fishing in the ICCAT Convention Area

[55] Recommendation by ICCAT on a Multi-Annual Conservation and Management Program for Bigeye and Yellowfin Tunas

main commercial tunas, billfishes, small tunas and other bony fishes, and some sharks. However, it is important to distinguish between those fish species that are part of ICCAT convention mandate, for which ICCAT has responsibility to assess and manage them to ensure their sustainable use and conservation, from those species that are not covered by ICCAT convention mandate. Those species not formally included in the Convention mandate, ICCAT has still the responsibility, at least, to monitor the interaction of its fisheries on those fish species.

This ecosystem plan addresses the impacts of fishing effects interactions on retained and assessed fish species (interaction 5.5.1), and retained but not assessed fish species (interaction 5.5.2). Last, it also addresses the interactions between two different fisheries competing for the same targeted and retained species (interaction 5.5.3).

5.5.1 Impacts of fisheries on retained and assessed fish species

Description

This interaction is the most monitored in ICCAT of all as ICCAT was created to ensure the sustainable use of tuna and tuna like species. ICCAT has the responsibility to assess on principle the state of 28 species, of which 23 are found in the Tropical Ecoregion (Table 1). Those species are targeted by multiple fisheries and fleets (see conceptual model figures in section 4) and to date, ICCAT has conducted fishery stock assessments for all the principal market tuna species (5 species, 9 stocks), for 4 (7 stocks) of the 6 billfish species, and for the 2 shark species (7 stocks). For these species and stocks, for which fisheries stock assessment are available, there are a number of indicators that are routinely produced to monitored and track the state of the species in response to fishing.

What is the risk of not monitoring this interaction

Not monitoring the impacts of fisheries on target species can lead to overfishing of the stocks which can drive stocks bellow acceptable levels of productivity and risk (overfished and/or overfishing status), followed by depletion and collapses if overfishing is not addressed.

Management objectives

- Keep ICCAT species not overfished and ensure overfishing is not occurring

-Rebuild overfished ICCAT species

Candidate indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are potentially available	Indicators currently not monitored in ICCAT for which data are not readily available
• Single species total or spawning stock biomass relative to a reference level (e.g. Bmsy, SSBmsy or proxies) • Single species fishing mortality relative to a reference level (e.g. Fmsy or proxies) • Single species size based indicators (e.g., mean length, 95th percentile of the length distribution, proportion of fish larger than the mean size of first sexual maturation) • Single species age-based indicators • Single species relative indices of abundance (e.g., standardized CPUEs) • Ichthyoplankton abundance indices (for bluefin tuna)	• Fish condition (length-weight residuals) for main commercial species • Distributional range (including extent, center of gravity, pattern within range at different depths, and pattern along environmental gradients) • Species size at first sexual maturation and whether it changes over time • Sex ratio	• Population genetic structure • Ichthyoplankton abundance indices (for other species other than bluefin)

Data sources, data gaps and research needs

The majority of the indicators proposed are routinely estimated and monitored for some ICCAT species assessed (e.g. blue fin tuna) as part of the stock assessment evaluations. For some species such as bluefin tuna, a larger number of indicators are routinely produced including indicators of single species spawning stock biomass, fishing mortality rates, as well as a myriad of size and age based indicators that are usually estimated by fleet, combination of fleets or area. Other ICCAT species are assessed with much simpler stock assessment models, and therefore a smaller set of indicators are routinely produced. For the Eastern Atlantic bluefin tuna, ichthyoplankton abundance indices have also been recently started to be estimated and monitored seeking for alternative indices of abundance using aerial surveys, yet its high cost stops from being done for other tuna species.

On top of the most widely used indicators aforementioned, there are also multiple indicators to monitor the impacts of multiple fisheries on fish stocks that can be estimated based on the datasets hold by ICCAT (mainly the Task I and Task II datasets) and datasets collected by National observer programs not administered by ICCAT. For example, monitoring the distributional range of species by measuring changes in the extent and center or gravity in their distributions, and their longitudinal and latitudinal trends can provide information about the impacts of fishing on these species, as well as their responses to climate change. Changing distribution in major tuna and tuna-like species distributions can alter biological relationships between species at local scales. Furthermore, fish condition, measured for example as the residuals of the length weight relationship, can be used as an indicator of somatic growth in fishes. This indicator monitors the weight of the fish per unit of body length, when the residuals are positive indicates that fish are in better condition, while when negative indicate poorer conditions. The condition of fish might be altered by fishing pressures or also environmental effects as well as density dependent effects. This indicator does not only monitor the condition of individual stocks, but when combined across stocks, it can provide information about the ecosystem productivity. This indicator could be potentially estimated with the data sets obtained by the National observer programs. Last, monitoring species size at first sexual maturation overtime, or their sex ratio, and their genetic population structure can also provide information about the fishing pressure upon specie. High fishing pressures shifts populations towards younger, smaller and more quickly maturing individuals, which ultimately can reduce the resilience of fishes to ecosystem changes and environmental variations. Yet the data needed to estimate and monitor these indicators are not regularly collected in ICCAT.

Recommendation for indicator development

- Fish condition and maturity measures over time.
- Age and length structure of the populations.
- Fishery independent abundance estimates (for example, using biomass information from FAD buoys, close-kin abundance estimates for small size populations, etc.).
- Joint CPUEs for multiple fleets to improve the fishery dependent abundance indices.
- Changes in the distributional range of species which might result from fishing or climate change responses.

Relevance and implications for management

(a) How is the commission addressing the risk now?

- It has conducted fishery stock assessments for all principal market tunas, and majority of billfishes and some shark species for which population status is monitored with a range of biomass, size and age-based indicators.

- It is testing the usefulness of survey-based indicators as an alternative indicator of abundance independent to fisheries.

(b) *What other actions might the Commission put in place to address and mitigate the risk?*

- Conduct fishery stock assessments using data-poor assessment methods or indicator-based analysis for the rest of species in the ICCAT list
- Continue improving the data reporting and compliance of Task I and II which currently forms the basis for all stock assessments conducted in ICCAT.
- Research the potential of the data collected by National observer programs to support indicator development.
- Research the feasibility to obtain fishery independent biomass abundance indices.

5.5.2 Impacts of fisheries on retained and non- assessed fish species

Description

There is a large number of fish species which are retained by ICCAT fisheries that are not currently assessed in ICCAT and therefore their status is unknown. However, it is important to distinguish those that are considered ICCAT species, for which ICCAT is responsible to assess and manage them (Table 1), and those species which are not under the formal adopted ICCAT species list but still interact with ICCAT fisheries. Those species not formally included in the Convention mandate, ICCAT has still the responsibility, at least, to monitor the interaction of its fisheries on those fish species, and minimize its impacts. For those non-assessed species, ecological risk assessments (ERA) are crucial to identify species most vulnerable to fisheries which allows to focus resources on a few set of species for monitoring purposes.

A larger number of bony fishes (other than principal market tunas and billfishes) and sharks are known to interact and are retained by ICCAT fisheries (Mejuto *et al.*, 2009; Amandé *et al.*, 2010; Coelho *et al.*, 2012). ERA for teleost fishes (other than the principal market tunas and billfishes) caught by longline and purse seine fisheries in the Atlantic Ocean revealed that the top three fish species most at risk in the Atlantic ocean and that should have priority assessments were Little tunny *Euthynnus alleteratus*, Wahoo *A. solandri*, and King mackerel *Scomberomorus cavalla (Lucena Frédou et al., 2016)*. Of these species, *E. alleteratus* and *A. solandi* is found in the Tropical Ecoregion. A similar ERA of sharks to longline fisheries showed that the bigeye thresher, longfin and shortfin mako and porbeagle sharks were the most vulnerable species to longline fisheries. Of those species, longfin mako is the one species that can still be retained in

ICCAT fisheries and has not yet been assessed in ICCAT (Cortés *et al.*, 2018). There are no assessment for ray species. Rays are not retained in longline and purse seine fisheires. The most encountered species is the pelagic stingray *Pteroplatritygon violácea.*

What is the risk of not monitoring this interaction

The abundance of species most vulnerable to ICCAT fisheries, those being highly susceptible to being caught by ICCAT fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Monitor and prevent overfishing of ICCAT fish species (retained but not assessed) most at risk.

-Monitor, minimize and reduce the impact of fishing on non-ICCAT fish species.

Candidate Indicators to evaluate whether objectives are met

Priority species to develop the indicators:

Bony fish – Little tunny (Euthynnus *alleteratus)* and wahoo (*Acanthocybium solandi)* for longline and purse seine fleets. Unknown species for gillnets.

Sharks – Longfin mako for longline fleets. No sharks are retained in purse fisheries. Unknown species for gillnets, noting that most species, including sharks, are still likely retained in those more coastal fisheries.

Rays – Rays are not retained in longliners. Rays are not retained in purse seiners. Unknown species for gillnets, noting that most species, including sharks and rays, are still likely retained in those more coastal fisheries.

Indicators which are currently monitored in ICCAT	**Indicators currently not monitored in ICCAT for which data are available**	**Indicators currently not monitored in ICCAT for which data are not available**
• Total catches of retained and non-assessed ICCAT species • Single species catch and catch rate indicators* • Single species size based indicators (mean length, 95th percentile of the length distribution, proportion of fish larger than the mean size of first sexual maturation) *	• Number of retained and non-assessed species interacting with ICCAT fisheries • Total catches of retained and non-assessed species interacting with ICCAT fisheries • Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) • Fish condition (length-weight residuals) for main commercial species	• Species size at first sexual maturation

*while these indicators have been estimated for some of the sharks and small tuna species they are not necessarily updated regularly and monitored closely by ICCAT.

Data sources, data gaps and research needs

In order to monitor this interaction successfully, first the number of species interacting with ICCAT fisheries needs to be revised by the SUBECO on ecosystems since this list is not well-defined. ICCAT secretariat has created a list with all fish species interacting with ICCAT fisheries based on the catch data reporting of the CPCs. This list includes species under the ICCAT Convention Mandate (Table 1) but also other fish species caught by ICCAT fisheries not included in the Convention Mandate. In its current form it has an unreliable list of species that cannot be used to inform ecosystem indicators. The ICCAT

SUBECO has noticed that this list needs to be revised because (1) it has errors in the species names (e.g. some species not found in the Atlantic Ocean), (2) there have been changes in the taxonomic classifications of the species, (3) some species interact very rarely with ICCAT fisheries, which does not justify its monitoring. The ICCAT SUBECO has recommended to revise this list and produce a coherent and consistent list of retained species for monitoring purposes based on an established criterion.

There is little information available to determine the stock structure and to carry quantitative assessments of stock status for the small tunas and Spanish mackerels under the ICCAT mandate. Total catches derived from Task I for the non-assessed fish species remains underreported which limits its utilization for developing catch-based indicators. Similarly, the catch and effort and size-based data (Task II) reported by CPCs to the Secretariat for these species also remains patchy and fragmented temporally and spatially for most species. Furthermore, the underreporting of catches of most species would potentially also limit the development of distributional range indicators based on catches. Therefore, the potential uses of task I and II datasets for indicator development will need to be researched for each species individually, specially if those indicators would be monitored spatially. For the rest of bony fishes interacting with ICCAT fisheries not covered in the ICCAT mandate, there is virtual no data hold in the Secretariat to estimate any type of indicators.

The monitoring of the retained but not-assessed species relies on the data collected by the different National observer programs. Size and weight data collected from observer programs potentially could be used to develop size-based indicators as well as fish condition indicators. Monitoring the size at which species matured and its inter-annual variability as well as their potential response to fishing pressure might be difficult at this stage since these data is not being currently collected for this purpose.

Recommendation for indicator development

- Focus on developing indicators for those species covered in the ICCAT convention mandate.
- Identify and monitor those species most vulnerable to specific ICCAT fisheries.
- Explore the potential of using data derived from the National observer programs to develop size based and distributional range indicators.
- Explore the use of data poor limited stock assessment model to monitor the status of these species.

Relevance and implications for management

(a) How is the commission addressing the risk now?

- It is focusing on developing indicators for those species covered in the ICCAT convention mandate but progress has been slow due to quality and availability of catch, effort and size data.
- It has conducted a series of ecological risk assessments to identify species of bony fish, sharks and rays most-vulnerable and at risk from longline and purse fisheries.

(b) *What other actions might the Commission put in place to address and mitigate the risk?*

- ICCAT should produce a coherent and consistent revised list of retained fish species that interact with ICCAT fisheries for monitoring purposes.
- In addition to monitoring those species covered in the ICCAT convention mandate, it should also monitor closely those bony fish, sharks and ray species most vulnerable to longline and purse fisheries identified in the ecological risk assessment.
- Urge CPCs to provide accurate statists, including catches (and discards dead and alive) as well as catch and effort and size data from all ICCAT fisheries (including artisanal and recreational fisheries).
- Conduct an ecological risk assessment to identify those bony fish, shark and ray species most vulnerable to gillnet fisheries.

5.5.3 Impacts of one fishery on another fishery by exploiting the same pool of species (multispecies tropical tuna complex)

Description

It is well known that most of the catch of bigeye and yellowfin tuna catches in purse seiners setting on FADs consists mostly of juvenile individuals. Purse seiners using FADs target mainly mature skipjack tuna, which implies that the stock can be fished at higher levels without large impacts on future spawning potential. Yet, juveniles of yellowfin and bigeye tuna tend to aggregate on these surface gear making them more susceptible to be caught. The same occurs in the baitboat fishery where the yellowfin and bigeye tuna caught are immature. This implies that the fishing pressure on yellowfin and bigeye tuna can result on important impacts on future spawning potential. The catch of bigeye and yellowfin tunas in purse seiners setting on free schools consists primarily of mature individuals. Longline fisheries mostly catches adult yellowfin and bigeye tunas.

What is the risk of not monitoring this interaction

There are potential conflicts between longline fisheries and baitboat/purse fisheries if clear objectives and allocations are not established between major fishing gears. The high fishing pressure by purse seine setting on FADs and bait boat on small and juveniles of yellowfin and bigeye tuna can result on impacts on future spawning potential of these species. This is having an impact on the status of yellowfin and bigeye tuna species, by reducing potential yield and stock size (Dagorn, 2011). The loss in potential yield happens when the mix of fishing gears tend to select individuals that are below the age/size that maximizes the yield per recruit. Since baitboat and purse seiners are targeting tunas mostly below the age size that maximizes the yield per recruit, it is increasing this loss of potential yield. Furthermore, any amount of fishing on a population will reduce the stock size, what it is important is to maintain the spawning stock biomass above the size that would be able to produce the maximum sustainable yield. Both the catch of juveniles and adults reduces spawning stock biomass and catching juvenile tunas does not necessarily lead to overfishing (Dagorn, 2011).

While the multifishery nature in ICCAT fisheries is partially accounted in the single species stock assessment and resulting management advice, there is not a multispecies assessment approach to fully understand the consequences of undertaking specific management to simultaneously harvest MSY for the three tropical species.

Management objectives

-Maintain all tropical tuna stocks not overfished and ensure overfishing is not occurring (e.g. green quadrant of the Kobe plot).

-Prevent overfishing of all tropical tuna stocks.

-Rebuild overfished tropical tuna stocks.

-Define clear objectives and allocations between major fishing gears.

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are potentially available	Indicators currently not monitored in ICCAT for which data are not available
• Length based indicators for species caught by different fisheries and fleets • Total catches of species by different fisheries and fleets • CPUEs of species by different fisheries and fleets • Multispecies B/Bmsy and F/Fmsy	• The loss of potential yield in bigeye and yellowfin	

Data sources, data gaps and research needs

The Commission conducts regularly single species assessment for each tropical tuna species and monitors closely a myriad of catch-based and size-based indicators for the tropical species complex for the different fisheries and fleets. It has not conducted yet multispecies stock assessments for the tropical tuna complex, as well as developed management strategies to understand the consequences of undertaking specific management to simultaneously harvest MSY for the three tropical species. However, a multi-species MSE for the tropical tuna species complex has currently started to be developed by the SCRS, and is planned to provide initial results by 2021. The loss of potential yield in bigeye and yellowfin is currently being assessed to inform the management of these species (ICCAT, 2018) to understand the consequences of simultaneously harvesting MSY for the three tropical species.

Recommendation for indicator development

- Length-based indicators by different fisheries and fleets.
- Multispecies MSY indicators.
- Multispecies target and reference points.

Relevance and implications for management

(a) How is the commission addressing the risk now?

- Conducts a single species assessment for each tropical tuna species, and monitors catch-based and size-based indicators for each fishery and fleet for each tropical tuna species.

- A multi-species MSE for the tropical tuna complex has been requested by the Commission and has started to be developed by the SCRS.
- Considering the relative contribution of different gears in the recovery and management of tropical species (bigeye and yellowfin tunas).

(b) *What other actions might the Commission put in place to address and mitigate the risk?*

- Formulate multispecies management objectives.
- Conduct multispecies stock assessments for the tropical tuna complex, as well as develop management strategies to understand the consequences of undertaking specific management to simultaneously harvest MSY for the three tropical species (ICCAT 2017, 2018).
- Alternatively, develop management strategies for the tropical tuna complex based on the most vulnerable species or any other indicator for the tropical tuna complex
- Support research and adopt management regulation to reduce the bycatch of juvenile tunas, particularly bigeye tuna.

5.6 Fishing effects on non-retained vulnerable (fish and non-fish) species

Multiple species interact and are caught by ICCAT fisheries that are not retained and are discarded (bony fish, sharks) or release (sea turtles, seabirds, marine mammals) for several reasons. One reason because of their low commercial value (some bony fish, sharks and rays) or because there are non-retention measures in place by ICCAT (some sharks, sea turtles, seabirds, marine mammals). ICCAT fisheries operating in the Tropical Ecoregion are diverse (mainly surface setting longliners, deep setting longliners, purse seiners setting on free schools, purse seiners setting on FADs and baitboats) (section 3.1.1) and are known to interact, catch and subsequently discard a large number of species across a wide range of taxonomic groups (Bony fishes, sharks , rays, sea turtles, marine mammals and seabirds) (sections 3.3.2).Driven by the different types of fisheries (purse seiners, longliners and baitboats) and different fishing strategies within the same gear (e.g. deep vs surface longliners) targeting different species and therefore having a distinct impact on species and the marine ecosystem, this ecosystem plan addresses the impacts of fishing effects on non-retained vulnerable species for each type of fleet separately.

5.6.1 Impacts of longliners (shallow and deep setting longliners) on vulnerable taxa

Description

In order to monitor and reduce the impacts of longline fisheries on vulnerable taxa, setting both on shallow or deep waters, it is important to distinguish between interactions and mortality rates. Some fisheries employ post-capture mitigation measures as they attempt to decrease the mortality rates of the species (Clarke *et al.*, 2014). Longline fisheries interact with a wide range of taxa that are non-retained (i.e., discarded) and released back into the sea dead or alive (bony fish, sharks, rays, sea turtles and marine mammals). In general terms, the cumulative magnitude and regional extent of the longline interaction (across all the fleets) with the different taxa (bony fish, sharks, rays, sea turtles and marine mammals) and post-mortalities is poorly known. There are some exemptions since some national fleets monitor and report their level of interactions with vulnerable taxa (see section 3), yet the spatial and temporal scale of the reporting remains poor and the observer coverage used for the reporting also remains low. We tried to differentiate between the impacts of deep setting longliners and surface longliners on the different taxa, since these fleets target different species at different depths and therefore it is expected they might have different impact on the type of vulnerable taxa, extent of interacting and mortality rates. Yet, it was not possible to assess the differential impact of both fishing strategies for most taxa groups because data is not disaggregated to the type of longline. Therefore, the impacts of both types of longline fisheries were combined, even though, and when available, specific details on those differential impacts are provided.

There are few studies identifying those taxa and species most vulnerable to be caught by longline gears using ecological risk assessments, which allows focusing resources on a few set of species for monitoring purposes. The impacts of longline fisheries on seabirds in the Tropical Ecoregion is negligible (Gilman, 2011). An ecological risk assessment of sharks to longline fisheries revealed that the bigeye thresher was the most vulnerable species (and non-retained) to longline fisheries and highly susceptible to be caught by both deep and surface longline gears (Cortés *et al.*, 2015). Furthermore, bigeye thresher had the lowest productivity of all shark species, as well as ranked among the highest susceptible to longline gear. Ecological risk assessment of sea turtles to longline and purse seine fisheries showed longline fishing poses greater threat to turtles than purse seiners (Angel *et al.*, 2014). The olive ridley, leatherback and hawksbill are the most vulnerable turtle species to both gear types, longliners and purse seiners in the Tropical

Ecoregion. A recent meta-analysis of longline bycatch rates estimated the total number of sea turtles interactions (all species combined) with pelagic longline gear in the ICCAT convention area showed a high number of interactions of the olive ridley, green turtle and leatherback interacting with longline fisheries in the Tropical Ecoregion and suggested this area was a hotspot area for these three species (McKee Gray & Diaz, 2017). With regards to sea-turtles, it is important to note that the rate of interactions is higher in shallow setting longlines compared to deep setting. On the other hand, the mortality rates are higher in deep setting longlines as, contrary to shallow longlines, in deep sets the captured turtles do not have access to the sea surface for breathing. It has not been possible to compute an ecological risk assessment for mammals to longline fisheries (or purse seiners) because it has not been possible to estimate the susceptibility scores for any of the marine mammals (Arrizabalaga *et al.*, 2011). Still there is evidence that the number of species of marine mammals interacting with longliners is lower than with other gears (purse seine and gillnets). Further, some interactions with longlines refer to sighting and/or depredation events, where the marine mammals are not actually captured by the fishing gear but interact with the gear and often prey (depredate) the catch. The magnitude and regional extent of these mammal interactions with the different gears and post-mortalities is poorly known.

What is the risk of not monitoring this interaction

The abundance of species most vulnerable to ICCAT fisheries, those being highly susceptible to being caught by ICCAT fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Minimize and reduce the number of interactions of fishing on non- retained vulnerable species

-Increase the post-release survival of non-retained vulnerable species

-Monitor and prevent overfishing of non- retained vulnerable species

-Protect species most at risk

Candidate Indicators to evaluate whether objectives are met

Priority species to develop the indicators:

Bony fish – There are not non-retention measures in place for any species

Sharks – Bigeye thresher (*Alopias superciliosus),* oceanic whitetip (*Carcharhinus longimanus*), hammerheads (*Sphyrna* genus, noting that the species that interacts more with highs seas oceanic longlines is the smooth hammerhead - *Sphyrna zygaena*)

Rays - Interactions of Manta and devil rays with oceanic longlines are limited. The pelagic stingray has the largest number of interactions, and it is usually discarded due to low commercial value.

Sea turtles - The olive ridley (*Lepidochelys olivacea)*, leatherback (*Dermochelys coriacea),* green (*Chelonia mydas)* and hawksbill (*Eretmochelys imbricata)* turtles.

Marine mammals – Extent of interactions and most vulnerable species unknown. Three species are known to interact with longlines. Ecological risk assessment has not been conducted.

Seabirds – Negligible impacts on seabirds

Indicators which are currently estimated and/or monitored in ICCAT	**Indicators currently not monitored in ICCAT for which data are potentially available**	**Indicators currently not monitored in ICCAT for which data are not available**
• Number of interactions for some fleets with limited spatial and temporal coverage • Number of bycatch vulnerable species release dead and alive for some fleets with limited spatial and temporal coverage • Post release mortality for some species and fleets	• Bycatch per unit effort, including standardization to serve as proxies of abundance levels • Frequency of bycatch or total number of interactions of bycatch species across all fleets • Discard survival of bycatch species (total number of individuals release dead and alive per fleet) • For fish and sharks -single species size based indicators (mean length, 95th percentile of the length distribution, proportion of fish larger than the mean size of first sexual maturation) • For fish and sharks - distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) • For fish and sharks -Single	• Population level mortality of bycatch species • Population genetic structure • For sea turtles, marine mammals - Biomass/abundance of species • For sea turtles, marine mammals -Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients)

	species biomass/abundance/catch rate indicators • For fish and sharks -Single species catch	

Data sources, data gaps and research needs

The most important indicators are bycatch rates (i.e. number of individuals caught per a given unit effort, for example sea turtles per 1000 hooks set for longline fisheries) and total number of individuals captured per fleet and it important that both of these indicators should be used together as an overall indicator to monitor bycatch trends over time. Then, it would be important to scale those values to the actual mortality rates, including both at-vessel and post-release mortality rates. Changes in the abundance of a population might also affect the bycatch rates by increasing them (if population increasing) or decreasing them (if population decreasing). The estimation of these indicators depends on the observer data collected in the National observer programs of each CPC, and while some CPCs collect and report these measures to ICCAT, the majority do not collect and/or report it, and if reported, the spatial and temporal extent of the data is too fragmented and too coarse to compute reliable indicators that can be used to provide management advise. The post-release mortality for vulnerable taxa after being caught by longliners is poorly known even for individual fleets.

Furthermore, while the number of interactions of longliners with vulnerable taxa (and mortality rates) might be monitored and reported to ICCAT by a number of fleets in the Tropical Ecoregion region, it remains poorly understood the total cumulative impacts across all fleets within the Tropical Ecoregion. This hinders any quantitative assessment to determine the impact of longline fisheries on the state of any species. Without concerned collaborative efforts by all CPCs to estimate total interactions and discard rates, as well as to estimate total dead discard rates, based on information collected in the observer programs of their fleets, quantifying total number of interactions and mortality for vulnerable taxa seems unachievable.

The lack of quantitative assessments is in part because these assessments as well as many of the proposed indicators above, rely on data collected by the observer programs and on the level of coverage of these programs. For longliners, while the minimum level of observer coverage is 5%, many countries are not achieving these levels (ICCAT, 2012). The use of electronic monitoring systems to increase the observer coverage in large scale longline fisheries should be further encouraged as well as supporting the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner.

Recommendation for indicator development

- Bycatch rates (total number of interactions per unit effort) as well as bycatch. mortality rates (i.e. number of individuals death per a given unit effort).
- Total number of individuals death per fleet.
- Total number of release alive.
- Post release mortality for different species.

Relevance and implications for management

(a) *How is the Commission addressing the risk now?*

- Contracting Parties have to collect, monitor and report to the Secretariat the level of interactions with vulnerable taxa, yet the reporting is low.
- The minimum level of observer coverage in fleets is 5%, but many countries are not even achieving this level. And even if achieved, many times the data is not properly reported.
- Adoption of mitigation measures to reduce impacts of fisheries and encouraging further research and testing of more efficient mitigation methods to reduce the impacts of fisheries (e.g. use of artificial hook, smart-hooks, painted bait, etc.).

(b) *What other actions might the Commission put in place to address and mitigate the risk?*

- Encourage and fund collaborative efforts undertaken by Contracting Parties to quantify the cumulative impacts including total number of interactions, discard rates and mortality rates of vulnerable taxa based on information collected in the observer programs of their fleets.
- The level of observer coverage in longliners should be increased further and progressively (for example in 2016 a proposal was tabled to increase it to 20%) to improve the reliability of the data collected in these programs (ICCAT, 2018).
- Encourage the use of electronic monitoring systems to increase the observer coverage and the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner(ICCAT, 2018).
- Require the monitoring of the number of interactions with marine mammals in the ST09forms.
- Conduct ecological risk assessments for marine mammals.

- Explore the utility of the data collected from observer programs to estimate alternative indicators such as the distributional range of the species.

5.6.2 Impact of purse seine associated to free schools on vulnerable taxa

Description

In order to monitor and reduce the impacts of purse fisheries associated to free schools on vulnerable taxa, it is important to distinguish between interactions and mortality rates. Some purse seine fisheries employ post-capture mitigation measures as they attempt to decrease the mortality rates of the species (Hall & Roman, 2013). Purse fisheries setting on free schools interact with a wide range of taxa that is non-retained which is discarded or release back into the sea dead or alive (bony fish, sharks, rays, sea turtles and marine mammals) (Amande´ *et al.*, 2010). On general terms the cumulative magnitude and regional extent of purse seine interaction (across all the fleets) with the different taxa (bony fish, sharks, rays, sea turtles and marine mammals) and post-mortalities is poorly known. There are some exceptions since some national fleets monitor and report their level of interactions with vulnerable taxa (see section 3). In some fleets, the observer coverage is 100% and therefore the spatial and temporal scale of the reporting is of good quality.

Purse seiners poses negligible threats to turtles relative to longlines, however they are still captured in purse seiners setting on free schools (Amande´ *et al.*, 2010; Bourjea *et al.*, 2014). While the total number of sea turtles interactions with purse seine gear have not been estimated and it is not known in the ICCAT convention area, the number of interactions and bycatch rates of sea turtles of purse seiners is known for some fleets (Amande´ *et al.*, 2010; Bourjea *et al.*, 2014). The EU purse seine fishery, which operates entirely in the Tropical Ecoregion, reported that the leatherback turtle had the largest number of interactions with purse seiners setting on free schools between 2003-2007. For sharks and rays, hammerhead and oceanic white tip sharks and mobula species (*Mobula coilloti, M. mobular and M. birostri*s) are the most frequently species encountered by purse seiners setting on free schools(Amande´ *et al.*, 2010). A more recent study estimated that the European Spanish and France purse seine fishery operating in the Atlantic Ocean incidentally caught annually 218 (standard deviation 150) individuals between 1995 and 2011, with more than 75% release alive (Bourjea *et al.*, 2014). This study also showed that the number of by-caught turtles per observed set is very similar in both purse seine fishing modes, nets setting on free schools and FADs.

Purse seine operations interact with a larger number of marine mammals than longline operations. The presence of this interaction does not imply these species are caught in significant quantities or that individuals die after being caught. However, the magnitude and regional extent of these mammal interactions with the different gears and post-mortalities is poorly known. The EU purse seine tuna fishery operating in the eastern tropical Atlantic has estimated the percentage of cetaceans associated with fishing sets was around 3.6%, where 0.74% of sets had cetaceans encircled (Escalle *et al.*, 2015). This study used captain's logbook information (1980-2011) and observers' data (1995 to 2011). Of the 155 cetaceans encircled in the EU purse seine sets (93 baleen whales, 62 delphinids, 0 sperm whales) between 1995 and 2011, the immediate apparent survival rate was high (92%) (Escalle *et al.*, 2015).

What is the risk of not monitoring this interaction

The abundance of species most vulnerable to ICCAT fisheries, those being highly susceptible to being caught by ICCAT fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Minimize and reduce the number of interactions of fishing on non- retained vulnerable taxa

-Increase the post-release survival of non-retained vulnerable species

-Monitor and prevent overfishing of non- retained vulnerable species

-Protect species most-at-risk

Candidate Indicators to evaluate whether objectives are met

Priority species to develop the indicators:

Bony fish – There are not non-retention measures in place for any species

Sharks – Hammerhead sharks and oceanic whitetip

Rays - Mobula species (Mobula coilloti, M. mobular and M. birostris)

Sea turtles - Leatherback turtle (*Dermochelys coriacea)*

Marine mammals – Priority species unknown. Ecological risk assessments have not been conducted for any gear.

Seabirds – Negligible impacts on seabirds		
Indicators which are currently estimated and/or monitored in ICCAT	**Indicators not currently not monitored in ICCAT for which data are potentially available**	**Indicators not currently monitored in ICCAT for which data are not available**
• Number of interactions for some fleets with limited spatial and temporal coverage • Number of bycatch vulnerable species release dead and alive for some fleets with limited spatial and temporal coverage • Post release mortality for some species and fleets	• Bycatch per unit effort • Frequency of bycatch and total number of interactions of bycatch species • Discard survival of bycatch species (total number of individuals killed per fleet) • Population level mortality of bycatch species • For fish and sharks -Single species size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) • For fish and sharks - Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) • For fish and sharks -Single species biomass/abundance/catch rate indicators • For fish and sharks -Single species catch	• For sea turtles, marine mammals - Biomass/abundance of species • Population genetic structure • For sea turtles, marine mammals -Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients)

Data sources, data gaps and research needs

The catch statistics (Task I and Task II) for the non-retained bony fishes, sharks and rays are of low quality due to the large underreporting by CPCs. The quantity of fish non-retained, and therefore discarded at sea, dead or alive, is generally poorly monitored, as this is poorly or non-reported in logbooks. Yet these data are collected by some fleets via logbooks or as part of the observer programs.

Data collected by the National observers programs still remains the main source of information to develop most of the indicators proposed above. Similar to the measures of impacts derived from longliners, the most important indicators to measure impacts of purse seiners on vulnerable taxa should be bycatch rates (i.e. number of individuals killed per a given unit effort) and total number of individuals killed per fleet and it important that both of these indicators should be used together as an overall indicator to monitor bycatch trends over time.

The estimation of these indicators still depends on the observer data collected in the National observer programs of each CPC. While some CPCs collect and report these measures to ICCAT, the majority do not report it, and if reported, the spatial and temporal extent of the data is too fragmented and too coarse to compute reliable indicators that can be used to provide management advise. There are some exceptions since some national fleets monitor and report their level of interactions with vulnerable taxa (see section 3).

While the minimum level of observer coverage is 5%, some countries are not achieving these levels, while others have 100% observer coverage (ICCAT, 2012). The use of electronic monitoring systems to increase the observer coverage in large scale purse fisheries should be further encouraged as well as supporting the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner (ICCAT, 2018).

Recommendation for indicator development

- Bycatch rates (total number of interactions per unit effort or production of target species) as well as bycatch mortality rates (i.e. number of individuals death per a given unit effort or production of target species).
- Total number of death individuals per fleet.
- Total number of release alive.
- Post release mortality for different species.

Relevance and implications for management

(a) *How is the Commission addressing the risk now?*

- CPCs have to collect, monitor and report to the Secretariat the level of interactions and mortality rates of vulnerable taxa, yet the reporting level is low.
- The minimum level of observer coverage is 5 %, while some countries are not achieving this levels, others have 100 observer coverage.
- Adoption of mitigation measures to reduce impacts of fisheries and encouraging further research and testing of more efficient mitigation methods to reduce the impacts of fisheries.

(b) *What other actions might the Commission put in place to address and mitigate the risk?*

- While it has adopted a measure to prohibit the discards of target tunas in tropical tuna purse seine fisheries, which can help improve the reliability of catch statistics for the main target tunas as well as improve regional food security, the expansion of this measure to other bonyfish species should be investigated.

- Encourage and fund collaborative efforts involving relevant CPCs to quantify the cumulative impacts including total number of interactions, discard rates and mortality rates of vulnerable taxa based on information collected in the observer programs of their fleets.
- The level of observer coverage in industrial purse seiners should be increased progressively to 100% for all year round to improve the reliability of the data collected in these programs.
- Encourage the use of electronic monitoring systems to increase the observer coverage and the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner.
- Require the monitoring of the number of interactions with marine mammals in the ST09forms
- Explore the utility of the data collected from observer programs to estimate alternative indicators such as the distributional range of the species

5.6.3 Impact of purse seine associated to FADs on vulnerable taxa

Description

In order to monitor and reduce the impacts of purse fisheries associated to FADs on vulnerable taxa, it is important to distinguish between interactions and mortality rates. Some purse seine fisheries employ post-capture mitigation measures as they attempt to decrease the mortality rates of the species (Hall & Roman, 2013). Purse fisheries setting on FADs interact with a wide range of taxa that is non-retained which is discarded or released back into the sea dead or alive (bony fish, sharks, rays, sea turtles and marine mammals) (Amande´ *et al.*, 2010). On general terms the cumulative magnitude and regional extent of purse seine interaction (across all the fleets) with the different taxa (bony fish, sharks, rays, sea turtles and marine mammals) and post-mortalities is poorly known. There are some exceptions since some national fleets monitor and report their level of interactions with vulnerable taxa (see section 3.3.3). In some fleets, the observer coverage is 100% and therefore the spatial and temporal scale of the reporting is of good quality.

Purse seiners pose negligible threats to turtles relative to longlines, however they are still captured in purse seiners setting on FADs (Amande´ *et al.*, 2010). While sea turtles are caught in small numbers by purse seiners and they can be release alive relatively easily, if entangle in the FADs and not released they may die (Hall & Roman, 2013). While the total number of sea turtles interactions with purse seine gear have not been estimated and it is not known in the ICCAT convention area, the number of interactions and bycatch rates of sea turtles of purse seiners is known for some fleets (Amande´ *et al.*, 2010). The EU purse seine fishery, which operates entirely in the Tropical Ecoregion, reported that the green and loggerhead turtles had the largest number of interactions with purse seiners setting on FADs between 2003 and 2007. A more recent study estimated that the European Spanish and France purse seine fishery operating in the Atlantic Ocean incidentally caught annually 218 (standard deviation 150) individuals between 1995 and 2011, with more than 75% release alive (Bourjea *et al.*, 2014). This study also showed that the number of by-caught turtles per observed set is very similar in both purse seine fishing modes, nets setting on free schools and FADs. For sharks and rays, the silky shark and the giant manta ray (*Mobula birostris*) was the one with the largest number of interactions with purse seine associated to FADs (Amande´ *et al.*, 2010). The EU purse seine tuna fishery setting on FADs operating in the eastern tropical Atlantic has reported zero interactions with marine mammals (Amande´ *et al.*, 2010). Longline fisheries also interact with marine mammals, but the extent of the interactions is poorly documented. Overall, the magnitude and regional extent of these mammal interactions with the different gears and post-mortalities is poorly known.

What is the risk of not monitoring this interaction

The abundance of species most vulnerable to ICCAT fisheries, those being highly susceptible to being caught by ICCAT fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Minimize and reduce the number of interactions of fishing on non- retained vulnerable taxa

-Increase the post-release survival of non-retained vulnerable species

-Monitor and prevent overfishing of non- retained vulnerable species

-Protect species most-at-risk

Candidate Indicators to evaluate whether objectives are met:

Priority species to develop the indicators:

Bony fish – There are not non-retention measures in place for any species

Sharks – Silky shark (*Carcharhinus falciformis)) and Oceanic whitetip shark*

Rays - Giant manta ray (*Mobula birostris*)

Sea turtles - Green and loggerhead turtles

Marine mammals – Priority species unknown. Ecological risk assessments have not been conducted for any gear.

Seabirds – Negligible impacts on seabirds

Indicators which are currently estimated and/or monitored in ICCAT	**Indicators currently not monitored in ICCAT for which data are potentially available**	**Indicators currently not monitored in ICCAT for which data are not available**
• Number of interactions for some fleets with limited spatial and temporal coverage • Number of bycatch vulnerable species release dead and alive for some fleets with limited spatial and temporal coverage • Post release mortality for some species and fleets	• Bycatch per unit effort • Frequency of bycatch and total number of interactions of bycatch species • Discard survival of bycatch species (total number of individuals killed per fleet) • Population level mortality of bycatch species • For fish and sharks -Single species size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) • For fish and sharks -Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) • For fish and sharks -Single species biomass/abundance/catch rate indicators • For fish and sharks -Single species catch	• For sea turtles, marine mammals -Biomass/abundance of species • Population genetic structure • For sea turtles, marine mammals -Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) •

Data sources, data gaps and research needs

The catch statistics (Task I and Task II) for the non-retained bony fishes, sharks and rays are of low quality due to the large underreporting by CPCs. The quantity of fish non-retained, and therefore discarded at sea, dead or alive, is generally poorly monitored, as this is poorly or non-reported in logbooks. Yet, these data are collected by some fleets via logbooks or as part of the observer programs.

Data collected by the National observers programs still remains the main source of information to develop most of the indicators proposed above. Similar to the measures of impacts derived from longliners, the most important indicators to measure impacts of purse seiners on vulnerable taxa should be bycatch rates (i.e. number of individuals killed per a given unit effort) and total number of individuals killed per fleet and it important that both of these indicators should be used together as an overall indicator to monitor bycatch trends over time.

The estimation of these indicators still depends on the observer data collected in the National observer programs of each CPC, and while some CPCs collect and report these measures to ICCAT, the majority do not report it, and if reported, the spatial and temporal extent of the data is too fragmented and too coarse to compute reliable indicators that can be used to provide management advise. There are some exceptions since some national fleets monitor and report their level of interactions with vulnerable taxa (see section 3).

For purse seiners, while the minimum level of observer coverage is 5%, some countries are not achieving these levels while others have 100% observer coverage (ICCAT, 2012). The use of electronic monitoring systems to increase the observer coverage in large scale purse fisheries should be further encouraged as well as supporting the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner (ICCAT, 2018).

Recommendation for indicator development

- Bycatch rates (total number of interactions per unit effort or production of target species) as well as bycatch mortality rates (i.e. number of individuals death per a given unit effort or production of target species)
- Total number of individuals death per fleet
- Total number of release alive
- Post release mortality for different species

Relevance and implications for management

(a) How is the commission addressing the risk now?

- CPCs have to collect, monitor and report to the Secretariat the level of interactions and mortality rates of vulnerable taxa, yet the reporting level is low.
- The minimum level of observer coverage is 5%, whole some countries are not achieving this levels, others have 100 observer coverage.
- It has a requirement for purse seiners for using non-entangling and biodegradable FADs to minimize impacts on vulnerable taxa.
- It has adopted a measure to prohibit the discards of target tunas in tropical tuna purse seine fisheries (Rec 17-01), which can help improve the reliability of catch statistics for the main target tunas as well as improve regional food security.
- Encourages further research and testing of more efficient mitigation methods to reduce the impacts of fisheries (e.g. shark deterrent measures).

(b) What other actions might the Commission put in place to address and mitigate the risk?

- Ensure requirements for non-entangling and biodegradable FADs are being met by CPCs to reduce impacts on vulnerable taxa.
- While it has adopted a measure to prohibit the discards of target tunas in tropical tuna purse seine fisheries, which can help improve the reliability of catch statistics for the main target tunas and regional food security, the expansion of this measure to other bonyfish species should be investigated.
- Encourage and fund collaborative efforts involving relevant CPCs to quantify the cumulative impacts including total number of interactions, discard rates and mortality rates of vulnerable taxa based on information collected in the observer programs of their fleets
- To make mandatory the progressive increase of observer coverage to 100% including human and EMS for all year round to improve the reliability of the data collected in these programs.
- Encourage the use of electronic monitoring systems to increase the observer coverage and the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner.
- Require the monitoring of the number of interactions with marine mammals in the ST09forms
- Explore the utility of the data collected from observer programs to estimate alternative indicators such as the distributional range of the species

- Test and develop emergent mitigation methods to reduce impacts of fisheries (e.g. shark deterrent measures)

5.6.4 Impact of baitboats on vulnerable taxa and bait species

Description

There are few studies reporting the interactions of baitboats on vulnerable taxa, although the magnitude of the impacts is believed to be low. Cape Verde, Canary, Madeira, Sao Tome y Principe and the Azores islands, Senegal, and other countries have pole and line fisheries.

What is the risk of not monitoring this interaction

Not accounting for the impacts on baitboat fisheries on vulnerable taxa as well as the impact of baitfish use on these fisheries.

Management objectives

-Minimize and reduce the number of interactions of fishing on non- retained vulnerable species.

Candidate Indicators to evaluate whether objectives are met

Priority species to develop the indicators:

Baitfish -Unknown impacts on species

Bony fish – Unknown impacts on species

Sharks – Unknown impacts on species

Sea turtles - Unknown impacts on species

Marine mammals – No impacts

Seabirds – Unknown impacts on species

Indicators which are currently estimated and/or monitored in ICCAT	Indicators not currently not monitored in ICCAT for which data are potentially available	Indicators not currently monitored in ICCAT for which data are not available
	• Bycatch rates and bycatch mortality rates • Total number of individuals release dead • Total number release alive • Post-release mortality of different species • Total number of species used as baits • Total catches/catch rate of baitboat species	

Data sources, data gaps and research needs

CPCs with baitboat fisheries do not report data on the type and quantity of baitboat used in their fisheries. There are not known studies on this topic.

Recommendation for indicator development

- Bycatch rates (total number of interactions per unit effort or production of target species) as well as bycatch mortality rates (i.e. number of individuals death per a given unit effort or production of target species)
- Total number of individuals dead per fleet
- Total number of release alive
- Post release mortality for different species

Relevance and implications for management

(a) *How is the Commission addressing the risk now?*

- The risk is not being addressed in any aspect or form

(b) *What other actions might the Commission put in place to address and mitigate the risk?*

- Monitor the type of species and quantities interacting with baitboat fisheries
- Monitor the type of species and quantities used as baitboat per fleet
- Promote the development of observer programs on these fisheries

5.6.5 Impact of gillnets on vulnerable non-retained taxa

Description

Gillnet fisheries are poorly monitored in the Atlantic Ocean and they might have a large impact on marine ecosystems. The extent of these catches in the Tropical Ecoregion is unknown. Gillnets fisheries interact with a wide range of taxa that are retained and also that are non-retained and therefore are released back into the sea dead or alive (bony fish, sharks, rays, sea turtles and marine mammals). In general terms, the cumulative magnitude and regional extent of the gillnet interactions (across all the fleets) with the different taxa (bony fish, sharks, rays, sea turtles and marine mammals) and post-mortalities is poorly known in the Tropical Ecoregion.

What is the risk of not monitoring this interaction

The abundance of species most vulnerable to ICCAT fisheries, those being highly susceptible to being caught by ICCAT fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Minimize and reduce the number of interactions of fishing on non- retained vulnerable species

-Increase the post-release survival of non-retained vulnerable species

-Monitor and prevent overfishing of non- retained vulnerable species

-Protect species most at risk

Candidate Indicators to evaluate whether objectives are met

Priority species to develop the indicators: **Bony fish –** Unknown impacts on species **Sharks** – Unknown impacts on species **Sea turtles -** Unknown impacts on species **Marine mammals –** Unknown impacts on species **Seabirds –** Unknown impacts on species		
Indicators which are currently estimated and/or monitored in ICCAT	**Indicators currently not monitored in ICCAT for which data are potentially available**	**Indicators currently not monitored in ICCAT for which data are not available**
	• Bycatch per unit effort • Frequency of bycatch and total number of interactions of bycatch species • Discard survival of bycatch species (total number of individuals killed per fleet) • Population level mortality of bycatch species • For fish and sharks -Single species size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) • For fish and sharks - Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) • For fish and sharks -Single species biomass/abundance/catch rate indicators • For fish and sharks -Single species catch	• For sea turtles, marine mammals - Biomass/abundance of species • Population genetic structure • For sea turtles, marine mammals -Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients)

Data sources, data gaps and research needs

CPCs with gillnet fisheries do not report data on the type and quantity of baitboat used in their fisheries. There are not known studies on this topic.

Recommendation for indicator development

- Bycatch rates (total number of interactions per unit effort or production of target species) as well as bycatch mortality rates (i.e. number of individuals death per a given unit effort or production of target species)
- Total number of individuals dead per fleet
- Total number of release alive
- Post release mortality for different species

Relevance and implications for management

(c) How is the Commission addressing the risk now?

- The risk is not being addressed

(d) What other actions might the Commission put in place to address and mitigate the risk?

- Identify relevant fisheries and regions where gillnet fisheries operate
- Monitor the type of species and quantities captured by gillnet per fleet

5.7 Fishing effects on community structure and function, food webs and biodiversity

5.7.1 Impact of total removals on ecosystem components due to fishing and predation mortality

Description

Direct effects of fishing on targeted and bycatch species are well known in the scientific community (see sections 5.5 and 5.6 above about effects on retained and non-retained species). But the potential effects of fishing on the whole ecosystem due to direct and indirect cascading effects have also been recognized (Jennings & Kaiser, 1998). Fishing can affect trophic interactions and could lead to species replacement and shifts in community composition (Stevens, 2000). Since most of the fish species caught by ICCAT fisheries have a high trophic level, any potential change in the status of one of these species might cascade down the food web (Myers *et al.*, 2007), getting different responses from other components. These responses will be different if the ecosystem is top-down, wasp-waist or bottom up controlled (Cury *et al.*, 2003). Properly understanding the ecosystem structure and functioning (directly related to biodiversity - (Strong *et al.*, 2015)) is therefore, key for implementing adequate management measures that would support a sustainable fishing activity in this tropical Atlantic ecoregion. Improving knowledge of the food-web dynamics and identifying key ecosystem components (apex predators usually play that role (Camphuysen, 2006) will also be part of this process.

What is the risk of not monitoring this interaction

By ignoring the indirect effects of fishing we might not correctly assess the magnitude of deterioration of the structure and function of ecosystems. Without knowing the extent of these indirect impacts, we cannot design appropriate measures to fully mitigate against those impacts, affecting the goods and services that societies obtain from marine ecosystems.

Management objectives

-Preserve foodwebs

-Restore ecosystem structure and function

-Maintain biodiversity

-Identify/preserve keystone species

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimate and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are available	Indicators currently not monitored in ICCAT for which data are not available
	• Group spawning stock biomass relative to a reference level (e.g. Bmsy or proxies) • Biomass indicators (total, guild/community) • Proportion of non-declining exploited species • Recovery in the Population Abundance of Sensitive Species • Group Fishing mortality relative to a reference level (e.g. Fmsy or proxies) • Community size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation)(catch based) • Proportion of predatory fish or "Large Species Indicator" (catch data) • Abundance-Biomass Comparison (ABC) curve • Mean Trophic Level Indicators (catch data) • Mean maximum length of community (catch data) • Species diversity indices (Shannon/Simpson/Evenness/Richness) (catch data) for each major gear • Tropicalization index	• Community size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (model based) • Mean Trophic Level Indicators (model derived) • Size spectra (total, by guild/community) (model based) • Mean maximum length of community (model derived) • Species diversity indices (Shannon/Simpson/Evennes s/Richness) (model derived) • Proportion of predatory fish or "Large Species Indicator" (model derived)

Data sources, data gaps and research needs

The effects of fishing on the different ecosystem components in terms of both direct effects on retained and non-retained ICCAT species and indirect effects on other components due to the trophic relationships existing between them, has been very scarcely evaluated in the Tropical Ecoregion. A recent ecosystem model developed by Forrestal (2016) showed a first attempt to analyze the effects of the tuna purse seine fishery on the ecosystem of the Gulf of Guinea, based on a previous work developed in a smaller region of that Gulf (Schultz, 2001; Schultz & Menard, 2003). This work provided some insights about the structure and functioning of this ecosystem showing that it might be less resilient to perturbations, including anthropogenic influences, due to its non-mature ecosystem nature.

However, the ecosystem model by Forrestal is based on a static model, showing a snapshot of the ecosystem in a given time period. In this case the model represented the average condition of the ecosystem from 2003- 2013. But using a time dynamic model or even a spatially-dynamic one would be recommendable to more accurately analyze the effects of fishing on the whole food web, that would, of course, be dependent on the energy fluxes of the system. Diet information is scarce and implementing research programs for analyzing the trophic dynamic of this tropical Atlantic system would be required.

For getting dynamic models both in time and space, and assessing the effect of fishing on top of the existing predation mortality on the different ecosystem components and also on the whole system, historical data for ICCAT databases can be used, both from the catch and the effort databases as well data derived from the single-species fishery stock assessments.

Recommendation for indicator development

- Support studies of fish diet, feeding ecology and food habits to support the development of ecosystem models and better understand trophic interactions and foodweb dynamics in marine ecosystems
- Develop ecosystem/food web models to derive model/based indicators at community and/or ecosystem scale
- Continue improving the reliability of catch and size statistics
- Increase observer's coverage to continue improving the reliability of observer data sets

Relevance and implications for management

(a) How is the Commission addressing the risk now?

- The Commission is not currently addressing, from an integrated perspective, the indirect impacts of fishing on marine food webs, however, at the single-species level, the Commission keeps improving the reliability of catch statistics, an important source of information for integrative approaches. For example, it has banned discards of target tuna in tropical tuna purse seine fisheries in 2017, which will improve the reliability of catch statistics.

(b) What other actions might the Commission put in place to address and mitigate the risk?

- The Commission should promote and support the use of multispecies and ecosystem models for producing both, tactical (short-medium term) and strategical (long-term) advice for management.

- The commission should make use of the existing data collected by the observers' programs, evaluating their potential use for developing ecosystem and/or community scale indicators
- Promote research to increase existing knowledge on ecosystem structure, trophic interactions and biodiversity in order to maintain the species interactions sustaining energy flow in the ecosystem and avoid crossing thresholds that might rapidly move the ecosystem into a new, unknown state.
- When developing an ecosystem-based fisheries management plan, consider apparent ecosystem-level risks and balancing tradeoffs from an understanding of different ecosystem interactions.

5.8 Effects of manageable and non-manageable pressures on habitats of ecological significance

5.8.1 Climate and fishing effects on habitats of ecological significance

Description

Mapping habitats of ecological significance is important for determining the biological and ecological features of communities of special importance and determining areas of high biological value or diversity. Furthermore, knowledge of the spatial extent of the fishing impacts on these habitats is also needed to inform management strategies to minimize and avoid fishing impacts. New technologies such as satellite tracking are showing how highly migratory pelagic species use habitat hotspots as well as how these habitats hotspots overlap with fishing fleets. These technologies can be used to map habitats of special concern and inform ocean-scale spatial and dynamic management of fisheries (Hussey *et al.*, 2015; Dunn *et al.*, 2016; Queiroz *et al.*, 2016). The identification of habitats of special concern for species is also increasingly becoming an essential task to design effective responses to climate change as well as other marine threats (Brierley & Kingsford, 2009; Bell *et al.*, 2013). When this knowledge is available for multiple species, mapping areas of ecological significance for multiple taxa and their degree of overlap can be used to inform cross taxa area-based management. This can be done by allocating the spatial and temporal distribution of fishing activities to minimize their impacts and designing mitigation strategies for climate change.

What is the risk of not monitoring this interaction

Lack of good understanding of habitats of ecological significance can reduce the value of marine spatial planning, since the spatial planning will not be informed by management strategies to minimize and avoid fishing impacts as well as mitigation strategies for climate change.

Management objectives

-Reduce or avoid impacts of fishing on habitats of ecological significance

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in ICCAT	Indicators currently not monitored in ICCAT for which data are potentially available	Indicators currently not monitored in ICCAT for which data are not available
	• Mapping areas of special importance for life history stages of species (e.g. spawning areas, migratory corridors) • Mapping areas for vulnerable, threatened, declining species • Mapping areas of high biological diversity • Mapping habitat suitability of species and changes in habitat suitability due to climate change • Percent overlap of habitat of ecological significance by high fishing pressure • Percent area close to a specific gear	

Data sources, data gaps and research needs

Mapping habitats of ecological importance for species requires knowing their spatio-temporal environmental and habitat preferences. This requires the collection and use of multiple sources of information, from spatial data collected by the fisheries (catch distribution) or on observers program (e.g. species absence/presence and catches, individual samples for reproductive studies) to the collation of physical and biological environmental covariates by the same fishing boats where the observers operate or from external sources that need to be matched to the observer data collection geolocations. At the end, these types of studies will require to make use of the existing data collected by the National observers' programs, and evaluating their potential use for developing habitat-based indicators. It will also be critical to prioritize for what species the habitat mapping should be focused. It is recommended to use new technologies such as satellite tracking to identify how migratory pelagic species use habitat hotspots as well as how these habitats hotspots overlap with fishing fleets, which can be used to map habitats of special concern and to inform ocean-scale spatial and dynamic management of fisheries (Hussey *et al.*, 2015; Dunn *et al.*, 2016; Queiroz *et al.*, 2016).

The data derived from tagging programs also offers an opportunity to identify habitats of special ecological significance. ICCAT has developed an international cooperative tagging program in the Atlantic Ocean and its adjacent seas, and it is involved in several tagging programs (e.g. the Atlantic-wide research program for bluefin tuna -GBYP, Atlantic Ocean Tropical Tuna Tagging - AOTTP). These tagging programs have been mostly designed to increase the understanding on the population dynamics of tunas and their basic life histories including estimates of longevity, growth, and natural mortality, and tuna movements and their interactions with fishing gears (Fonteneau & Hallier, 2015). The data derived from these programs is underutilized to support habitat research. Yet these tagging programs are slowly revealing critical information of seasonal migrations, habitat utilization, breeding migration, migration corridors, hot spots, and physical oceanographic patterns that are important to understand how tunas use the open ocean environment e.g. (Block *et al.*, 2001; Galuardi & Lutcavage, 2012).

Recommendation for indicator development

- Extend the use of the data derived from the National observer programs to identify habitat of ecological significance and encourage cross-taxa studies
- Explore the use of data from tagging programs to identify habitat of ecological significance and expand these programs to include the most vulnerable bycatch species in ICCAT fisheries
- Identify the most vulnerable habitats of ecological significance

Relevance and implications for management

(a) How is the Commission addressing the risk now?

- The Commission has requested through several Recommendations and Resolutions to conduct research to identify habitats of special concern for some species of sharks (Recommendations 04-10, 07-06, 09-07, 10-08, 15-06), tunas (Recommendation 08-04, 14-04) and identify the ecological importance of Sargassum for tuna and tuna-like species (Resolutions 05-11, 12-12), but these management measures do not call for the protection of habitats of special concern for any of the species.
- Research studies on the habitats of ecological significance (e.g. reproduction, migration, feeding, hotspots) and habitat utilization and preferences for some relevant ICCAT species have been presented at and investigated by the SCRS. Yet

their robustness still needs to be evaluated before they can be used to provide management advise to the Commission. The Commission has not formally identified, mapped or protected any habitats of special concern for relevant species.

(b) *What other actions might the Commission put in place to address and mitigate the risk?*

- Define clear operational objectives to address the importance of habitats of ecological significance and habitat utilization.
- Set a habitat research agenda and continue supporting habitat studies and the mapping of habitats of ecological significance for ICCAT species as well as identify a list of priority species (e.g. most vulnerable, threatened species) to focus on.

6 A STRATEGY FOR COMMUNICATION AND PRODUCING ECOSYSTEM ADVICE

6.1 A communication strategy to disseminate the ecosystem plan.

The pilot ecosystem plan needs to be shared and communicated to different audiences including the SUBECO, the SCRS and the Commission. A communication strategy is proposed for sharing the Pilot Ecosystem Plan in a logical and strategic way (Table 3).

Table 3. Proposal of a communication strategy to disseminate the ecosystem plan.

Communication strategy			
Target audience	**Communication method (how & where)**	**Key messages**	**Timing**
Scientists	-Presentation of Plan to the SCRS Subcommittee on Ecosystems (SUBECO)	-Plan needs to be revised by the SUBECO -SUBECO may request additional corrections and tasks	SUBECO MEETING 2019
Scientists	-Presentation of Plan to the annual SCRS Meeting	-Plan needs to be revised by SCRS - SCRS may request additional corrections and tasks -Fit the plan within the current structures of the SCRS	SCRS MEETING 2019
Scientists and managers	-Presentation of Plan to Dialogue Meeting between scientists and managers (SWGSM)	-Plan needs to be revised by SWGSM - SWGSM may request additional corrections and tasks	SWGSM MEETING 2019
*Commission	-Presentation of Plan to the ICCAT annual meeting	-Inform the Commission on the purpose and implications of the plan -Seek a request from the Commission to develop a formal plan	ICCAT 2019

*While we recommend the plan is not presented to the Commission until an ecosystem risk assessment is incorporated into the plan, to rank priorities and action for the Commission, it is critical the Commission requests the development of an ecosystem plan

6.2 A strategy to operationalize an ecosystem approach to fisheries management

Operationalizing an EAFM requires three major steps: ecosystem planning, ecosystem assessments and linking them to fisheries management (Figure 22). This ecosystem plan also proposes a series of steps and how they are connected to better link ecosystem science and fisheries management advice.

Operationalizing the ecosystem approach to fisheries managment: feedback between planning, assessments and the management proces

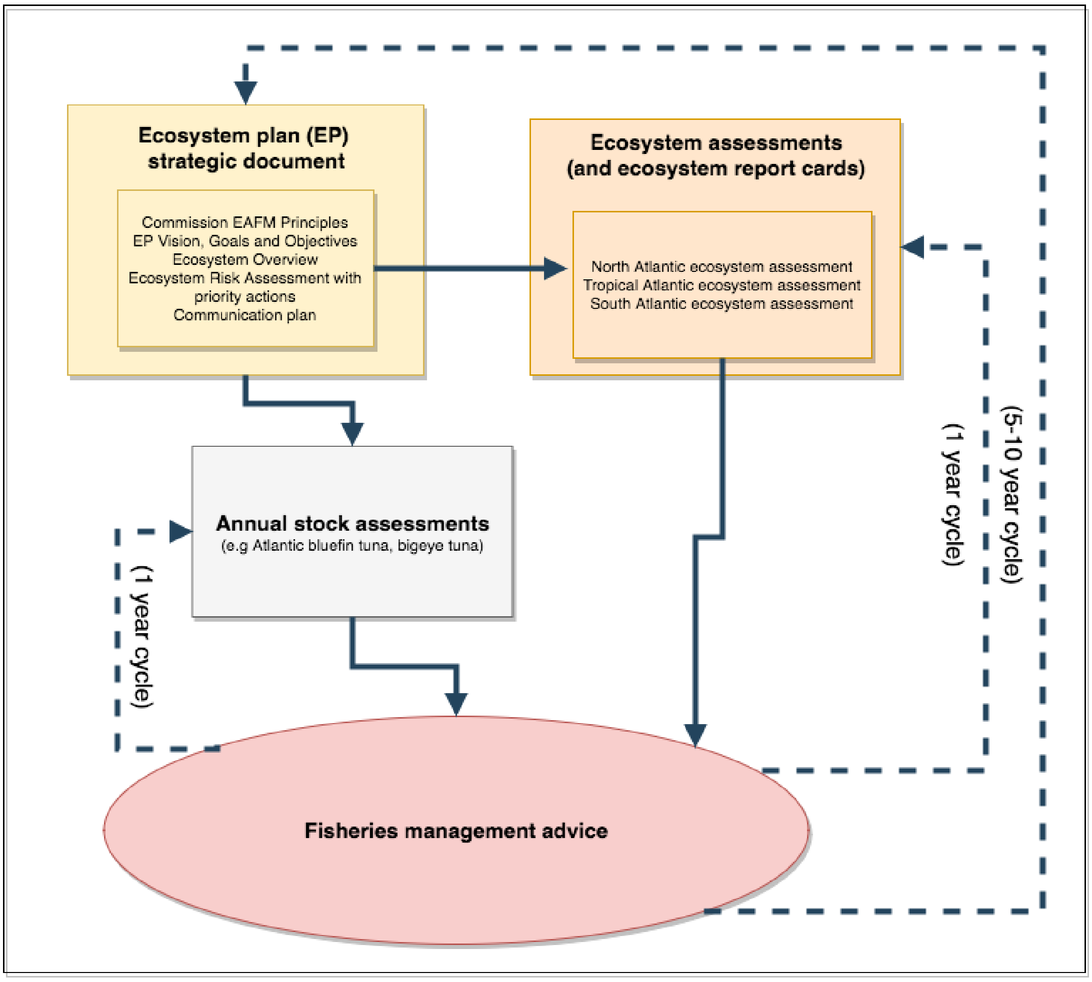

Figure 22. Operationalizing an EAFM requires the feedback between ecosystem planning, ecosystem assessments and fisheries management.

7 RECOMMENDATIONS TO FORMALIZE AN ECOSYSTEM PLAN IN ICCAT

Table 4. Recommendations to formalize the ecosystem plan, including the expected timing and potential milestones.

#	Recommendations/action item	Timing	Milestone
1	The pilot Ecosystem Plans should be presented, discussed and reviewed by the ICCAT Sub-Committee on Ecosystems (SUBECO) and the Standing Committee on Research and Statistics (SCRS) to evaluate its usefulness and promote further steps.	Short-term	Ecosystem plan presented at the ICCAT SUBECO 2019 meeting
2	The regionalization of the ecosystem plan, its potential benefits and drawbacks, need to be further discussed and reviewed by the SUBECO and the SCRS.	Short-term	Ecosystem plan and implications of regionalizing the ecosystem plan presented at the ICCAT SUBECO 2019 meeting
3	Future versions of an ecosystem plan should incorporate an ecosystem risk assessment, which will become a cornerstone of the plans. An ecosystem risk assessment will determine the degree of importance of each of the interactions and issues identified in the pilot ecosystem plans. It will help prioritize the main issues and research actions that need to take place to avoid unwanted risk through appropriate management actions to the Commission.	Short-term	ICCAT requests to the SCRS to develop formal ecosystem risk assessments to be developed as part of the pilot ecosystem plans
4	An EAFM engagement strategy and standardized EAFM road map materials for widespread use should be developed to communicate the importance of ecosystem planning and ecosystem assessments to the Commission.	Short-term	SCRS to develop outreach materials for Commission
5	The ICCAT SUBECO should continue the development of ecosystem assessments (and ecosystem report cards). The on-going assessments in ICCAT can benefit from the current ecosystem plan and vice versa and both efforts should be coordinated. The pilot ecosystem plan identifies and proposes candidate indicators that can inform the current development of ecosystem assessments in ICCAT.	On-going	The ICCAT SUBECO develops the first version of an ecosystem assessment and ecosystem report card to be presented to the Commission
6	ICCAT Commission needs to agree on an ecosystem vision, goals and objectives for the pilot Ecosystem Plan (or any ecosystem plan). The Commission should request to the SCRS to develop a formalized Ecosystem Plan(s).	Medium-term*	ICCAT Commission agrees on vision, goals and objectives for the Ecosystem Plans ICCAT requests to the SCRS to develop a formal ecosystem plan
7	An Ecosystem Plan Team should be created in ICCAT to oversight the development of the ecosystem plan(s) and to provide recommendations and guidance to the SCRS and the Commission.	Medium-term	Ecosystem Plan Team created by the SCRS or SUBECO

8	Future versions of an ecosystem plan should identify how the ecosystem plan interacts with other Commission processes as well as other SC activities and research programs.	Medium-term	Commission requests to the SCRS to develop a formal ecosystem plan
9	Future version of an ecosystem plan should consider including a section on skills and capabilities to support the implementation of the plan, as well as identify continuous financial support to ensure its implementation.	Medium-term	Commission requests to the SCRS to develop a formal ecosystem plan
10	An Ecosystem Plan Coordinator/Analysist at the ICCAT Secretariat would facilitate the development of many of the activities proposed here.	Medium-long	Ecosystem Plan Coordinator/Analysist hired at the ICCAT Secretariat
11	Future versions of an ecosystem plan should consider including the socio-economic and governance aspects of fisheries in the region covered by the plan. Until the socio-economic and governance considerations are addressed properly, an ecosystem plan will only be partially guiding the operationalization of EAFM in the covered region.	Long-term	Socio-economic Working Group created at ICCAT. Short term consultancy acquired to develop a strategy to develop the socio-economic components of an ecosystem plan. Each CPC develops a National Plant report on economic and socio-economic considerations of their tuna- and tuna-like fisheries.

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19. APPENDIX 5.2. - PILOT ECOSYSTEM PLAN IN IOTC

1 INTRODUCTION

Key message

- Effective operational plans are needed to link higher level policies into management actions.
- Ecosystem plans are driven by objectives centered on the ecosystem, and not on individual species or stocks.
- This ecosystem plan aims to guide the operationalization of an EAFM in the Temperate Ecoregion of the Indian Ocean.
- While the ecoregion has well-defined geographic boundaries, these boundaries should be relaxed when developing ecosystem analyses and assessments to allow understanding of the external pressures, impacts and ecosystem processes governing the ecoregion. However, the ecosystem-level management advice should be focused on the most pressing high priority issues and challenging needs of the ecoregion.

1.1 Main objectives and purpose of the ecosystem plan

The main purpose of this pilot ecosystem plan is to facilitate the implementation and operationalization of the Ecosystem Approach to Fisheries Management (EAFM) in the Indian Ocean Tuna Commission (IOTC). While IOTC has committed to operationalize the EAFM within its Convention Area, its ecosystem-based research and activities have been implemented in an *ad hoc* way, without having a long-term vision and a formalized plan to prescribe how fisheries will be managed from an ecosystem perspective (Juan-Jordá *et al.*, 2017). Here, a pilot ecosystem plan is developed for the Temperate Ecoregion of the Indian Ocean to guide the operationalization of an EAFM in this region. This ecosystem plan is based on objectives centered on the ecosystem and not on one individual species or stock targeted by IOTC fisheries in this region. At this stage, this pilot ecosystem plan seeks to create awareness about the need for ecosystem planning, create discussion about what elements need to be part of a planning process, and intents to be the foundation for future participatory and consultative ecosystem plans in the IOTC convention area.

The EAFM aims to balance the impacts of fisheries on the ecosystems and the ecosystem services derived from them (FAO, 2003). The EAFM should be treated as a process; a process that needs to get updated and adapted as new information and tools become available. This adaptive management requires effective planning. Therefore, ecosystem plans need to be operational and adaptive. Operational ecosystem plans are designed to translate higher level policies and objectives into actions (Staples *et al.*, 2014). Ecosystem plans are considered a tool that can serve as a framework to identify and formalize ecosystem goals and objectives, plan actions based on priorities, measure performance of the whole fishery system, address trade-offs, and incorporate them in fisheries management (Levin *et al.*, 2018). It is important that ecosystem plans are tailored to a well-defined region in order to focus on its priorities and singularities.

There are multiple purposes and benefits in developing an ecosystem plan, which ultimately aims to guide the implementation of an EAFM in a region (NPFMC, 2007; Staples *et al.*, 2014; Levin *et al.*, 2018), including:

(1) It creates a transparent process that may help the Commission to set ecosystem goals and management objectives;

(2) It provides a framework for strategic planning to guide and prioritize fishery and ecosystem research, modelling and monitoring needs;

(3) It facilitates the integration of information and knowledge from different fisheries operating in a region and their cumulative impact on the ecosystem;

(4) It provides a framework to document current and best practices in the region as well as the impediments hindering the operationalization of EAFM in the region;

(5) It provides a framework to identify key ecosystem components in the region, their interconnectedness, and their importance for specific management questions;

(6) It helps the Commission to understand the cumulative effects of fisheries and emergent trade-offs between multiple objectives;

(7) It serves as a communication tool to better link ecosystem science and policy and as a dialogue forum for managers, scientist and stakeholders;

1.2 Geographic area of the ecosystem plan

The geographic area of the ecosystem plan covers the Temperate Ecoregion of the Indian Ocean (Figure 1). Two candidate ecoregions within the convention area of IOTC were proposed in the project *EASME/EMFF/2016/008 SC02 Selecting ecosystem indicators for fisheries targeting highly migratory species*. The boundaries of the ecoregions rest on three pillars of information: the existing knowledge of biogeographic classifications of the pelagic environment, the spatial distribution of tuna and tuna-like species and communities they form, and the spatial dynamics of the main fishing fleets targeting them (for more details on the delineation of ecoregions see Task 3 of SC02 final project report). Each ecoregion is characterized by greater similarity in biogeographic and oceanographic characteristics, in tuna and billfish communities and the type of fishing fleets exploiting them. The proposed ecoregions aim to focus fisheries management on a specified place and on priority issues facing the most challenging needs for each region.

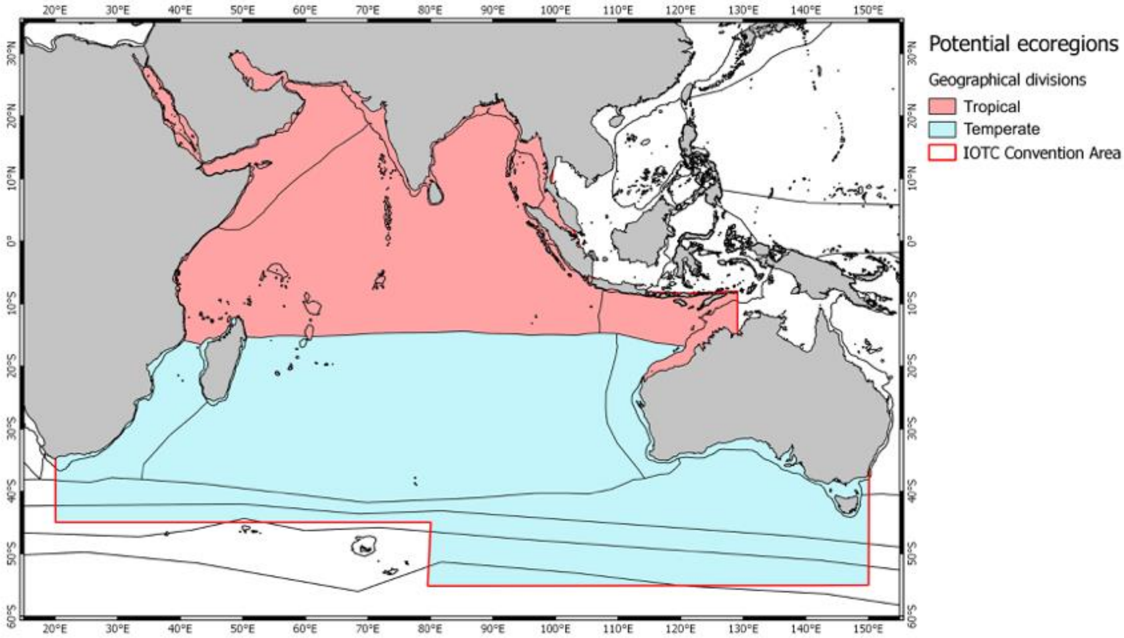


Figure 1. Proposal of ecoregions within the IOTC Convention area. The Temperate Ecoregion is the core area of this ecosystem plan.

The Temperate Ecoregion is the result of combining several provinces of the Spalding biogeographic classification (Spalding *et al.*, 2012) into one larger region. The provinces combined were the Indian Ocean Gyre, Agulhas current, and Leeuwin Current provinces as well as some areas of the subtropical Convergence, Subantarctic and Antarctic Polar Front provinces. The Temperate Ecoregion is characterized by a subtropical gyre, which generally results in oligotrophic waters. It represents a transitional area between the more tropical waters in the north and temperate and Antarctic waters in the south. The IOTC is responsible to manage the tuna and tuna like species in this region. The species primarily targeted in this ecoregion are albacore tuna and swordfish, followed by yellowfin and bigeye tuna at the northern edges of the region. These species are primarily targeted by industrial longline fleets. Blue shark and shortfin mako are also important bycatch fish species which are also retained by longline fleets. There are also artisanal fisheries operating in the region off the southeastern African continent. Southern bluefin tuna also occupies the most southern waters of the Temperate Ecoregion, but its management is under the purview of another tuna RFMO, namely the Convention for the Conservation of Southern Bluefin Tuna (CCSBT). The Temperate Ecoregion is also home to a large diversity of species which are associated to, depend on and support the populations of tuna and tuna-like species. Many of these species also interact and are caught accidentally by IOTC fisheries, including some sharks, marine turtles, marine mammals and seabirds.

While the combined Spalding's provinces form the core geographic area of this plan, the geographic boundaries should be relaxed to allow understanding of the external pressures, impacts and drivers on the ecoregion. When operationalizing an ecosystem approach, the main interactions between IOTC fisheries and the different ecosystem components need to be identified and monitored to provide effective ecosystem advice. Effective ecosystem advice is crucial not only to ensure sustainable fisheries of tuna and tuna-like species but also to minimize their impacts on the ecosystem to avoid undesired ecosystem states.

1.3 A snapshot of the key elements of the ecosystem plan

The development of an ecosystem plan requires the use of multiple tools and the development of multiple elements and processes. Here, the pilot ecosystem plan developed for the Temperate Ecoregion includes the following main core elements which will be developed individually in the following sections (Figure 2). Each key element is briefly presented and described below:

11. **Strategic vision and goals –** An ecosystem plan needs clear statements of vision, goals and objectives. A vision is a top-level aspiration of the Commission, a long-term statement of the aspirations of the Commission of what the future would look like if management is successful (Staples *et al.*, 2014). This vision

should encapsulate key principles of the ecosystem approach such as the sustainable use of fish resources, the conservation of biodiversity and the maintenance of resilient ecosystems.

12. **Ecosystem overview** –The ecosystem overview aims to integrate and synthesize the current knowledge of the main pressures and drivers that contribute to the state, and changes in the state, of the different ecosystem components in the ecoregion covered by the plan. It also allows identifying how the different ecosystem components interact and relate to each other, highlighting those emergent issues that need to be monitored. Ecosystem overviews also facilitate the identifications of data and research gaps in the region. It can be used as a tool to synthesize information to the Commission.

13. **Conceptual ecosystem models** – Conceptual ecosystem models are a tool that allows visualizing those relevant ecosystem components and their interconnection. It also allows identifying and raising a manageable number of issues that may need to be researched separately or as a whole and ensures that no critical components are missed. Conceptual ecosystem model can also help to identify trade-offs of management actions on different components of the ecosystem, which may lead to more informed decision making. In addition, the conceptual ecosystem models can also be used as a tool to synthesize information to the Commission (as well as the public). Therefore, it can be used as a communication tool for ecosystem science.

14. **Skeleton of indicator-based ecosystem assessments** - The ecosystem overview and conceptual ecosystem models for the Temperate Ecoregion allows to identify those issues that needs to be addressed in the ecosystem plan, and those issues or ecosystem elements that would require monitoring or further research. Here, a general framework is designed where all relevant ecosystem interactions that need to be monitored and assessed by the Commission are listed. For each interaction, a list of ecosystem indicators is proposed as well as potential management objectives to track the state of each relevant interaction.

15. **Strategy for communication and provision of advice –** The pilot ecosystem plan needs to be shared and communicated to different audiences including the Scientific Committee and the Commission. A communication strategy is proposed for sharing results in a logical and strategic way. This ecosystem plan also

identifies and proposes a series of products and activities that could be developed to better link ecosystem science and fisheries management advice.

The aforementioned elements are considered to be the first steps towards the development of a formal ecosystem plan in IOTC. At present, the current state and formulation of elements included in the ecosystem plan should be seen as preliminary as they are still under development and need to be openly discussed with the Scientific Committee and Commission. Furthermore, the elements developed under this plan should not be considered as a complete list. Future revisions of this pilot ecosystem plan could also envision to include additional elements. For example, it could include a section with management actions needed to meet each specific objective, a section on skills and capabilities to support the implementation of the plan, as well as identify continuous financial support to ensure its implementation, to name a few.

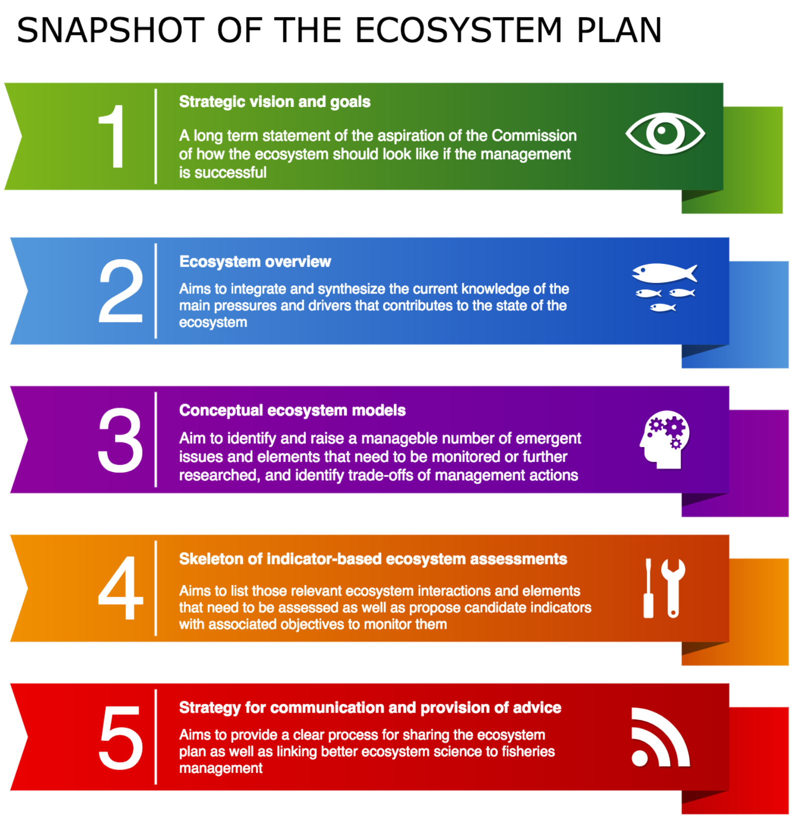


Figure 2. A snapshot of core elements of the pilot ecosystem plan for the Temperate Ecoregion.

1.4 Main scope of the ecosystem plan

This pilot ecosystem plan focuses on the operationalization of an ecosystem approach to "fisheries" management, by identifying and addressing issues that can only be dealt by the fisheries sector and by IOTC fisheries. It does not cover other human sectors such as navigation, tourism or pollution as these are not under the manageable activities of IOTC. However, this non-fishery derived pressures might also have an impact on marine ecosystems and ultimately the conservation and sustainable use of tuna and tuna-like species. Addressing them might require more cross sectoral management and coordination with other international and intergovernmental institutions. This plan does not address these cross sectoral interactions.

Furthermore, it is important to highlight that this plan only addresses the ecological component of an EAFM. While, an EAFM rests on the three pillars of sustainability including the ecological well-being, socio-economic well-being and good governance (FAO, 2003); this plan only focuses on developing the ecological aspects to be taken into account when providing ecosystem advice, and does not address the socio-economic and governance aspects of fisheries. Until the socio-economic considerations and governance are addressed properly, this pilot ecosystem plan will only be partially guiding the operationalization of EAFM in the Temperate Ecoregion.

2 STRATEGIC VISION, GOALS AND OBJECTIVES

Key message

- The Commission needs to agree on the vision for this (or any) ecosystem plan.
- This plan illustrates examples of ecosystem visions adopted by other organizations to guide the Commission to develop its own.

A vision is a top-level aspiration of the Commission, a long-term statement of the aspirations of the Commission of what the future would look like in the Temperate Ecoregion if fisheries management is successful (Staples *et al.*, 2014). Ideally a strategic vision should be discussed and agreed by the Commission. This pilot ecosystem plan provides three examples of ecosystem vision statements adopted by other organizations and programs and highlights their commonalities to guide the Commission on what key principles should be included when developing its own.

Examples of vision statements:

The North Pacific Fisheries Management Council in the USA adopted in 2014 an ecosystem policy that expressed the Council aspiration to continue moving towards implementing the ecosystem approach to fisheries management. The policy included a value statement, vision statement, implementation strategy and ecosystem goals. Its ecosystem vision articulates:

> "The Council envisions sustainable fisheries that provide benefits for harvesters, processors, recreational and subsistence users, and fishing communities, which (1) are maintained by healthy, productive, biodiverse, resilient marine ecosystems that support a range of services; (2) support robust populations of marine species at all trophic levels, including marine mammals and seabirds; and (3) are managed using a precautionary, transparent, and inclusive process that allows for analyses of trade-offs, accounts for changing conditions, and mitigates threats."

The Mid-Atlantic Fishery Management Council in the USA approved its first strategic plan including a vision, a series of goals and strategies in 2013. Its vision statement articulates:

> "Healthy and productive marine ecosystems supporting thriving, sustainable marine fisheries that provide the greatest overall benefit to stakeholders."

In Europe, the Marine Strategy Framework Directive (MSFD) adopted in 2008 is the main environmental policy for the marine domain, which main goal is to achieve Good Environmental Status (GES) of EU marine waters by 2020. The Directive defines GES as:

> *" The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive" Article 3"*

Also relevant for the European marine domain, the Common Fishery Policy (CFP), last updated in 2014, sets the rules for managing European fishing fleets and fish stocks, which objectives aligns with the main objective of the MSFD. The CFP overall objective is

> *".. shall ensure that fishing and aquaculture activities are environmental sustainable in the long-term and are managed in a way that is*

> *consistent with the objectives of achieving economic, social and employment benefits, and of contributing to the availability of food supplies."* and the CFP also articulates *"should contribute to the protection of the marine environment, to the sustainable management of all commercially exploited species, and in particular to the achievement of good environmental status by 2020…".*

These policy and vision statements encapsulate key principles of the ecosystem approach to fisheries management including (1) the sustainable use of fish resources, (2) the conservation of biodiversity and the maintenance of resilient and productive ecosystems, and (3) the provision of economic, social and employment benefits to stakeholders. These aforementioned principles should guide the Commission efforts to developing its own vision statement, strategic goals and objectives.

3 ECOSYSTEM OVERVIEW -UNDERSTANDING THE TEMPERATE ECOSYSTEM IN THE INDIAN ONCEAN

Key message

- The ecosystem overview was developed to facilitate the synthesis and integration of all relevant and available ecosystem information of the Temperate Ecoregion, so it can be better communicated to the Commission.
- The selective extraction of species by fishing and the production and dumping of marine debris derived from fishing activities are the main manageable pressures by IOTC causing an effect on the state of the ecosystem. Natural environmental variability and climate change are the main pressures non-susceptible to IOTC management.
- The state of the principal market tunas (and few billfish and shark species), which are the main targeted and retained species in IOTC fisheries, are relatively well known and monitored. There remain a large number of retained fish species for which their state is unknown. Furthermore, the state of the large majority of non-retained species including sharks, marine turtles, seabirds and marine mammals are also poorly known and monitored.
- The impacts of IOTC fisheries on the community structure and marine foodweb also remain poorly monitored and understood.
- Habitat of ecological significance, which might include areas used by species for spawning grounds and migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate in a particular time, are also poorly monitored and understood.

The ecosystem overview for the Temperate Ecoregion aims to integrate and synthesize the existing knowledge of the main pressures and drivers that contribute to the state, and changes in the state, of the different ecosystem components in the ecoregion. Therefore, it requires prior identification of the main pressures impacting the state of the marine ecosystem, and identification of what ecosystem components are being affected and impacted by these pressures (Figure 3). The ecosystem overview also aims to identify how the different ecosystem components interact and relate to each other, raising up those emergent issues that need to be monitored in the ecoregion and those research gaps that need to be addressed for a complete view of the system.

A distinction is made between pressures that can be controlled by IOTC management and those that cannot be controlled (Figure 3). The most important manageable pressure is commercial fishing, which selectively extracts a number of species but indirectly also impacts other marine species (incidental captures). The unquantified illegal, undeclared and unregulated (IUU) fishing occurring in the area, if any, should also be accounted for as an additional human activity exerting pressure on the species being extracted and the broader ecosystem as well as impacting the fisheries operating in the region. Another manageable pressure consists on the production and dumping of marine litter derived from the commercial fisheries and potentially also derived from the IUU fisheries in the region. Finally, the changing oceanographic conditions of the region as well as climate change are the most important unmanageable pressures by IOTC. Changing oceanographic conditions and climate change potentially can affect and impact the state of the ecosystem and all its components including the productivity of the system all the way to the upper trophic levels of the marine foodweb. While there is still a debate whether climate change is a driver or a pressure in the system, here it is treated as a pressure following this definition: a pressure "is the result of a driver-initiated mechanisms (human activity/natural process) causing an effect on any part of an ecosystem that may alter the environmental state" (Oesterwind *et al.*, 2016). By following this definition, climate change can be attributed to pressure categories resulting from both anthropogenic and natural drivers (Figure 3).

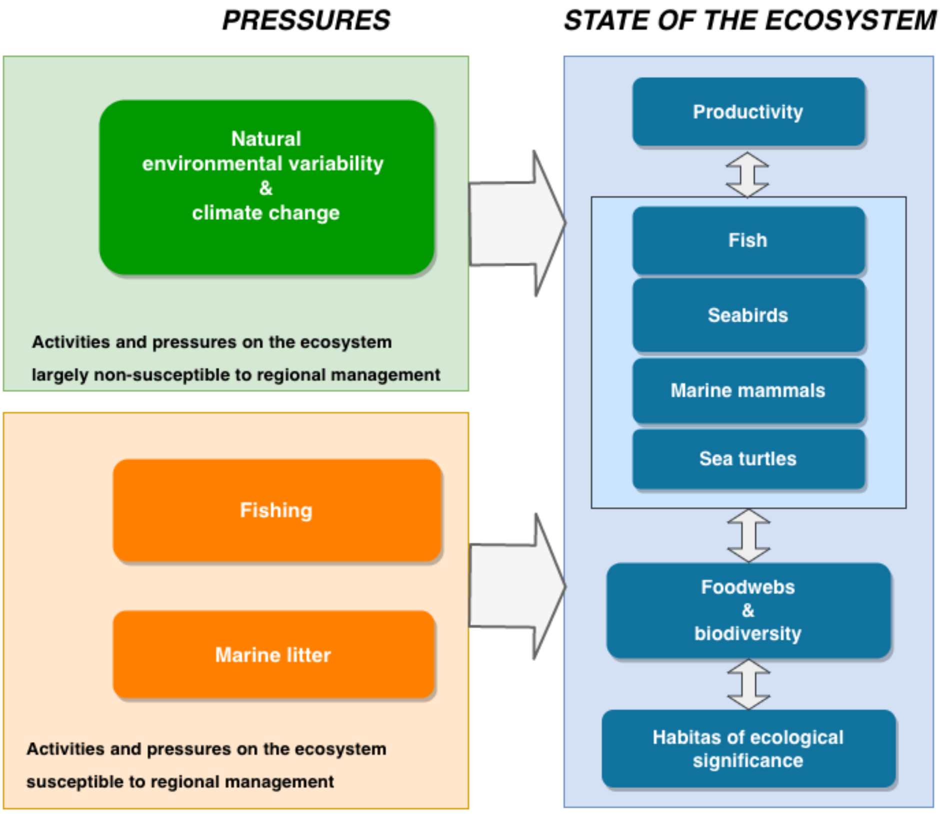


Figure 3. Overview of the Temperate Ecosystem in the Indian Ocean with the major regional drivers, pressures affecting the state of the different ecosystem components.

This ecosystem overview also describes the state and the changes in state of the different components of the ecosystems and describes the main interactions between the existing pressures and the different states of the ecosystem (Figure 3). The state of the main ecosystem components described in the ecosystem overview are (1) the productivity of the system (plankton communities), (2) fishes, (3) megafauna including seabirds, sea turtles and marine mammals, as well as (4) how these species interact forming complex food webs and sustain marine biodiversity. Finally, the overview also describes how species (and the different stages of their life cycles) interact in space and time forming habitats of ecological significance. Furthermore, when describing the state of the different taxonomic groups, it is important to distinguish between species that are targeted as well as retained by the IOTC fisheries from those species that are not necessarily targeted but that are either retained by IOTC fisheries because of their commercial value or are not retained (and therefore discarded either death or alive) due to lack of commercial value or non-retention measures in place (e.g some sharks, seabirds, sea turtles).

3.1 Pressures susceptible to regional management

This section aims to provide an overview of the main manageable pressures causing an effect on the state of any part of the ecosystem. First, it describes the main commercial fisheries, including the main gears and flag states, operating in the region as well as the main fish species targeted and caught by these fisheries. It also presents our current knowledge on the IUU fishing occurring in this region. Last, it presents an overview on the current understanding of the production and dumping of marine debris derived from IOTC fishing activities in the region.

3.1.1 Selective extraction of species through fishing

The reported landings of major commercial tuna and billfishes was around 52 thousand annual tonnes between 2012 and 2016 in the Temperate Ecoregion (Figure 4a). Catches decreased since the year 2000 to 2008 (driven by the decrease in catches by the deep-freezing longline fleets), then increased up to 2016 (driven by the increase in catches by the fresh longline fleets). In 2016 the majority of the catches were albacore tuna (47.5%), followed by swordfish (21%), yellowfin tuna (21%), bigeye tuna (9%) and skipjack tuna (2%) in the Temperate Ecoregion (Figure 4.b). Industrial longliners are the major fisheries operating in the Temperate Ecoregion. Longline fishing started in 1952 by the Japanese fleet which rapidly expanded over the entire Indian Ocean. Korea, Taiwan and China also have important longline fisheries in the Indian Ocean, which were followed by thousands of small Indonesian fresh fish longliners (Ardill *et al.*, 2012). In the Temperate Ecoregion, the longline fishery can be subdivided in three different types depending on what species are being targeted or the type of processing. These include fresh longliners (FLL), deep freezing longliners (LL) and longliners targeting swordfish (ELL) (Figure 4c). Other gears also catch tunas and tuna-like species in the Temperate Ecoregion, such as gillnets and harpoons, but these are poorly monitored and overseen in IOTC (Figure 4c).

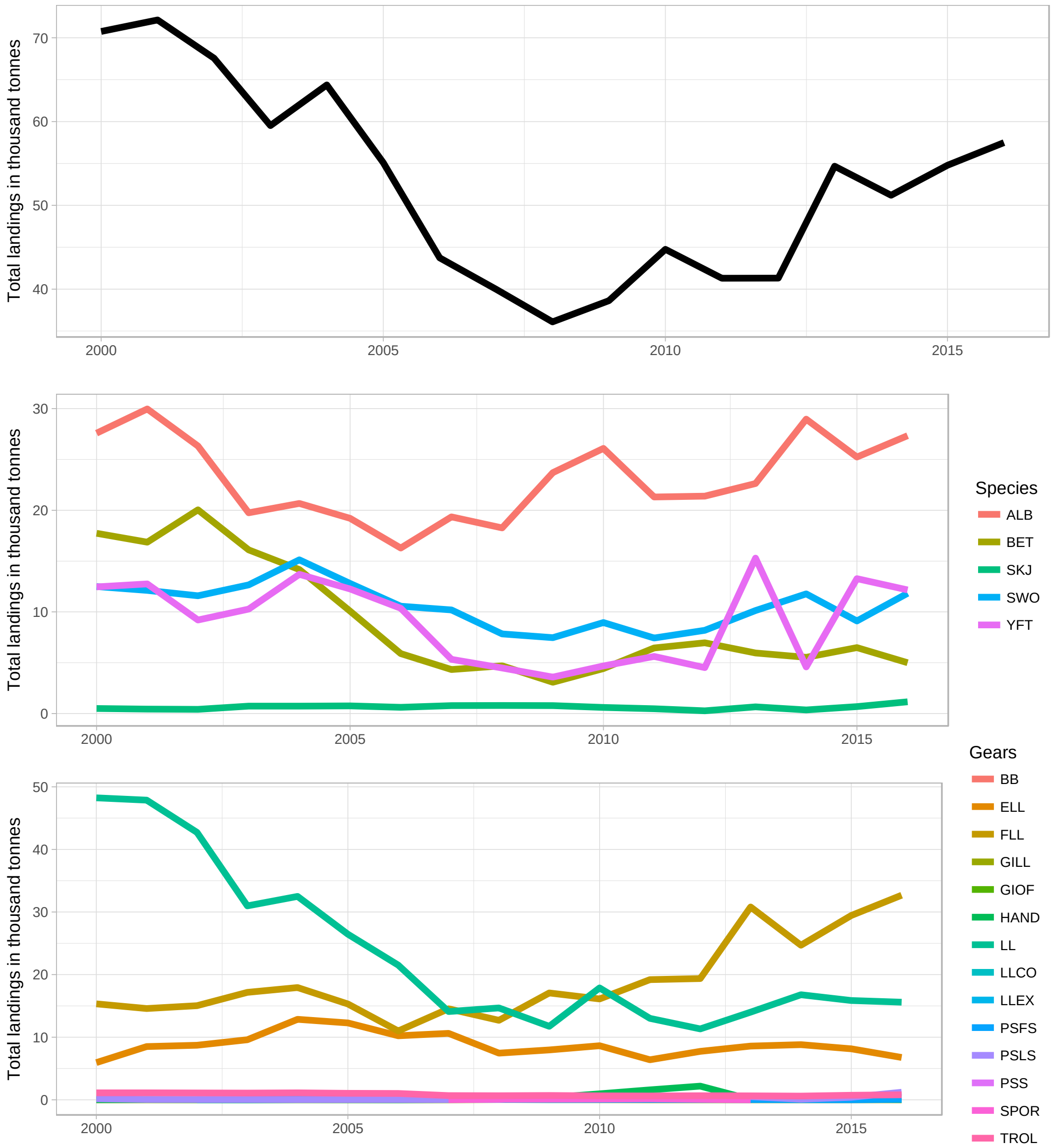


Figure 4. Total reported catches in the Temperate Ecoregion between 2000 and 2016. (a) total for all species combined; (b) by species: albacore tuna (ALB), bigeye tuna (BET), yellowfin tuna (YFT), skipjack tuna (SKJ) and swordfish (SWO); (c) by main gear groups: bait boat (BB), longline targeting swordfish (ELL), longline fresh (FLL), gillnet (GILL), handline (HAND), deep-freezing (LL), coastal longline (LLCO), exploratory longline (LLEX), purse seine freeschool (PSFS), purse seine log school (PSLS), small purse seine (PSS), sport fishing (SPOR), troll line (TROL). Data source: Notice that the estimated georeferenced catches provided by the IOTC Secretariat and used in this analysis are highly uncertain.

Fresh longliners (FLL) refer to small semi-industrial fishing boats that can only refrigerate the fish and operate for 10-12 days relatively close to their ports. They have a limited capacity to expand to remote areas. By the contrary, deep freezing longliners (LL) refer to more industrial fleets that can operate for longer than 4 months at a time, without coming to port and have the capacity to access remote areas. Both fresh longliners (FLL), deep freezing longliners (LL) catch principally tuna species, primary albacore and yellowfin tunas, while the industrial longliners catalogued as ELL target catch primary swordfish (Figure 5).

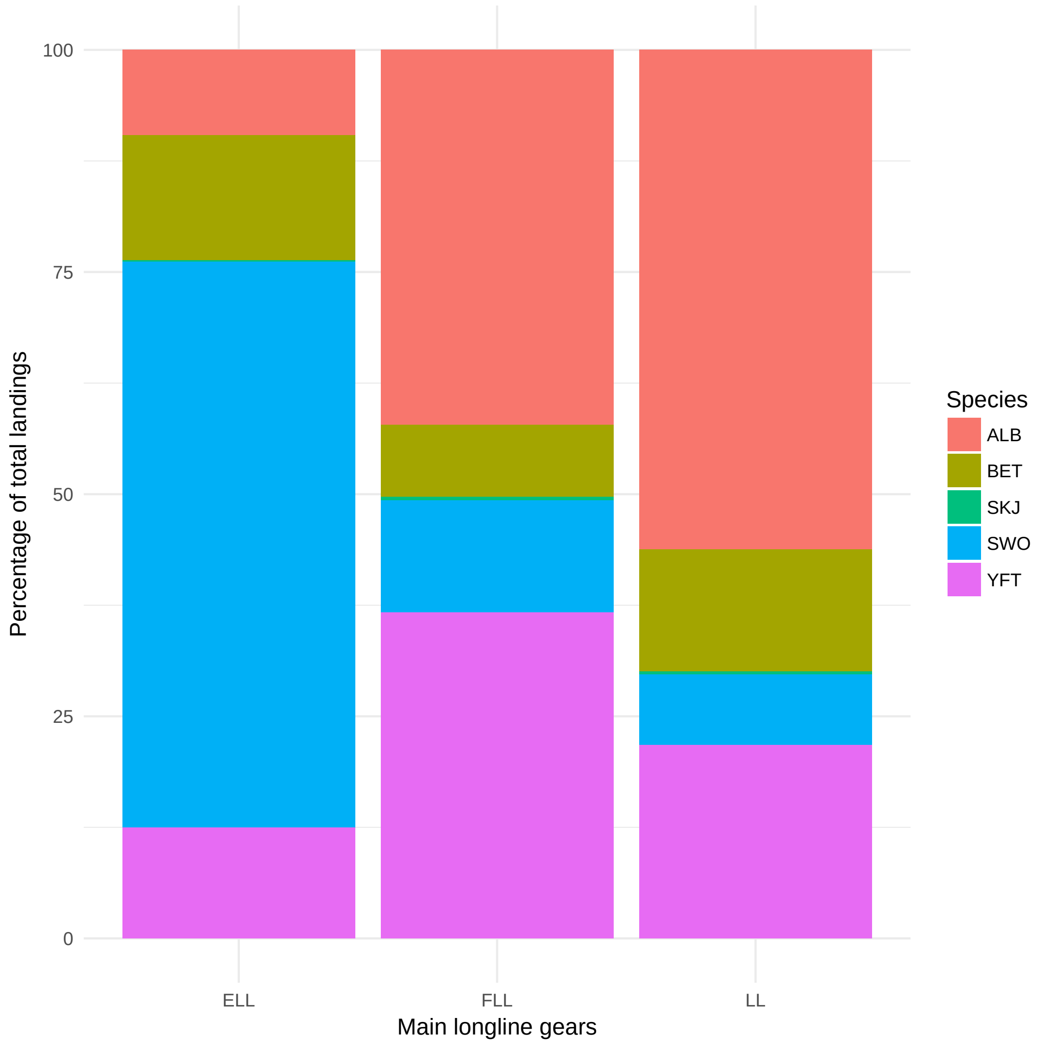


Figure 5. Percent of total landings by species for main longline gears in the Temperate Ecoregion between 2014-2016. For species and gear codes see Figure 4. Data source: Notice that the estimated georeferenced catches provided by the IOTC Secretariat and used in this analysis are highly uncertain.

The catches for the year 2016 provide an indication of the performance of the fisheries in the ecoregion. About 57% of the catches in the Temperate Ecoregion were made by fresh longline fisheries, followed by deep-freezing industrial longline fisheries (27%) and longliners targeting swordfish (11.7%) (Figure 4c). Between 2014 and 2016, the most important flag states operating in the Temperate Ecoregion have been Indonesia (27.4% of catches), Taiwan (12.4%), Madagascar (9.7%), Japan (8%), EU Reunion (6.7%), EU Spain (4.5%), Phillippines (3.9%), EU Portugal (2.9%), Korea (2.86%) and India (2.8%) (Figure 6a). The Indonesian catches for the last five years are in the process of being revised in the IOTC database, which will have an impact on the estimated catches in the region for the most recent years. There are other 15 flags operating in the area catching the remaining 16% of the total. Indonesia and Taiwan mostly operate fresh longliners catching albacore, bigeye and yellowfin tuna (Figure 6b and 6c). Madagascar operates mostly with troll vessels and catch yellowfin and skipjack tuna. Japan, Korea, Philippines, Indonesia operate deep-freezing industrial longliners catching mostly yellowfin and albacore. EU Reunion, EU Spain and EU Portugal operate industrial longliners mostly catching swordfish.

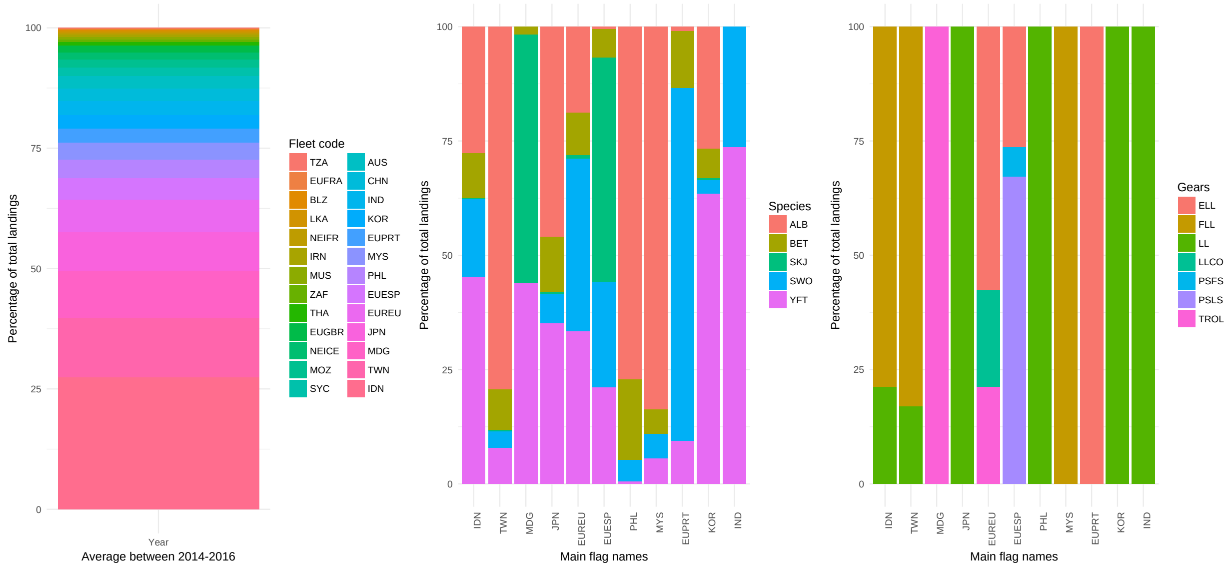


Figure 6. Main fishing nations or CPCs (Contracting Party or Cooperating non-Contracting Party, Entity or Fishing Entity) in IOTC operating in the Temperate Ecoregion (a) Flag names making 100% of the total landings in the Temperate Ecoregion. (b) Percent of total landings by species for main CPCs making 84% of the total landings in the Temperate Ecoregion. (c) Percent of total landings by gear for main CPCs making 84% of the total landings in the Temperate Ecoregion. For species and gear codes see Figure 4. Data source: Notice that the estimated georeferenced catches provided by the IOTC Secretariat and used in this analysis are highly uncertain.

It is important to notice that the georeferenced catches for the major tunas and swordfish used in these analyses are estimated by the Secretariat with high uncertainties, using a number of techniques that becomes less accurate when no georeferenced catch-and effort information is available from the country source. Many countries do not provide the spatial information of their catches to the Secretariat.

The extent and magnitude of the IUU fisheries capturing tuna and tuna like species is unknown or poorly known in the region. It is advisable to investigate whether there are illegal activities that might be exerting a significant additional pressure on tuna and tuna like species and associated ecosystem, which are currently unaccounted in fisheries assessments in IOTC.

3.1.2 Marine debris

Abandoned, lost and discarded fishing gear potentially can also potentially cause ecological problems for marine species and sensitive habitats as well as socio-economic problems for the fishing fleets when lost unintentionally. One ecological problem derived from these abandoned, lost or discarded fishing gears is that lost floating gears may continue to catch organisms (known as ghost fishing). Not accounting for the mortality due to ghost fishing in population and stock assessment models has the potential to make less effective the harvest strategies of managed species as well as affect the population viability of the most vulnerable species such as sea turtles, marine mammals, seabirds and some sharks and bony fishes (Coggins *et al.*, 2007; Gilman *et al.*, 2013). Furthermore, the abandoned, lost and discarded fishing gear (here referred as marine debris) can also end up stranded on beaches and sensitive coastal areas such as coral reefs (Maufroy *et al.*, 2015; Zudaire *et al.*, 2018).

Over the last decades the amount of these marine debris has increased substantially globally with the expansion of fishing effort and with the transition to more durable and more buoyant fishing materials (Gilman, 2015). Potentially fishing boats operating in the Temperate Ecoregion may lose gear (or associated), discard gear or abandon gear, yet the extent and magnitude of the marine debris derived by longliners or gillnets (the major gears operating in this region) is unknown or poorly known. While the purse seine fishery is small in the Temperate Ecoregion, some drifting FADs and GPS buoys lost may impact some coastal areas (e.g. Madagascar coast) in the northern area of the Temperate Ecoregion. A recent study has estimated that between 1500-2000 GPS buoys may have been lost onshore and stranded on the coast each year in the Atlantic and Indian Ocean combined contributing to coastal marine debris (Maufroy *et al.*, 2015). In the Indian Ocean, beaching of buoys tends to concentrate off the Somalia, Kenya and Tanzania and only a small proportion of them reach the Mozambique channel and the northern coasts of Madagascar (Figure 7). These beaching events may be potentially occurring in sensitive areas such as coral reefs and estuaries.

Mitigating the impacts of lost drifting FADs and lost buoys is possible by avoiding deployment zones and time periods that increases the probability of losing leading to an increase in beaching events (Maufroy *et al.*, 2015).

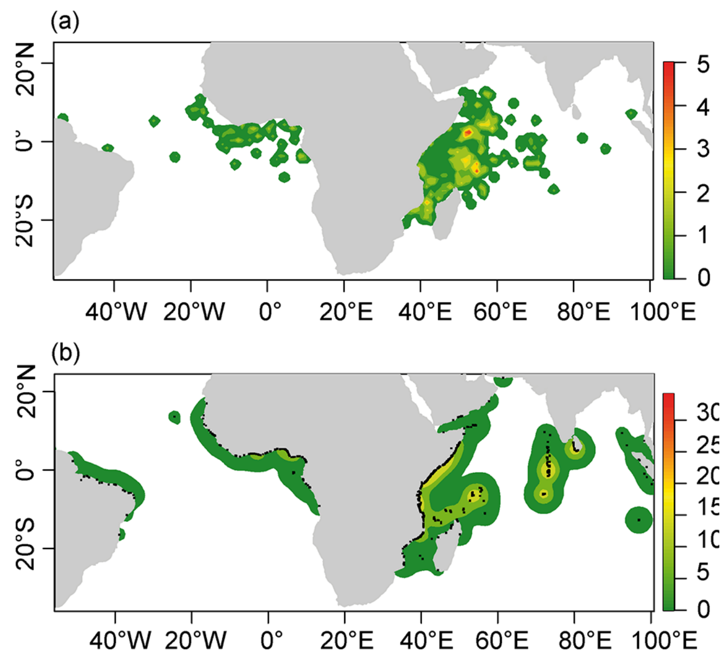


Figure 7. FAD beaching locations. (a) Deployment positions of FADs (b) Smooth densities of drifting FADs and black points corresponds to individual beaching positions. Figure extracted from (Maufroy *et al.*, 2015).

3.2 Pressures non-susceptible to regional management

In addition to the manageable pressures exerted by existing human activities in the Temperate Ecoregion of the Indian Ocean, there are other pressures that are difficult to be managed at a global and/or regional scale by IOTC, therefore they are referred as pressures non-susceptible to regional management. In this section, two different types of non-manageable pressures are described:

(1) Natural environmental variability, which is inherent to the geographical and oceanographical properties of the ecoregion (see subsection 3.2.1), and (2) Climate change, which has an intrinsic natural variability but is also affected by human activities (see subsection 3.2.2).

3.2.1 Main oceanographic features of the Temperate Ecoregion

The Temperate Ecoregion of the Indian Ocean encompasses several pelagic provices defined by Spalding *et al.* (2012). These include the Agulhas Current province, the southern Indian Ocean Gyre province and the Leeuwin Current province, containing also subareas of other three pelagic provinces that are part of the Southern Coldwater Realm (the Southern Subtropical Front, the Subantartic and the Antartic Polar Front provinces) (Figure 8). The unusual complexity of the cirulation of the Indian Ocean is driven by its natural shape, which causes the characteristic seasonal variability of the monsoon wind systems. Although the effects of monsoon forcing are most apparent in the Northern Hemisphere, there is also significant seasonal variability in the southern subtropical and midlatitude Indian Ocean related to the monsoon forcing *(Schott & McCreary, 2001).* The big central area corresponding to the southern Indian Ocean gyre is dominated by a large cirular anticlockwise current and is characterized by a large number of submarine plateau and ridges, that locally emerge as tiny isolated islands (Figure 9).

The southern Indian ocean, here the Temperate Ecoregion, is characterized by the westward flowing South Equatorial Current (SEC in Figure 9), to a large part supplied by the Indonesian Throughflow. It splits at the east coast of Madagascar near 17ºS into northward and southward branches, the Northeast and Southeast Madagascar Currents (NEMC and SEMC in Figure 9). The southward branch enters the Mozambique Channel, whith a sequence of eddies and dipoles that form the Agulhas Current (AC in Figure 9). The Agulhas and the Leeuwin currents are the western and eastern coastal limit of this gyre, respectively (Figure 9). Being one of the major currents of the Southern Hemisphere, the Agulhas current is characterized by moving warm water polewards, similar to the Leeuwin current, which leads into warmer continental shelf waters of Western Australia in winter and cooler in summer than in other corresponding regions of other continents.

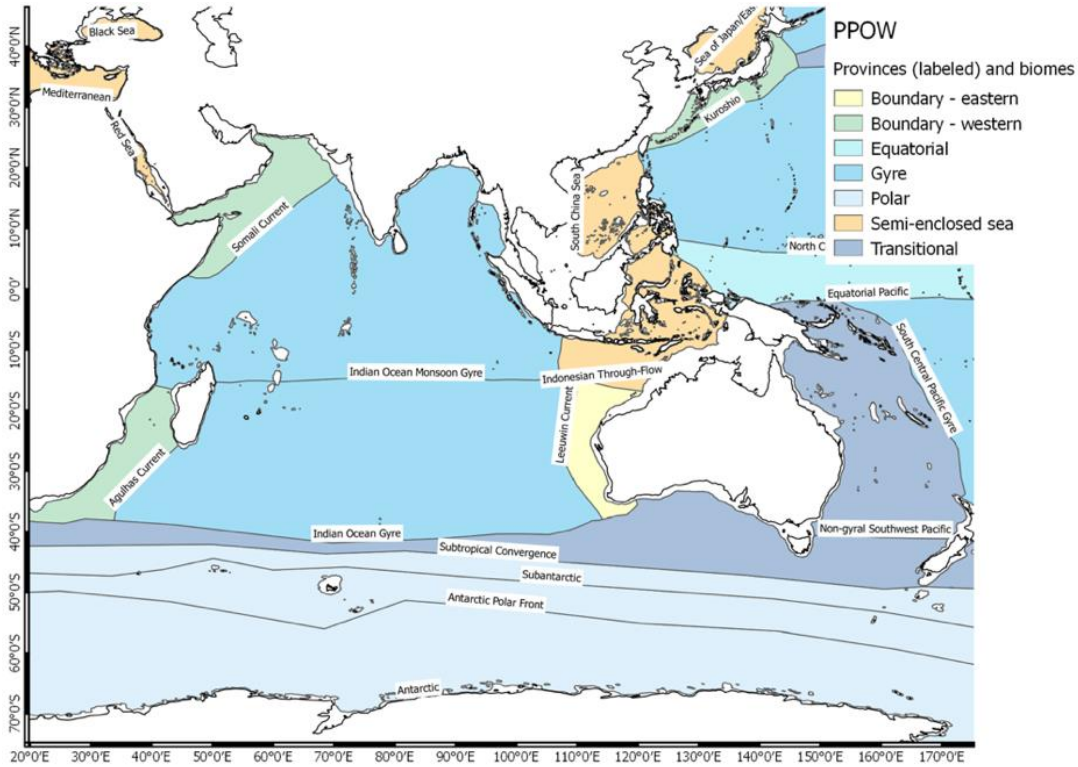


Figure 8. Pelagic Provinces of the World defined by Spalding *et al.* (2012).

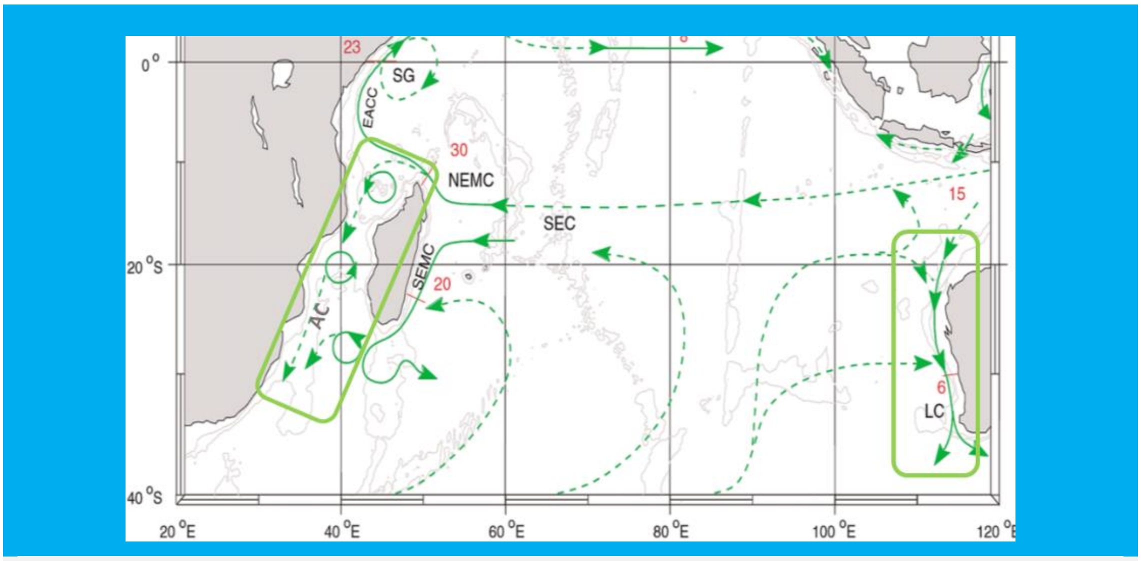


Figure 9. A schematic representation of identified current branches during the Southwest Monsoon. Current branches indicated are the South Equatorial Current (SEC), Northeast and Southeast Madagascar Current (NEMC and SEMC), East African Coast Current (EACC), Southern Gyre (SG), Agulhas Current (AC) and Leeuwin Current (LC). Differences in currents during Northwest Monsoon are less in this Temperate Ecoregion compared to the Northern Indian Ocean. *Modified from (Schott & McCreary, 2001).*

3.2.2 Climate change

Climate change has been characterized as a pressure that cannot be completely eliminated or effectively addressed by any short-term and regional management measure (Oesterwind *et al.*, 2016). Changes on environmental conditions will have direct and indirect impacts on the status of different components of the pelagic ecosystem (Bromhead *et al.*, 2015). Limited research on the potential changes caused by climate on highly migratory tuna and tuna-like species has been carried out in the Indian Ocean and in particular in the Temperate Ecoregion (see for example Dueri *et al.* (2014)). Most of the climate research has been carried out in other oceans (Lehodey *et al.*, 2010; Nye, 2010), demonstrating that climate and environmental variability can affect both the biology of the highly migratory tuna and tuna-like species and the fisheries targeting them. Báez *et al.* (2011) showed that climatic oscillations can affect the physical condition of albacore tuna in the Mediterranean Sea, by having an accumulated effect along its life history and affecting the number of spawning events that can be carried out throughout its life. Báez (2015) also showed that climatic oscillations could change the migration pattern of oceanic sharks annually, modifying its local abundance. (Bigelow *et al.*, 1999) investigated how the environmental conditions can affect the fisheries targeting swordfish and blue sharks in the North Pacific, showing that variables such as salinity and temperature among other variables are related to the catch-per-unit-effort of those fisheries. On the Temperate Ecoregion and the Indian Ocean in general, there is a need to better understand the physical processes driven by climate change and their potential effects on highly migratory tuna and tuna-like species to allow for a rapid response from managers and decision makers.

A recent study from the IUCN highlights that there is high uncertainty of how individual tuna populations will respond to rising ocean temperatures and synergistic effects of other climate change outcomes such as O2 concentrations, pH, direction and speed of currents, vertical mixing and changes in eddies (Gilman *et al.*, 2016). In general, oceanic tunas, billfishes and oceanic sharks are expected to respond to this changes by 1) adopting new cooler subtropical areas for spawning, either replacing or in addition to existing tropical spawning sites, due to expected changes in temperature; 2) altering their migration phenology, including changing the timing of spawning and truncating the spawning season. These changes can cause alterations in distributions and survival rates of larvae and young age classes, reducing recruitment and biomass in existing spawning grounds, but increasing recruitment and biomass at new spawning grounds; 3) altering their foraging distributions to higher latitudes and to different longitudes, and alter their vertical depth distributions.

Gilman *et al.* (2016) also highlight that there is high uncertainty of how oceanic tunas and billfishes will respond to rising ocean temperatures and in turn will affect pelagic ecosystem structure, processes and stability. For example, effects of climate change outcomes on the productivity of lower- and mid-trophic levels in tuna food chains, as well as changes in vertical and horizontal distributions, and changes in tuna access to prey at depth due to increased stratification and decreased O2 concentrations may test the resistance and resilience of tunas to climate change.

3.3 State of the main ecosystem components

This section aims to describe the state and the changes in state of the different components of the ecosystems in the Temperate Ecoregion, as well as the main links and interactions between the existing pressures and the state of the ecosystem components (Figure 3). While the ecosystem overview aims to describe the state of productivity, fishes, and megafauna including marine mammals, seabirds and sea turtles as key components of the ecosystem, for practical reasons, when describing the state of the different taxonomic groups, it is important to distinguish between those species retained and non-retained by IOTC fisheries. Therefore, for practical reasons, the state component of the ecosystem overview is divided in the following major sections (Figure 10):

- ***State of retained species:*** it includes a description of the state of the main fish species retained by IOTC fisheries and how the main manageable pressures are impacting their state. The retained species include the main commercial tunas, billfishes and sharks as well as the neritic tunas and other bony fish species caught and retained by IOTC fisheries because of their commercial value. Each fishery preferentially targets and retains a set of species but may also catch other fish species, that although not primarily targeted, are also retained for commercial reasons.
- ***State of non-retained species:*** it includes a description of the state of the main species (fish and non-fish) incidentally caught by IOTC fisheries and non-retained either because of their low commercial value or the non-retention measures in place. This also includes some shark species, sea turtles, seabirds, and marine mammals. It also summarizes the current knowledge on the extent of IOTC fisheries interactions on these species in the ecoregion.

- ***State of foodweb and biodiversity:*** it includes a brief description of our state of knowledge about the ecosystem structure and functioning. Key trophic relationships are detailed and the potential impacts of the fishing activity on the dynamics of the ecosystem are assessed, based on the existing knowledge from the Temperate Ecoregion.
- ***State of habitats of ecological significance:*** it includes a description of our state of knowledge on habitats of ecological significance for the species in the area interacting with IOTC fisheries and how these fisheries might be impacting them. Habitat of ecological significance might include areas used by species for spawning grounds and migration corridors, productive areas for feeding, or areas of with a large aggregation of species and high biodiversity.
- ***State of productivity:*** it includes a small description of the productivity of the region and main spatio-temporal patterns.

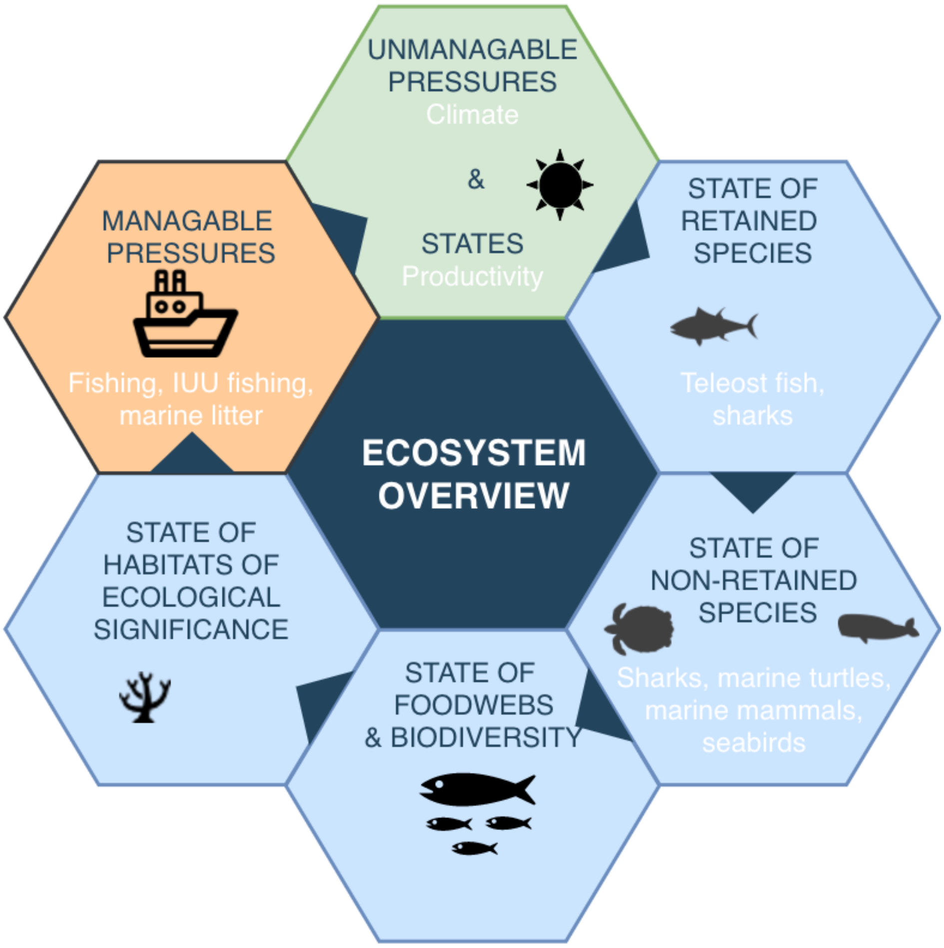


Figure 10. Main ecosystem components to be described in the ecosystem overview.

3.3.1 Retained species including bony fishes and sharks

IOTC fisheries retain a large number of fish species. However, it is important to distinguish between those fish species that are part of IOTC convention mandate, for which IOTC has responsibility to assess and manage to ensure their sustainable use and conservation, from those species that are not covered by IOTC convention mandate. For those species not formally included in the Convention mandate, IOTC still of its fisheries on those fish species.

The species covered by the IOTC Convention mandate are defined in the Article 3 of the IOTC Agreement (Table 1). It covers a total of 16 species including 5 principal market tunas, 6 neritic tunas and mackerels, and five billfishes (Table 1). Therefore, IOTC has the responsibility to assess the state of 16 fish species and has a series of data requirements for them. Southern bluefin tuna, although included in the IOTC mandate, is managed by other tuna RFMO (CCSBT). All these species except, Indo-Pacifc king mackerel (*Scomberomus guttatus*) are found in the Temperate Ecoregion.

Table 1. Species covered in the IOTC convention mandate.

FAO English name	Scientific name
Yellowfin tuna	*Thunnus albacares*
Skipjack	*Katsuwonus pelamis*
Bigeye tuna	*Thunnus obesus*
Albacore tuna	*Thunnus alalunga*
Southern Bluefin tuna	*Thunnus maccoyii*
Longtail tuna	*Thunnus tonggol*
Kawakawa	*Euthynnus affinis*
Frigate tuna	*Auxis thazard*
Bullet tuna	*Auxis rochei*
Narrow barred Spanish Mackerel	*Scomberomorus commersoni*

Indo-Pacific king mackerel	*Scomberomorus guttatus*
Indo-Pacific Blue Marlin	*Makaira mazara*
Black Marlin	*Makaira indica*
Striped Marlin	*Tetrapturus audax*
Indo-Pacific Sailfish	*Istiophorus platypterus*
Swordfish	*Xiphias gladius*

IOTC has conducted fisheries stock assessments for all IOTC species under its mandate (Figure 11). Overall, the exploitation status is known for 12 of the 15 stocks under the IOTC mandate. The status of southern bluefin tuna is not included in Figure 11, since it is managed by other tuna RFMO (CCSBT). Five stocks are currently overfished and experiencing overfishing (yellowfin tuna, black marlin, striped marlin, longtail tuna and narrow-barred Spanish mackerel), two stocks are not overfished but are experiencing overfishing (blue marlin and Indo-Pacific sailfish) and five stocks are not overfished and not experiencing overfishing (albacore tuna, bigeye tuna, skipjack tuna, swordfish, and kawakawa). Finally, three stocks have been assessed but their status was undetermined (bullet tuna, frigate tuna and Indo-Pacific mackerel).

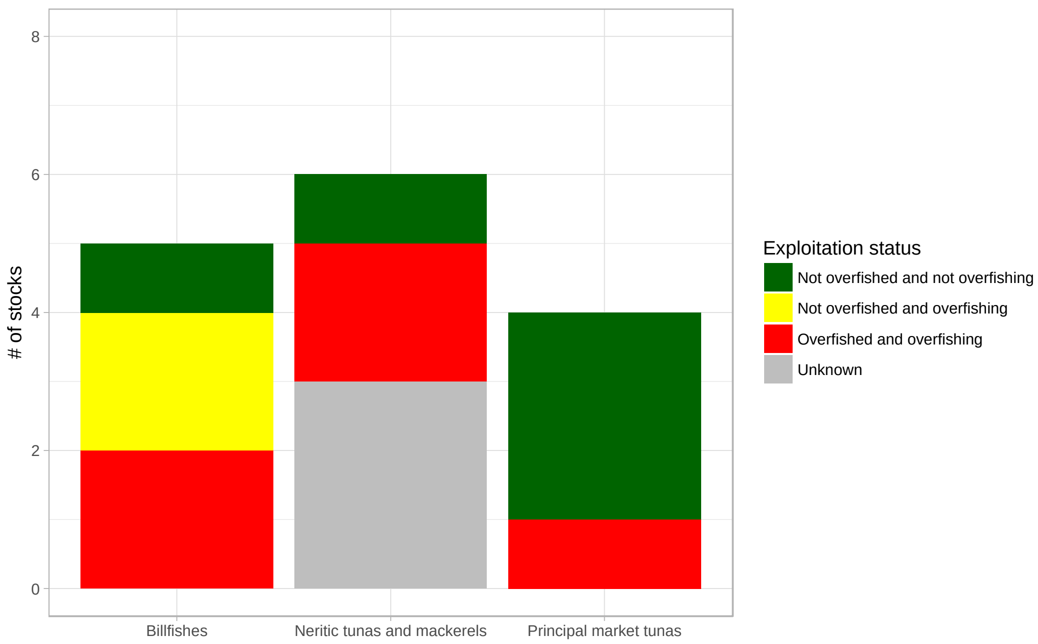


Figure 11. Stock status for IOTC fish species in convention mandate (IOTC, 2018a).

Sharks are not part of the 16 species directly under the IOTC mandate (Table 1), yet sharks are frequently caught in association with fisheries targeting IOTC species. Some of the shark species might be retained for their commercial value, others might be discarded due to their non-commercial value or non-retention measures. Moreover, some fleets (for example, the Indonesian, Taiwanese, Spanish and Portuguese fisheries, Japan) are known to actively target both sharks and IOTC species simultaneously. Therefore, in 2012 and 2013, the Commission identified other fish species, especially species of pelagic sharks which make an important bycatch of IOTC fisheries (Table 2) (IOTC Secretariat, 2014). Now, IOTC CPCs are requested to report fishery statistics for these species or species groups in Table 2 at the same level of detail as for the 16 species directly under IOTC mandate (Table 1). But notice the list of shark species interacting with IOTC fisheries is larger than those in Table 2. There are other shark species that may be incidentally caught in some IOTC fisheries (Table 3), however most shark species listed in Table 3 are not oceanic or pelagic sharks. While some catches might get reported to IOTC, their quality is very low and irrelevant (IOTC Secretariat, 2014).

Table 2. Other species identified by the Commission which make an important bycatch of IOTC fisheries. It mostly includes oceanic sharks commonly caught incidentally in IOTC fisheries. Cells shaded in grey refer to individual species or species groups for which reporting of fisheries statistics is obligatory, using the same standards as those used for IOTC species (Table 1); vertical bar cells refer to individual species or species groups for which reporting of fisheries statistics is voluntary; white cells refer to individual species or species groups for which reporting of fisheries statistics is encouraged (IOTC Secretariat, 2014).

	IOTC Code	Group	Species English name	Species French name	Species scientific name	Gear Types[T1]			
						LL	PS	GI	OT
1.	SSP	Billfish	Shortbill spearfish	*Makaire à rostre court*	*Tetrapturus angustirostris*				
2.	MZZ		Other bony fishes nei	Autres poissons osseux nca	*Osteichthyes*				
3.	BSH	Sharks	Blue shark	Peau bleue	*Prionace glauca*				
4.	POR	Sharks	Porbeagle	Requin-taupe commun	*Lamna nasus*				
5.	OCS	Sharks	Oceanic whitetip shark	Requin océanique	*Carcharhinus longimanus*				
6.	PSK	Sharks	Crocodile shark	Requin crocodile	*Pseudocarcharias kamoharai*				
7.	TIG	Sharks	Tiger shark	Requin tigre commun	*Galeocerdo cuvier*				
8.	WSH	Sharks	Great White shark	Grand requin blanc	*Carcharodon carcharias*				
9.	FAL	Sharks	Silky shark	Requin soyeux	*Carcharhinus falciformis*				
10.	DUS	Sharks	Dusky shark[T3]	Requin de sable	*Carcharhinus obscurus*				
11.	RHN	Sharks	Whale shark	Requin-baleine	*Rhincodon typus*		T2	T2	
12.	MAK	Sharks	Mako sharks nei	Requins-taupes nca	*Isurus spp.*				
13.	LMA	Sharks	Longfin mako	Petite taupe	*Isurus paucus*				
14.	SMA	Sharks	Shortfin mako	Taupe bleue	*Isurus oxyrinchus*				
15.	SPN	Sharks	Hammerhead sharks nei	Requins-marteaux nca	*Sphyrna spp.*				
16.	SPL	Sharks	Scalloped hammerhead	Requin marteau halicorne	*Sphyrna lewini*				
17.	SPZ	Sharks	Smooth hammerhead	Requin marteau commun	*Sphyrna zygaena*				
18.	THR	Sharks	Thresher sharks nei	Requins renards nca	*Alopias spp.*				
19.	ALV	Sharks	Thresher Shark	Renard	*Alopias vulpinus*				
20.	BTH	Sharks	Bigeye thresher	Renard à gros yeux	*Alopias superciliosus*				
21.	PTH	Sharks	Pelagic Thresher Shark	Renard pélagique	*Alopias pelagicus*				
22.	MAN	Sharks	Mantas and devil rays nei	Mantas et diables de mer nca	*Mobulidae*				
23.	RME	Sharks	Longhorned mobula	Mante diable	*Mobula eregoodootenkee*				
24.	RMJ	Sharks	Spinetail mobula	Mante aiguillat	*Mobula japanica*				
25.	RMO	Sharks	Smoothtail mobula	Mante à queue lisse	*Mobula thurstoni*				
26.	RMB	Sharks	Giant manta	Manta géante	*Manta birostris*				
27.	PSL	Sharks	Pelagic stingray	Pastenague violette	*Pteroplatytrygon violacea*				
28.	RAJ	Sharks	Rays and skates nei	Rajidés nca	*Rajidae*				
29.	SKH	Sharks	Sharks, rays, skates, etc. nei	Requins, raies, etc. nca	*Elasmobranchii*				
30.	TTX	Other	Marine turtles nei	Tortues de mer nca	*Testudinata*	T2	T2	T2	T2
31.	MAM	Other	Marine mammals nei	Mammifères marins nca	*Mammalia*	T2	T2	T2	
32.		Other	Seabirds	Oiseaux de mer		T2		T2	

T1 Longline (LL), purse seine (PS), gillnet (GI); and other gears (OT), including pole-and-line, handline and trolling.

T2 Incidental catches shall be reported as the total number of specimens caught

T3 Dusky sharks are not included in the list of species agreed to by the Commission; however, some longline fleets report high catches of dusky sharks and therefore they have been included in the table

Table 3. Other shark species that may be incidentally caught in some IOTC fisheries (IOTC Secretariat, 2014).

	IOTC Code	Species English name	Species French name	Species scientific name
1.	OXY	Angular rough shark	Centrine commune	*Oxynotus centrina*
2.	MTM	Arabian smooth-hound	Emissole d'Arabie	*Mustelus mosis*
3.	SHBC	Banded cat shark	Holbiche des plages	*Halaelurus lineatus*
4.	ODH	Bigeye sand tiger shark	Requin noronhai	*Odontaspis noronhai*
5.	BLR	Blacktip reef shark	Requin pointes noires	*Carcharhinus melanopterus*
6.	CCL	Blacktip shark	Requin bordé	*Carcharhinus limbatus*
7.	NTC	Broadnose sevengill shark	Platnez	*Notorynchus cepedianus*
8.	BRO	Copper shark	Requin cuivre	*Carcharhinus brachyurus*
9.	CCG	Galapagos shark	Requin des Galapagos	*Carcharhinus galapagensis*
10.	ORR	Grey bambooshark	Requin-chabot gris	*Chiloscyllium griseum*
11.	AML	Grey Reef Shark	Requin dagsit	*Carcharhinus amblyrhynchos*
12.	CCM	Hardnose shark	Requin nez rude	*Carcharhinus macloti*
13.	SCK	Kitefin shark	Squale liche	*Dalatias licha*
14.	CPU	Little gulper shark	Petit squale-chagrin	*Centrophorus uyato*
15.	CYT	Ornate dogfish	Aiguillat élégant	*Centroscyllium ornatum*
16.	CCP	Sandbar shark	Requin gris	*Carcharhinus plumbeus*
17.	DOP	Shortnose spurdog	Aiguillat nez court	*Squalus megalops*
18.	ALS	Silvertip shark	Requin pointe blanche	*Carcharhinus albimarginatus*
19.	ORI	Slender bambooshark	Requin-chabot élégant	*Chiloscyllium indicum*
20.	CLD	Sliteye shark	Requin sagrin	*Loxodon macrorhinus*
22.	CEM	Smallfin gulper shark	Squale-chagrin cagaou	*Centrophorus moluccensis*
23.	SMD	Smooth-hound	Emissole lisse	*Mustelus mustelus*
24.	SLA	Spadenose shark	Requin épée	*Scoliodon laticaudus*
25.	SKPN	Spinner Shark	Requin tisserand	*Carcharhinus brevipinna*
26.	CCQ	Spot-tail shark	Requin queue tachet	*Carcharhinus sorrah*
27.	ORZ	Tawny nurse shark	Requin nourrice fauve	*Nebrius ferrugineus*
28.	GAG	Tope shark	Requin-hâ	*Galeorhinus galeus*
29.	SSQ	Velvet dogfish	Squale-grogneur velouté	*Zameus squamulosus*
30.	CCD	Whitecheek shark	Requin joues blanches	*Carcharhinus dussumieri*
31.	RHA	White-eyed shark	Requin museau pointu	*Rhizoprionodon acutus*
32.	OSF	Zebra shark	Requin zèbre	*Stegostoma fasciatum*
33.	HXT	Sharpnose sevengill shark	Requin perlon	*Heptranchias perlo*
34.	SBL	Bluntnose sixgill shark	Requin griset	*Hexanchus griseus*
35.	HXN	Bigeyed sixgill shark	Requin vache	*Hexanchus nakamurai*

Despite the large number of sharks and rays interacting with IOTC fisheries (around fifty-five species), the most frequently occurring sharks (reported in the catches for the entire Indian Ocean) are blue shark, which forms the largest proportion comprising 60% of the total reported catches, followed by silky, milk, threshers, hammerheads, makos, oceanic white tip sharks and manta rays forming a smaller percentage (IOTC, 2018b). All these shark species are oceanic and highly migratory capture mostly by industrial purse seiners and longliners, except milk sharks. Milk sharks are relatively smaller species coastal species captured mostly by gillnet fisheries. It is widely known the shark catches reported to IOTC are widely underreported.

The total catches of sharks (and by species) bycatch in IOTC fisheries in the Temperate Ecoregions are poorly known and cannot be estimated. On one side, the shark catches are known to be highly underreported historically to the IOTC Secretariat (for the entire Indian ocean). On the other side, the reported catches are aggregated to large areas, thus, missing the georeferencing needed to allocate them spatially at finer scales. Yet for some fleets operating in the Temperate Ecoregion the bycatch of sharks is well known to the species level, which can provide information on what are the main shark species interacting with IOTC fisheries in this region. The bycatch landed by the Spanish surface longline fleet targeting swordfish in the Indian Ocean, mostly inside the Temperate Ecoregion, shows that the most prevalent shark species in the catch are blue shark and shortfin mako, followed with much smaller proportions by longfin mako, silky shark, oceanic whitetip, porbeagle and hammerheads (Ramos-Cartelle *et al.*, 2008a; Ramos-Cartelle *et al.*, 2008b). Up to 14 different species of sharks are reported in the bycatch of the Spanish surface longline fleet targeting swordfish.

The IOTC considers seven species of sharks as key species or priority species for which executive summaries must be developed. These are blue shark, oceanic whitetip, scalloped hammerhead, shortfin mako, silky, bigeye thresher and pelagic thresher. Only blue shark has been assessed and its exploitation status is known. A stock assessment was conducted for blue shark in 2017 which showed the stock currently not overfished nor subject to overfishing, but the trajectories showed consistent trends towards the overfished and subject to overfishing status, meaning that future catches should be reduced in order to avoid population declines into the red quadrant of the Kobe plot. For the rest of the sharks, the stock status is unknown. There are plans to assess silky shark in 2019, an oceanic whitetip and shortfin mako shark in 2020 and indicator development is being developed for the rest of them. The reality is that the ability to assess the status of shark species remains constrained by the critical gaps in fisheries data (catch, effort and size data) reported by countries and biological data from most sharks species (IOTC, 2018b).

In the absence of reliable stock assessments for shark species, ecological risk assessments provide relative measures of vulnerabilities of each species to the different fisheries. In 2012 the Scientific Committee conducted a preliminary ecological risk assessment (ERA) for shark species (Murua *et al.*, 2012). This ERA, determined by a susceptibility and productivity analysis, ranked the relative vulnerability of 16 sharks to longline and purse fisheries in the IOTC area. This assessment identified the most vulnerable shark species to longline and purse seine fisheries, which has been used to set research and provide advice on shark management to the Commission. Oceanic whitetip shark was ranked as the most vulnerable to purse seine fishery, followed by silky shark and shortfin mako, while shortfin mako, bigeye thresher and pelagic thresher were ranked as the most vulnerable to longline gear (Murua *et al.*, 2012). An ecological risk assessment for sharks in gillnet fisheries in the Indian Ocean is still missing driven by a lack of data availability.

Several shark species known to interact with IOTC fisheries have been listed under Appendix II of the Convention on International Trade in Endangered Species (CITES). Smooth hammerhead (*Sphyrna zygaena*), scalloped hammerhead (*Sphyrna lewini*), oceanic whitetip sharks (*Carcharhinus longimanus*) and whale shark (*Rhincodon typus*) were listed under Appendix II of CITES 2013. Porbeagle and manta rays were also listed under Appendix II in CITES 2013. In 2016, the threshers (*Alopias spp.*), silky sharks (*Carcharhinus falciformis*) and the remaining mobulids (*Mobula spp.*) were also added to the Appendix II of CITES. CITES Appendix II carries a requirement that Parties issue export permits based on finding that take is legal and sustainable.

Aside from those fish species and groups listed in table 1 and 2, there are a larger pool of fish species that may interact with IOTC fisheries and that also may be retained for commercial use. Table 4 show an extended list of bony fish species that may be incidentally caught in some IOTC fisheries.

Table 4. Other bony fish species that may be incidentally caught in some IOTC fisheries (IOTC Secretariat, 2014).

	IOTC Code	Species English name	Species French name	Species scientific name The
1.	BAU	Australian bonito	Bonite bagnard	*Sarda australis*
2.	BAR	Barracudas	Brochets de mer	*Sphyraena spp*
3.	ESCL	Black escolar	Escolier noir	*Lepidocybium flavobrunneum*
4.	MAA	Blue mackerel	Maquereau tacheté	*Scomber australasicus*
5.	BUK	Butterfly kingfish	Thon papillon	*Gasterochisma melampus*
6.	DOL	Common dolphinfish	Coryphène commune	*Coryphaena hippurus*
7.	DOT	Dogtooth tuna	Bonite à gros yeux	*Gymnosarda unicolor*
8.	DBM	Double-lined mackerel	Thazard-kusara	*Grammatorcynus bilineatus*
9.	AMB	Greater amberjack	Sériole couronnée	*Seriola dumerili*
10.	RAG	Indian mackerel	Maquereau des Indes	*Rastrelliger kanagurta*
11.	KAK	Kanadi kingfish	Thazard kanadi	*Scomberomorus plurilineatus*
12.	KOS	Korean seerfish	Thazard coréen	*Scomberomorus koreanus*
13.	SPF	Longbill spearfish	Makaire à rostre	*Tetrapturus pfluegeri*
14.	OIL	Oilfish	Rouvet	*Ruvettus pretiosus*
15.	LAG	Opah	Opah	*Lampris guttatus*
16.	SAP	Pacific saury	Saurie	*Cololabis saira* population
17.	BRA	Pomfrets nei	Castagnoles	*Brama spp*
18.	CFW	Pompano dolphinfish	Dorade	*Coryphaena equiselis*
19.	RRU	Rainbow runner	Comète saumon	*Elagatis bipinnulata*
20.	SSP	Short-billed spearfish	Makaire à rostre court	*Tetrapturus angustirostris*
21.	STS	Streaked seerfish	Thazard cirrus	*Scomberomorus lineolatus*
22.	BIP	Striped bonito	Bonite orientale	*Sarda orientalis*
23.	WAH	Wahoo	Thazard bâtard	*Acanthocybium solandri*

status is unknown for all bony fishes included in Table 4. IOTC does not monitor closely the interactions of IOTC fisheries with none of these species. Yet for some fleets operating in the Temperate Ecoregion the bycatch of fish species (other than those included in the IOTC manadate-Table1) are known to the species level, which provide information on other fish species (non-IOTC fish species) interacting with IOTC fisheries in this region. The bycatch landed by the Spanish surface longline fleet targeting swordfish in the Indian Ocean, mostly inside the Temperate Ecoregion, shows that the most prevalent bony fish species in the catch are shortbill spearfish (*Tetrapturus angustirostris*), escolar fish (*Lepidocibium flavobunneum),* dolphin fish *(Coriphaena spp.) and barracuda species (Sphyraena spp)* (Ramos-Cartelle *et al.*, 2008a; Ramos-Cartelle *et al.*, 2008b). Up to different 11 bony fish species or species groups were reported in the bycatch of the Spanish surface longline fleet targeting swordfish. An ecological risk assessment for bony fish species interacting with IOTC fisheries in the Indian Ocean has been only carried out for purse seiner operating in the tropical region (Murua *et al.*, 2009b) and is still missing for the temperate region.

3.3.2 Non-retained fish and non-fish species including sharks, seabirds, marine turtles and marine mammals

Non-retained bony fish

The quantity of bony fish non-retained, and therefore discarded at sea, dead or alive is poorly monitored, as these species are poorly, or non-reported at all, in logbooks. Yet these data are collected by some fleets via logbooks or as part of the observer programs (IOTC Secretariat, 2014), for example see (Amande *et al.*, 2008) and (Ruiz *et al.*, 2018) for purse seiner non-retained bony fish information. This information is crucial to determine the extent of bycatch and discarding practices in the fisheries and to inform the assessments of the effects of fishing on ecosystems (Garcia *et al.*, 2003).

Non-retained sharks and rays

Thresher sharks and oceanic whitetip shark have non-retention measures in place (Resolution 12/09 and Resolution 13/06) in IOTC. Additionally, resolution 13/05 prohibits purse seine setting on whale sharks and call for safe release of the whale shark if it is inadvertently encircled in the net. All these species occur and interact with IOTC fisheries within the Temperate Ecoregion, but the degree and extent of the interactions are poorly unknown. Additionally, there are other pelagic sharks and rays that may also be captured by IOTC fisheries and, although they do not have non-retention measures in place, are still mostly discarded due to low or no commercial value, such as the crocodile shark, tiger shark or pelagic stingray (Capietto *et al.*, 2014; Cortés *et al.*, 2018). These species are also found in the Temperate Ecoregion. The post-release mortality for these non-retained sharks species after being caught by IOTC fisheries is poorly known for most species, as well as their overall effect on the populations are not well understood (Coelho *et al.*, 2012).

The fisheries population status is unknown in all the non-retained sharks. IOTC has not conducted fisheries assessment for these species. The fisheries data reported to IOTC are very incomplete and underestimate the true catches for these species (IOTC Secretariat, 2014). In addition, very few IOTC CPCs report dead discard estimates for the non-retained sharks. This hinders the possibility for quantitative assessment to determine the status of these species. Without concerned collaborative efforts by all CPCs to report all catches (retained and discarded) and dead discard rates, as well as to estimate total dead discard rates based on information collected in scientific observer programs of their fleets, quantifying total mortality for non-retained sharks seems unachievable (Cortés *et al.*, 2018).

All the non-retained sharks with non-retention measures are listed as threatened on the IUCN Red list as Vulnerable (oceanic whitetip, bigeye thresher, pelagic thresher common thresher, and whale shark). Additionally, these shark species have also been listed under Appendix II of the Convention on International Trade in Endangered Species (CITES).

Oceanic whitetip sharks (*Carcharhinus longimanus*) and whale shark (*Rhincodon typus*) were listed under Appendix II of CITES 2013. In 2016, the threshers (*Alopias spp.*) were also added to the Appendix II of CITES. CITES Appendix II carries a requirement that Parties issue export permits based on finding that take is legal and sustainable.

Non-retained seabirds

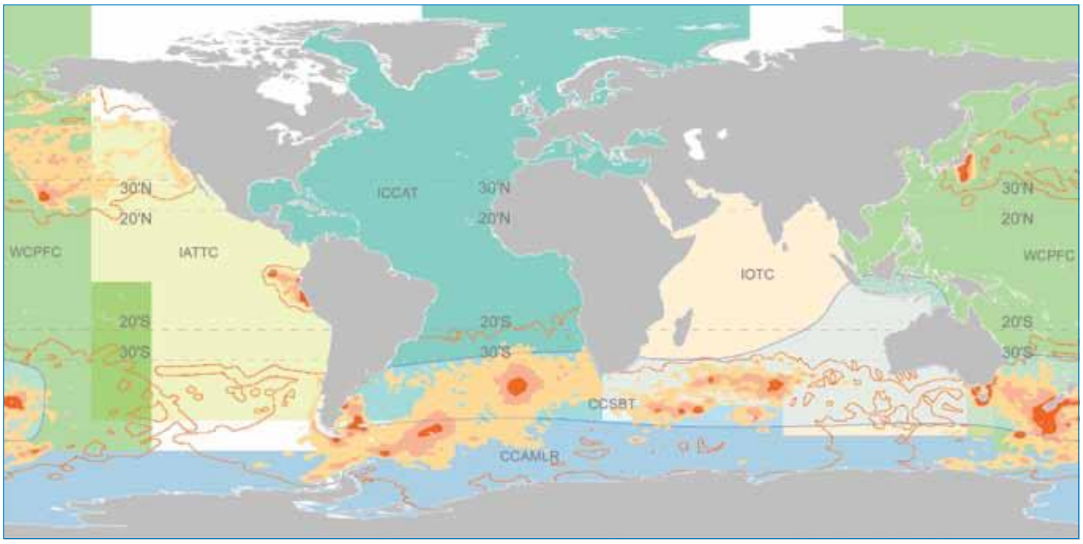
Seabirds live partly in a terrestrial environment for reproduction strategies and partly in the marine littoral and oceanic habitats for foraging or feeding. Multiple anthropogenic threats affect seabirds included fisheries bycatch mortality rates, habitat degradation and loss, overexploitation for their meat, bioaccumulation and pollution and sea level rise (Lascelles *et al.*, 2015). It is often difficult to disentangle these pressures, yet incidental capture in longline fisheries is the primary threat to seabirds at sea, particularly impacting albatrosses (family Diomedeidae) and petrels (family Procellariidae) (Alderman *et al.*, 2011; Croxall *et al.*, 2012; Clarke *et al.*, 2014). The incidental captures of seabirds in purse seine fisheries are low to negligible and in gillnet fisheries remains largely unknown (Zydelis *et al.*, 2013).

The overlap between the albatross and petrels and longline fisheries is highest in higher latitudes, south of 30 degrees (Figure 12) (Carneiro *et al.*, 2017). Therefore, the overlap between the albatross and petrel distributions and IOTC longline fisheries (tuna and swordfish longline fisheries) is significant in the southern parts of the Temperate Ecoregion during the seabird breeding season as well as non-breading seasons (Alderman *et al.*, 2011; Gilman, 2011).

In 2010, a level 1 ecological risk assessment of Indian Ocean seabirds (albatross and petrels) susceptible to bycatch in longline fisheries operations showed 19 species (of the 22 species) have a high behavioural susceptibility to being caught by longliners while the reminding 3 have a low behavioural susceptibility to being caught (Wanless & Misiak, 2016). Of the 22 species, 10 are listed as threatened on the IUCN Red List (Table 5), while four species are listed as Near threatened and two are listed as Least Concern. Despite efforts from IOTC and other tuna RFMOs to reduce the bycatch rates of seabirds, there remains much work to be done to prevent further seabirds population declines (Wanless & Misiak, 2016).

Despite CPCs being generally compliant in reporting requirements on seabird bycatch in longline fisheries as per Resolution 10/06, it has been difficult to conduct assessments of seabird catch levels across fleets driven by the lack of a structured and standardised reporting formats (Angel *et al.*, 2015). However, there are some on-going broad-scale fleet-specific assessments of seabird bycatch to estimate the total seabird bycatch through the Southern Ocean (including the Indian ocean) driven by collaborative efforts among CPCs (Abraham *et al.*, 2018; Winker *et al.*, 2018). These assessments are also planning to produce geospatial estimates of the total seabird bycatches as well as conduct a spatially explicit fisheries risk assessment of seabirds (Abraham *et al.*, 2018; Winker *et al.*, 2018).

BREEDING SEASON



NON BREEDING SEASON

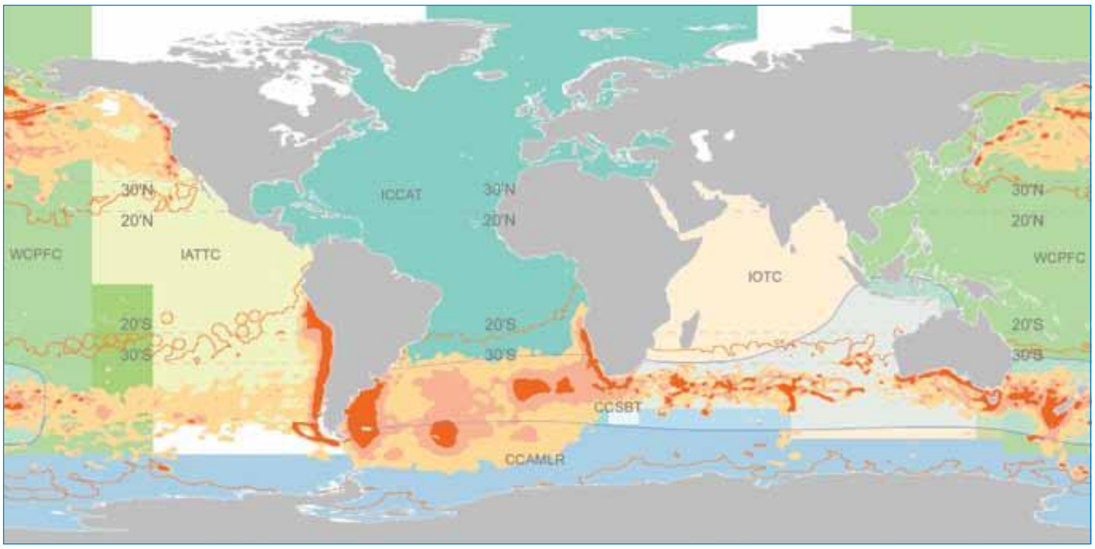


Figure 12. Global density distribution of albatrosses and giant petrels during their breeding seasons (top figure) and non-breeding seasons (bottom figure) in relation to the areas managed by the tuna RFMOs. Figures extracted from Alderman *et al.* (2011). Red, pink and orange shaded areas indicate the 50, 75, and 95% probability contours of albatross and giant-petrel distributions, and the single line indicates the full range based on data available to these analyses.

Table 5. IUCN Red List status of albatross and petrels at risk from tuna longline bycatch in the Indian Ocean (Wanless & Misiak, 2016).

Common name	Scientific name	Behavioural susceptibility to longline capture	IUCN Status 2013
Amsterdam Albatross	*Diomedea amsterdamensis*	High	CR
Tristan Albatross	*Diomedea dabbenena*	High	CR
Northern royal Albatross	*Diomedea sanfordi*	High	EN
Sooty Albatross	*Phoebetria fusca*	High	EN
Atlantic yellow-nosed Albatross	*Thalassarche chlororhynchos*	High	EN
Indian yellow- nosed Albatross	*Thalassarche carteri*	High	EN
Black-browed Albatross	*Thalassarche melanophris*	High	EN
Antipodean Albatross	*Diomedea antipodensis*	High	VU
Southern royal Albatross	*Diomedea epomophora*	High	VU
Wandering Albatross	*Diomedea exulans*	High	VU
Grey-headed Albatross	*Thalassarche chrysostoma*	High	VU
Southern royal Albatross	*Diomedea epomophora*	High	VU
Campbell Albatross	*Thalassarche impavida*	High	VU
Salvin's Albatross	*Thalassarche salvini*	High	VU
Campbell Albatross	*Thalassarche impavida*	High	VU
White-chinned Petrel	*Procellaria aequinoctialis*	High	VU
Light-mantled Albatross	*Phoebetria palpebrata*	Low	NT
Grey Petrel	*Procellaria cinerea*	High	NT
Shy Albatross	*Thalassarche cauta*	High	NT

White-capped Albatross	*Thalassarche steadi*	High	NT
Southern giant Petrel	*Macronectes giganteus*	Low	LC
Northern giant Petrel	*Macronectes halli*	Low	LC

Non-retained marine turtles

Globally there are seven species of sea turtles. Six of them are found in the Indian Ocean and are known to interact with IOTC fisheries through their distribution (Clarke *et al.*, 2014). These species are green turtle (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), flatback (*Natator depressus*), loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*). All are listed on the IUCN Red List as either Vulnerable (leatherback and olive ridley), Endangered (loggerhead and green), or Critically Engendered (hawksbill). Flatback turtle is listed as Data Deficient. The green, loggerhead and hawksbill turtles are the most common and widely distributed in the Temperate Ecoregion, particularly in the south west Indian Ocean (Temple *et al.*, 2018).

Fisheries bycatch of sea turtles are considered one of the major causes of decline of the species (Clarke *et al.*, 2014). In addition to fishing, sea turtles are also known to be threatened by a number of other threats, including poaching and utilization of their eggs, meat and other turtle products, coastal development, pollution and pathogens, and climate change (Wallace *et al.*, 2011; Wallace *et al.*, 2013). However, it is widely recognized that sea turtle interactions with fishing gear is among the most important threat to sea turtles, followed by climate change (Wallace *et al.*, 2011). Therefore, it is important to monitor and estimate the total number of interactions and mortality rates from fisheries bycatch in the IOTC fisheries.

Their threat status aligns with current efforts in IOTC to implement mitigation measures in IOTC fisheries that would avoid their incidental capture and entanglement. The IOTC adopted Resolution 12/04[56] *On the conservation of sea turtles,* which encourages CPCs

[56] http://www.iotc.org/cmm/resolution-1204-conservation-sea-turtles

to implement FAO guidelines for reducing sea turtle bycatch, provide data on fishing interactions, and implement safe handling protocols to maximize survival when are released. Yet, this resolution has been inconsistent among countries. The lack of reported data limits the ability to evaluate population impacts of fishing on sea turtles in the IOTC convention area as well as the assessment of the performance of the implementation of mitigation measures (Williams *et al.*, 2018).

In the absence of reliable data to quantify the cumulative impacts of the different fisheries on sea turtles and the total number of interactions and mortalities in the IOTC area, ecological risk assessments provide relative measures of vulnerabilities of each species to the different fisheries. In 2013 a qualitative level 1 ecological risk assessment was conducted for all species of marine turtles found in the IOTC area to evaluate their interactions with longline, purse seine and gillnet fisheries (Nel *et al.*, 2013). This preliminary ecological risk assessment indicated gillnets posed a greater threat to sea turtles, followed by longliners and to lesser extent by purse seiner. A more recent ecological risk assessment of the vulnerability of sea turtles to IOTC tuna fisheries, including longline, purse seine and gillnet fisheries, was conducted in 2018 (Williams *et al.*, 2018). This assessment showed that all sea turtles present in the Indian Ocean were found to be medium to highly vulnerable to the three types of gears. In general, sea turtles were found to be more vulnerable to gillnets and longline fisheries than purse seine fishing, driven by the large spatial area and depth distribution of longline fishing in the Indian ocean, and also the high post-capture mortality of sea turtles in gillnets. Relevant to the Temperate Ecoregion, this ecological risk assessment identified the green turtle southwest population, the loggerhead southwest population, the hawksbill southwest population and olive ridley west population to be highly vulnerable to longline fisheries and to be at medium risk from the gillnets and purse seiners. Leatherback southwest population was identified to be at medium risk from the three gears. Industrial purse seiners operate at the north western edge of the Temperate Ecoregion (northern edge of the Mozambique channel) which makes the number of potential interactions with sea turtles small in the ecoregion (Williams *et al.*, 2018). Gillnet fisheries, although included in the ecological risk assessments, are poorly monitored in the Temperate Ecoregion. Gillnet fisheries occur at least in Mozambique and Madagascar but their degree of interactions and impacts on sea turtles remain poorly known (Temple *et al.*, 2018).

While the total number of sea turtles interactions with longline gear (and total number of sea turtles released dead) have not been estimated and it is not known in the IOTC convention area, the bycatch rates of sea turtles of longliners is known for some fleets (e.g. Japanese, Taiwanese and Spanish fleets) operating in the Temperate Ecoregion. The Japanese longline fisheries observer programme fishing in IOTC and CCSBT areas between 2010 and 2015, and 1993 and 2015, respectively, observed 28 million hooks from shallower sets and 4 million hooks from deeper-sets (Okamoto & Oshima, 2017). Olive ridley, followed by loggerhead and leatherback occurred most frequently in the bycatch. The bycatch rate for leatherback, loggerhead and olive ridley was 0.00009, 0.0003 and 0 (per 10,000 hooks) for the shallower sets respectively, while the bycatch rate of the deeper sets was 0.001, 0.0003 and 0.012 for leatherback, loggerhead and olive ridley respectively. The green, hawksbill and flatback turtles were not caught. The loggerhead were mostly caught around South African waters by shallow-sets, and olive ridley was caught only north of 20° S. Leatherbacks were caught around South Africa and mostly equatorial waters by both set types (Okamoto & Oshima, 2017). Taiwan reported bycatch rates of 0 for all turtles in the southern Indian Ocean (south of 7°S), relevant to the Temperate Ecoregion, and reported bycatch rates of 0.0112 per 1000 hooks in the northern tropical Indian ocean for the period of 2004-2008. The species recorded included olive ridley, leatherback, loggerhead and green turtles(Huang, 2011). The Spanish longline fisheries observer programme observed 626400 hooks during 555 sets between 10°-35° S catching 22 turtles (0.035 per 1000 hooks), 21 of which were released alive. The turtles identified were loggerhead, leatherback and olive ridley (Mejuto *et al.*, 2006).

Gillnets are poorly monitored in most countries within the Temperate Ecoregion and elsewhere in the Indian Ocean, therefore their degree of interactions and impacts of fisheries on sea turtles remain poor (Temple *et al.*, 2018). Yet the incidental catches, as well as targeted catch, of sea turtles appear widespread in the small scale fisheries in the eastern African countries within the Temperate Ecoregions, with gillnets being one of the coastal fisheries targeting tunas, sharks and other species (Bourjea *et al.*, 2008).

Understanding the spatio-temporal characteristics of sea turtle bycatch by the different gears as well as the cumulative effects of the multiple gears and fleets and total number of sea turtle interactions and mortality rates remains a challenge in the Temperate Ecoregion and elsewhere in the Indian Ocean.

Non-retained marine mammals

Marine mammals consist of cetaceans (whales, dolphins and porpoises), pinnipeds (seals, sea lions and walruses), sirenians (dudongs and manateers), mustelids (sea otters and marine otters) and the polar bear. This section only focuses on cetaceans interactions (here referred as marine mammals) with IOTC fisheries in the Temperate Ecoregion. There are 42 species of marine mammals occurring within the IOTC area of competence (Table 6). It is poorly known the level of interactions of these species with the different gears operating in the IOTC region. Some IOTC CPCs report marine mammal fisheries interactions, but these data have been insufficient and virtually non-existent to calculate species-specific gear interactions and mortality rates at the temporal and spatial scales relevant to provide management advice. Ecological risk assessments of interactions between IOTC fisheries and marine mammals have not been conducted in the IOTC region. Thus, there is a general need to improve the monitoring of the interactions to determine if they are significant, and propose effective mitigation techniques to reduce incidental mortalities for those areas and gears needed.

Marine mammals have broad ocean-wide distributions and are known to interact widely with IOTC pelagic longline fisheries and coastal gillnet fisheries in the Temperate Ecoregion (Clarke *et al.*, 2014). With respect to longline fisheries, it is important to note that marine mammals interactions with longline gear can be classified as either depredation (when marine mammals remove part or all of the caught fish) or entanglement (when marine mammals get captured, i.e., hooked or entangled, with the gear). The presence of these interactions does not imply these species are caught in significant quantities or that individuals die after being caught. However, the magnitude and regional extent of these mammal interactions with the longline gears and post-mortalities is poorly quantified and known in the Temperate Ecoregion and elsewhere in the Indian Ocean. In the Indian Ocean, the interactions of marine mammals with longline fisheries most commonly involve false killer whale and short-finned pilot whales, and less frequently the killer whale (IOTC, 2007). Within the Temperate Ecoregion, some regional estimates from some longline fleets are available. Documented interactions of longline fisheries with marine mammals include Risso’s dolphins and short-finned pilot whales (off Réunion), humpback whales (off Madagascar), and false killer whale, spinner dolphin, finned pilot whales and possibly melon-headed whale (off Mayotte) (Kiszka *et al.*, 2008; Kiszka *et al.*, 2017).

Table 6. Species of marine mammals known to occur within the IOTC area of competence

	IOTC Code	Species English name	Species French name	Species scientific name
1.	BDW	Andrews' beaked whale	Baleine à bec de Bowdoin	*Mesoplodon bowdoini*
2.	BAW	Arnoux's beaked whale	Berardien d'Arnoux	*Berardius arnuxii*
3.	BBW	Blainville's beaked whale	Baleine à bec de Blainville	*Mesoplodon densirostris*
4.	BLW	Blue whale	Rorqual bleu	*Balaenoptera musculus*
5.	DBO	Bottlenose dolphin	Grand dauphin	*Tursiops truncatus*
6.	BRW	Bryde's whale	Rorqual de Bryde	*Balaenoptera edeni*
7.	CMD	Commerson's dolphin	Dauphin de Commerson	*Cephalorhynchus commersonii*
8.	DCO	Common dolphin	Dauphin commun	*Delphinus delphis*
9.	BCW	Cuvier's beaked whale	Ziphius	*Ziphius cavirostris*
10.	DDU	Dusky dolphin	Dauphin sombre	*Lagenorhynchus obscurus*
11.	DWW	Dwarf sperm whale	Cachalot nain	*Kogia simus*
12.	FAW	False killer whale	Faux-orque	*Pseudorca crassidens*
13.	FIW	Fin whale	Rorqual commun	*Balaenoptera physalus*
14.	PFI	Finless porpoise	Marsouin aptère	*Neophocaena phocaenoides*
15.	FRD	Fraser's dolphin	Dauphin de Fraser	*Lagenodelphis hosei*
16.	TGW	Ginkgo-toothed beaked whale	Baleine à bec de Nishiwaki	*Mesoplodon ginkgodens*
17.	BYW	Gray's beaked whale	Baleine à bec de Gray	*Mesoplodon grayi*
18.	BHW	Hector's beaked whale	Baleine à bec d'Hector	*Mesoplodon hectori*
19.	HRD	Hourglass dolphin	Dauphin crucigére	*Lagenorhynchus cruciger*
20.	HUW	Humpback whale	Baleine à bosse	*Megaptera novaeangliae*
21.	DHI	Indo-Pacific hump-backed dolphin	Dauphin à bosse de l'Indopacifique	*Sousa chinensis*
22.	IRD	Irrawaddy dolphin	Orcelle	*Orcaella brevirostris*
23.	KIW	Killer whale	Orque	*Orcinus orca*
24.	PIW	Long-finned pilot whale	Globicéphale commun	*Globicephala melas*
25.	BNW	Longman's beaked whale	Baleine à bec de Longman	*Mesoplodon pacificus*
26.	MIW	Minke whale	Petit rorqual	*Balaenoptera acutorostrata*
27.	DPN	Pantropical spotted dolphin	Dauphin tacheté pantropical	*Stenella attenuata*
28.	KPW	Pygmy killer whale	Orque pygmée	*Feresa attenuata*
29.	CPM	Pygmy right whale	Baleine pygmée	*Caperea marginata*
30.	PYW	Pygmy sperm whale	Cachalot pygmée	*Kogia breviceps*
31.	DRR	Risso's dolphin	Grampus	*Grampus griseus*
32.	RTD	Rough-toothed dolphin	Sténo	*Steno bredanensis*
33.	BSW	Sherpherd's beaked whale	Tasmacète	*Tasmacetus shepherdi*
34.	SHW	Short-finned pilot whale	Globicéphale tropical	*Globicephala macrorhynchus*
35.	SRW	Southern bottlenose whale	Hyperoodon austral	*Hyperoodon planifrons*
36.	EUA	Southern right whale	Baleine australe	*Eubalaena australis*
37.	RSW	Southern right whale dolphin	Dauphin aptère austral	*Lissodelphis peronii*
38.	SPP	Spectacled porpoise	Marsouin de Lahille	*Australophocaena dioptrica*
39.	SPW	Sperm whale	Cachalot	*Physeter catodon*
40.	DSI	Spinner dolphin	Dauphin longirostre	*Stenella longirostris*
41.	TSW	Strap-toothed whale	Baleine à bec de Layard	*Mesoplodon layardii*
42.	DST	Striped dolphin	Dauphin bleu et blanc	*Stenella coeruleoalba*

In general terms, marine mammal interactions with longline gears in the Indian Ocean has focused on reporting mainly depredations rates. The Japanese longline fleet has reported depredation losses from killer whales, false killer whales as well as sharks in yellowfin and bigeye tuna fishing grounds between Mozambique and Madagascar, albacore and swordfish fishing grounds south of Madagascar and off of South Africa as well as the southern bluefin tuna fishing grounds south of 35ºS (Nishida & Shiba, 2006). The pelagic longline fishery targeting tunas, swordfish and sharks off South Africa has reported depredation events by killer whales (*Orcinus orca*) with estimated depredation rates of 10-20% (Petersen & Williams, 2007; Kiszka *et al.*, 2017). The pelagic longline fishery targeting swordfish around the island of La Réunion has also reported depredations rates between 3.7%-5.5% as well as gear damages (Poisson *et al.*, 2007). The IOTC is the only tuna RFMO that initiated a five year research program on depredation issues in the Indian ocean between 1999-2004 which summarized and highlighted marine mammal and shark predations in the Indian Ocean (IOTC, 2007). These research program concluded that the fraction of total catch that suffers from depredation is less than 5% on average, yet large temporal and spatial variation on the depredation rates was observed (IOTC, 2007). This research program did not focus on hooking or entanglement of marine mammals in the Indian ocean, which remains still very poorly documented (Kiszka *et al.*, 2008).

More concerns exist with marine mammal interactions with coastal gillnets in the Indian Ocean, the interactions are poorly documented and more quantitative assessments are needed since gillnets are known to entangle and entrap marine mammals (Kiszka *et al.*, 2008; Kiszka *et al.*, 2017). Within the Temperate Ecoregion, documented interactions of gillnet fisheries with marine mammals include humpback whales, Indo-Pacific humpback dolphins, spinner dolphins, Fraser's dolphin, and bottlenose dolphin in Madagascar (Andrianarivelo, 2001; Razafindrakoto *et al.*, 2008) and humpback and bottlenose dolphins in Mozambique (Guissamulo & Cockcroft, 1997).

3.3.3 Community structure, foodwebs and biodiversity

Catches of tunas and billfishes have increased dramatically during the past 20 years in the Indian Ocean, very likely altering the structure and functioning of the ecosystems through trophic cascades. This might have led to changes on the top-down control exerted by these top-predators, which needs to be combined with the bottom-up effects caused by existing environmental and climatic changes. Studies based on trophic ecology and movements of top predators are useful to assess the impact of fisheries and climate on marine resources, and provide basic elements to construct ecosystem models. The available information about the dynamics of this temperate ecosystem in terms of energy flows, trophic relationships and biodiversity of its food web is very limited. Unlike the Pacific and Atlantic Oceans, few studies have investigated the diet of tunas and billfishes from stomach content analyses in the Indian Ocean, and those available studies mainly focused on the tropical ecoregion of the Indian Ocean (Watanabe, 1960; Kornilova, 1980; Roger, 1994; Maldeniya, 1996; Potier *et al.*, 2004; Potier *et al.*, 2007). Ménard *et al.* (2007) also analyzed the feeding ecology and spatial movements of swordfish and yellowfin tuna in the western Indian Ocean by using their stable isotopic compositions.

In a more recent study, Olson *et al.* (2016) summarized the existing knowledge about the trophic ecology of tuna species in the western Indian ocean, mainly yellowfin (*Thunnus Albacares)*, bigeye (*T. obesus)*, skypjack (*Katsuwonus pelamis)* and kawakawa (*Euthynnus affinis*). They highlighted that they mainly prey on fishes, crustacean and cephalopods, being preferences dependent on the predator species, but also on the season, bathymetry and distance from the coast. In general, the contribution of fish and crustaceans to their diet increases near the coast, and mesopelagic fish are reported to be a relevant prey for some tuna species such as albacore and bigeye tuna, although albacore tuna is primarily limited to more temperate areas. Temporal swifts have also been reported, highlighting for example, a swift in the diet of yellowfin and skipjack tuna between the 80's and the 00's, being *Engraulis japonicus* and *Natosquilla investigatoris* their main prey species in each period respectively for the western area of the Indian ocean. Cephalopod species such as *Histioteuthis bonnelliana*, *Loligo reynaudii* and *Sthenoteuthis oualaniensis* also appear as important preys for yellowfin and bigeye tuna, while they are considered not relevant for other more temperate species, such as the Southern Bluefin tuna.

Biodiversity in terms of alpha and beta diversity (number of species and change in species composition respectively) and evenness (relative abundance of species) have been investigated in the Tropical Indian Ocean in a recent study developed by Lezama-Ochoa (2016). This study analyzed by-catch diversity using the information obtained from the observer programs on the European purse seine fleets. They showed that not only the environment, but also the different fishing types of purse seiners determine differences in species composition. However, no clear pattern was found to explain the differences in species composition between areas and modes of fishing, probably due to low observation coverage during the period analyzed. This type of studies are relevant for providing a better understanding of the ecosystem processes (Lezama-Ochoa, 2016).

It needs to be highlighted that the majority of these research studies have been developed in the northern Indian Ocean (tropical ecoregion), and the development of these type of studies in the temperate area are still needed. Using ecosystem models to analyze the structure and functioning of this temperate system and to derive indicators related to the trophic composition and other community/ecosystem level characteristic is also recommended.

3.3.4 Productivity

In general, the Temperate Ecoregion of the Indian Ocean is a low productivity area compared with the more northward tropical and southward Antarctic areas (Siegel *et al.*, 2013) (Figure 13). There is also high productivity in areas associated with upwelling and the influence of the southern poleward areas. This higher productivity is more evident during the summer in the southern hemisphere (from November to February) (Figure 13) (Kaplan *et al.*, 2014).

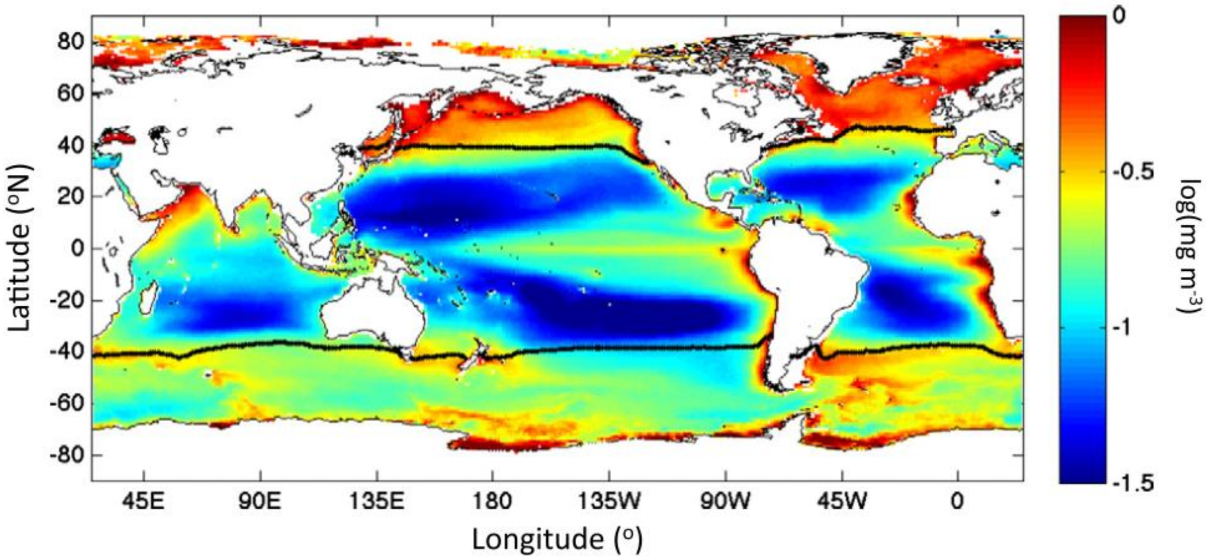


Figure 13. Mean *Chl-a* concentration from SeaWiFS Mission, from August 1, 1997 to December 14, 2010. Extracted from Siegel *et al.* (2013).

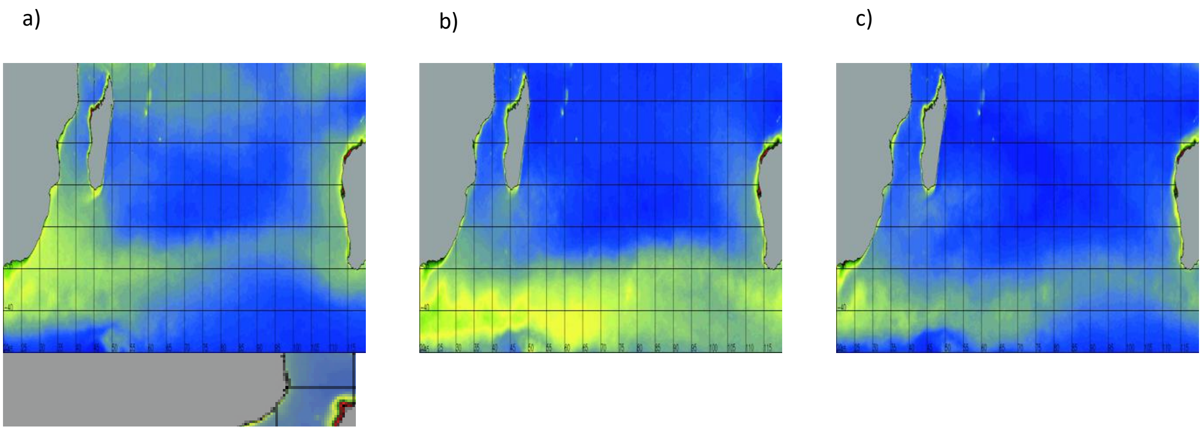


Figure 14. Interannual variability of primary production in the Temperate Ecoregion of the Indian Ocean. Figure a) is for the months July-October, (b) is for November-February and (c) is for March-June. Modified from Kaplan *et al.* (2014).

3.3.5 Habitats of ecological significance

Identifying habitats of ecological significance for the species interacting with IOTC fisheries is also an important tool for the management and conservations of species. Habitat of ecological significance might include areas used by species for spawning grounds and migration corridors, productive areas for feeding, or areas of high biodiversity where multiple species aggregate in a particular time. Consequently, understanding the environmental preferences of species and how they change temporally and spatially, as well as what other biotic factor such as prey preferences, determine the spatial patterns of species, is important to inform the management and conservation of species (Harrison *et al.*, 2017). In particular, when this knowledge is available for multiple species, mapping areas of ecological significance for multiple taxa and their degree of overlap can be used to inform cross taxa area-based management by allocating the spatial and temporal distribution of fishing activities to minimize their impacts.

Habitats of special concern (e.g. reproduction, migration, feeding, hotspots) and habitat utilization and preferences for relevant IOTC species have not been formally investigated and delineated by the Commission or the Scientific Committee. Although the importance of conducting habitat research is acknowledged in the research agenda of the Scientific Committee, research activities and practices to identify habitats of special concern and habitat preferences and utilization for relevant species have been relatively scarce in the IOTC area (Juan-Jordá *et al.*, 2017). The current Working Plan of the Working Party on Ecosystems and Bycatch includes some habitat research activities including connectivity, movements, habitats use and identification of biodiversity hotspots. Moreover, some recent initiatives also recognize the importance of habitat research such as the Shark Research Program for which satellite tagging is identified as priority for shark habitat preferences studies. Furthermore, some studies have been conducted to document habitat preferences and identify most important variables driving the spatio-temporal distributions of some IOTC target species (Arrizabalaga *et al.*, 2015b). Recent efforts to apply ecosystem and habitat modeling include a preliminary application of the SEAPODYM model to swordfish in the Pacific and Indian Oceans, although this model is at the very early stages of development and is not used to provide management advice (Dragon *et al.*, 2014). Other few research activities consist in accounting for environmental factors in several CPUE standardization techniques, particularly for target species in the Japanese longline fisheries (IOTC–WPEB09, 2013). Habitat research focused on the habitat utilization and preferences of bycatch species has been more scant. For blue shark, using detailed fishery observer data from multiple IOTC longline fleets, Coelho *et al.* (2018) mapped habitat use of various stages of the species. In that study, it was noted that adult blue sharks and pregnant females were predominant in the Tropical Regions, with those regions being most likely important mating grounds for the species, while the temperate regions aggregate mostly juveniles and could therefore be considered nursery grounds for the species. More research is needed to understand the spatio-temporal environmental preferences of species, as well as mapping these areas for multiple taxa to inform cross taxa area management.

A relevant process to follow is the Convention on Biological Diversity process to describe Ecologically Biologically Significant Marine Areas (EBSAs) in the world's oceans. This process, which started in 2008 has identified several EBSAs in the Indian Ocean and within the Temperate Ecoregion. The EBSAs have been chosen based on a criteria for identifying ecologically or biologically significant marine areas in need of protection in open-ocean waters and deep-sea habitat (Dunn *et al.*, 2014). These criteria accounts for (1) uniqueness or rarity (2) special importance for life history stages of species, (3) importance for threatened, endangered or declining species and/or habitats (4) vulnerability, fragility, sensitivity, or slow recovery (5) biological productivity (6) biological diversity and (7) naturalness. These EBSA process (and the areas chosen) provide a strong basis and a rich source of information to support marine spatial planning and ecosystem based management within national jurisdictions and areas beyond national jurisdictions (Dunstan *et al.*, 2016). IOTC fisheries is one potential pressure in these areas, and by committing to implement the ecosystem approach, the overlap and extent of IOTC fisheries on these areas needs to be monitored and quantified.

4 CONCEPTUAL ECOSYSTEM MODELS – UNDESTANDING THE KEY ECOLOGICAL INTERACTIONS IN THE TEMPERATE ECOREGION

Key message

- The conceptual ecosystem models developed have exposed 14 ecological interactions to be monitored by ICCAT in the Tropical Atlantic ecoregion in order to ensure the conservation and management of all its fisheries and avoid undesired changes of ecosystem state.
- At this stage, all the ecological interactions identified are treated as equally important to monitor changes in the state of the ecosystem and avoid undesired ecosystem states, however, some interactions might be more relevant than others.
- A future ecological risk assessment should determine the relative importance of these interactions, so the Commission can prioritize research, management actions and make choices between different risks.
- Regulatory and socio-economic interactions should also be identified in future revised ecosystem plans.

4.1 Conceptual ecosystem models of the Temperate Ecoregion

While the ecosystem overview developed in section 3 integrates the existing knowledge of the main pressures and drivers that contribute to the state of the different ecosystem components in the ecoregion, it also allows to identify how the different ecosystem components interact and relate to each other, raising up those emergent issues that IOTC may need to monitor closely in order to ensure the conservation and management of all its fisheries and avoid undesired changes of ecosystem state. For any ecosystem plan it is important to identify key interactions between the different ecosystem components to ensure a more holistic and integrative view of how the different pressures may be affecting species and the structure and functions of the ecosystem they rely. In doing so, we built several conceptual ecosystem models based on the information gathered in the ecosystem overview. In these conceptual ecosystem models, an "interaction" is defined as a component (or group of components) that has an impact on another component (or group of components). The lines indicate links or interactions between components, where an arrow indicates a positive effect on the terminal group, a dot indicates a negative effect on the terminal group, a stripe indicates a neutral effect on the terminal group and a diamond indicates an unknown effect on the terminal group. Furthermore, a solid line indicates direct interactions between components, while a broken line indicates indirect interaction between components driven by a third component. At the end, conceptual ecosystem models are tools that allow visualizing those relevant ecosystem components and their interconnection. They also allow identifying and raising manageable number of issues that may need to be research separately or as a whole and ensures that no critical components are missed. Conceptual ecosystem model can also help to identify trade-offs of management actions on different components of the ecosystem, which may lead to more informed decision-making. In addition, the conceptual ecosystem models can also be used as a tool to synthesize information to the Commission (as well as the public), through the inclusion in glossy educational material and presentations. Therefore, it can be used as a communication tool for ecosystem science.

Figure 15. General conceptual ecosystem model of the Temperate Ecoregion.

The general conceptual ecosystem model of the Temperate Ecoregion elucidates multiple and complex interactions between ecosystem components (Figure 14). *Commercial fisheries*, here seen as one stakeholder, has a negative link to *Retained species,* by decreasing their biomass and altering their size and age structure, while *Retained species* have a positive link to the *Commercial fisheries* stakeholders through the provision of catch and revenue. *Commercial fisheries* have a negative link to *Non-Retained species* by taking them accidentally and releasing them alive, injured or dead, which might have an impact on these populations. In return, *Non-retained species* have a negative link on *commercial fishery* stakeholders by producing them extra costs, for example, the time lost when handling accidental catches, the cost of applying mitigation measures, etc. Similarly, *Illegal, Unreported, Unregulated (IUU) fisheries* have a negative link to *Retained* and *Non-Retained species,* as these fisheries poses additional impacts on fish species and bycatch species which are not accounted in fisheries evaluations, while IUU fisheries benefit from these illegal catches (positive link from *Retained species and Non-retained species to* IUU fisheries). Thus, IUU fisheries is also negatively linked to *commercial fisheries* since such type of activities impact negatively *Commercial fisheries*. *Retained and Non-Retained species* interact with each other through reciprocal positive links and these positive links represent the reliance of these species on each other through trophic interactions such as the provision of food (predatory-pray interactions)*. Commercial and IUU fisheries* by having a negative impact on Retained and Non-Retained species, might also have an indirect negative link with *Foodwebs and Biodiversity*, if *Retained and Non-retained species* are not managed sustainably, which might impact the structure and function of ecosystems making them less resilience to exploitation and climate change.

Abandoned, lost and discarded fishing gear produced by fishing boats, here renamed as *Marine debris*, also can have a negative effect on the ecosystem (Figure 14). *Marine debris* has a direct interaction with *Retained and Non-retained species*, since the lost gears might continue catching and killing species (known as ghost fishing) which also can cause indirect impacts on *Foodwebs and Biodiversity*. At the same time, lost gear can also impact negatively fisheries.

Habitats of ecological significance have a positive direct link to *Retained and Non-retained species* through the provisions of necessary habitat for feeding, spawning, migration corridors, etc. as well as *Foodwebs and Biodiverity. Commercial fisheries* might indirectly impact *Habitats of Ecological Significance* by impacting species and reducing biodiversity (Figure 14).

General environmental impacts of *Climate change* were also included, but their impacts on *Productivity, Retained and Non-Retained Species, Habitats and Foodwebs* were deemed unknown, in part because there is very little research documenting its effect on the Temperate Ecoregion, and also because environmental impacts of climate change could be translated into multiple perturbations and impacts on the different components of the ecosystem in a number of ways (Figure 14). Similarly, *productivity,* producing bottom up changes in the ecosystem, may impact species all the way to the structure and functions of the ecosystem, and this was also considered as "unknown interactions" since it could also perturb and impact the system in multiple ways depending on the regime state of the system.

While the general conceptual ecosystem model presents the main ecosystem components and its main interactions relevant to the Temperate Ecoregion, due to its generality, it also obscures the more detailed interactions between the main fisheries operating in the area and its interactions with species, foodwebs and habitats of ecological significance. Therefore, based on the information gathered in the ecosystem overview, we also constructed more detailed conceptual ecological models which focused on the interactions of each fisheries with the rest of the ecosystem components to identify and list those fishery-dependent ecological interactions that IOTC may wish to monitor and well as to identify fishery to fishery interactions. First, we constructed a conceptual model for the three main fisheries of the region (Figure 16-18). : (1) surface setting longliners targeting mainly swordfish and blue sharks (coded as ELL in Figure 4-5), (2) deep setting longliners mainly targeting tunas. These include the fresh longliners (FLL) and deep freezing longliners (LL), and (3) gillnet fisheries. We did not construct a conceptual model for purse seine fisheries as these fisheries only relatively minor in the region and they operate at the northern limit of the Temperate Ecoregion. Second we constructed a conceptual model where all the fisheries level conceptual models in Figure 16-18 were merged together to understand fishery to fishery interactions as well as the cumulative effect of multiple fisheries on the state of the ecosystem components (Figure 19).

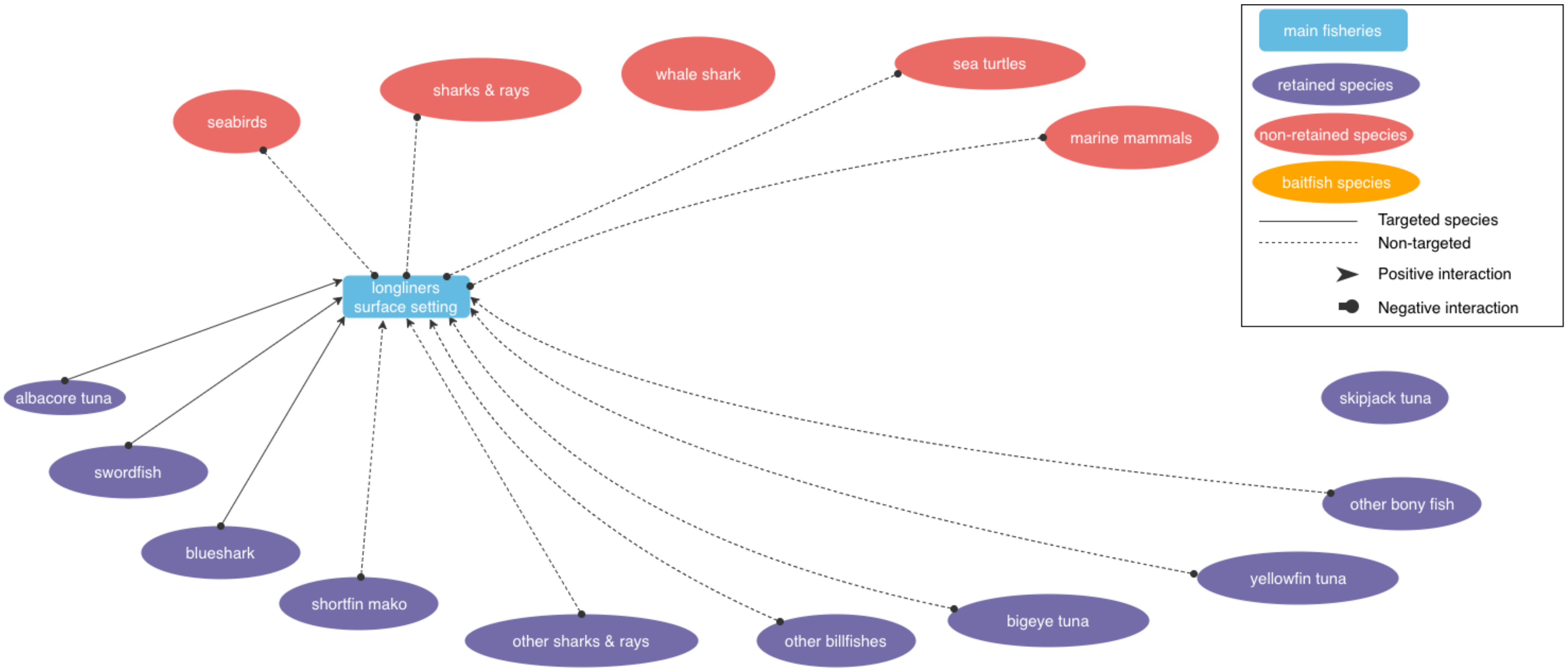


Figure 16. Conceptual ecosystem model of the surface setting longline fisheries operating in the Temperate Ecoregion.

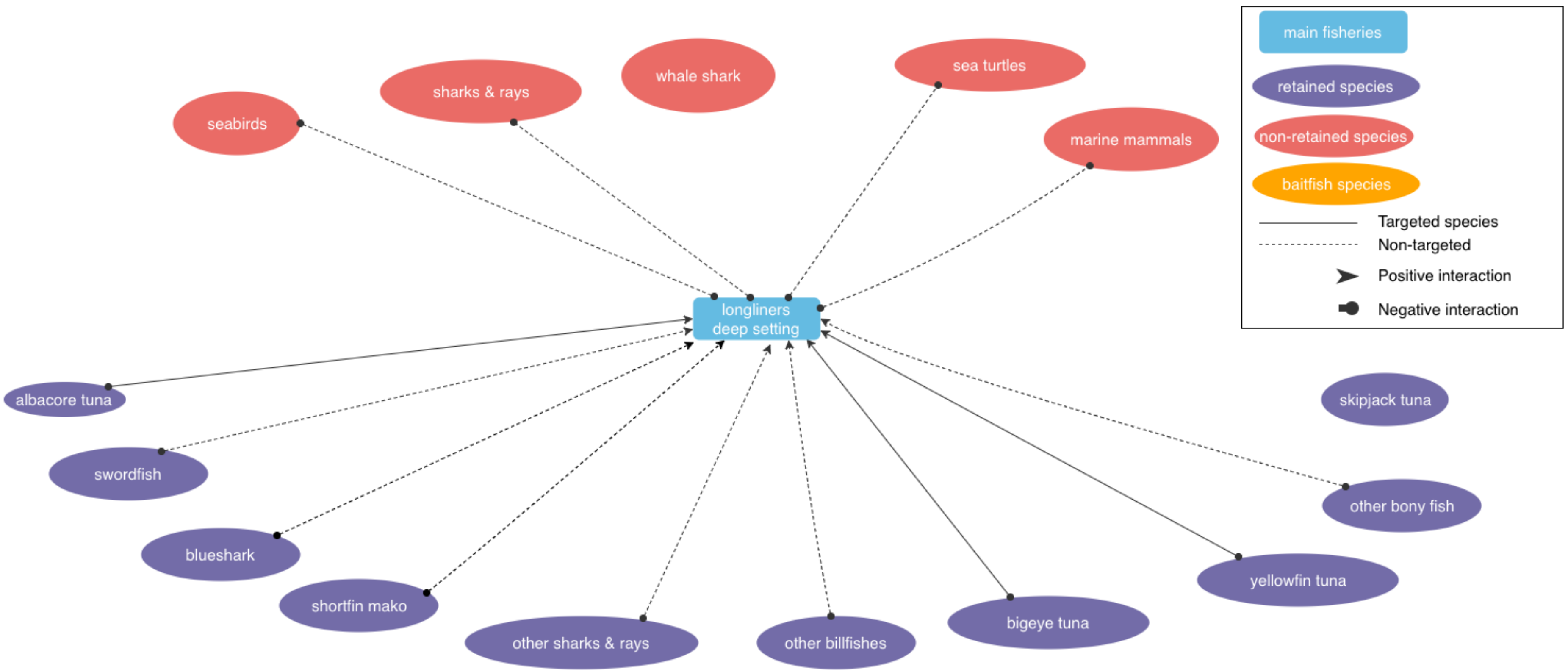


Figure 17. Conceptual ecosystem model of the deep setting longline fisheries operating in the Temperate Ecoregion.

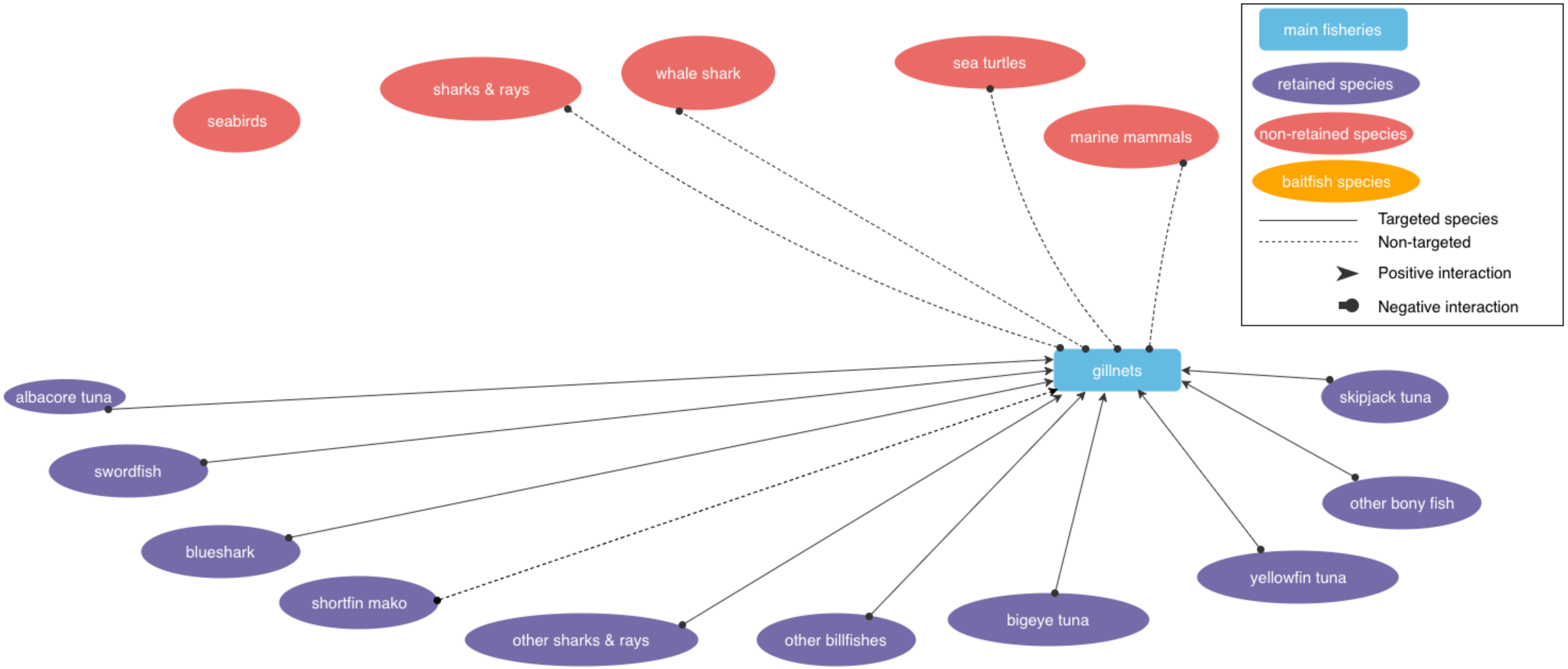


Figure 18 . Conceptual ecosystem model of gillnet fisheries operating in the Temperate Ecoregion.

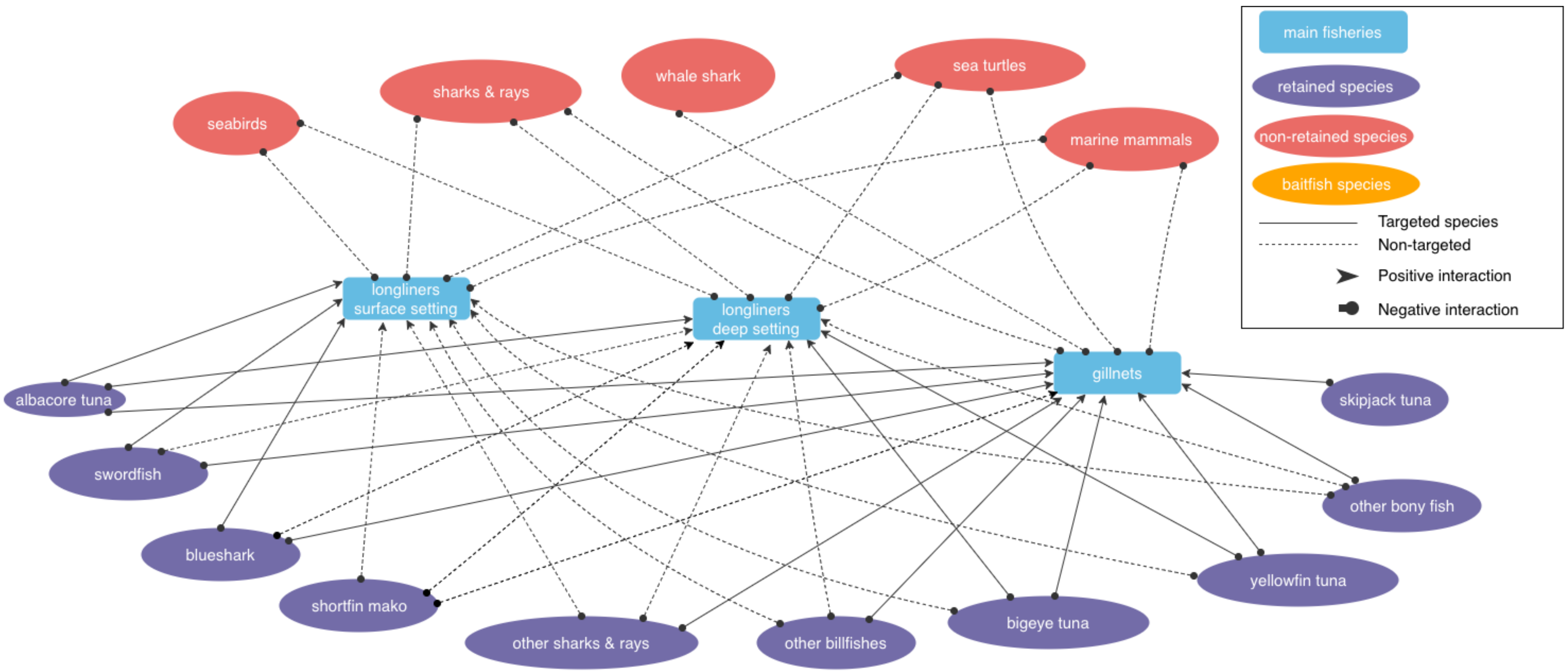


Figure 19. General multifishery conceptual ecosystem model of the Temperate Ecoregion.

4.2 Key ecological interactions to be monitored in the Temperate Ecoregion

The conceptual ecosystem models presented in section 4.1 were used to identify broad interactions categories and key ecological interactions within each broad category (Figure 20)) which are deem relevant to be monitored in the temperate Indian ecosystem.

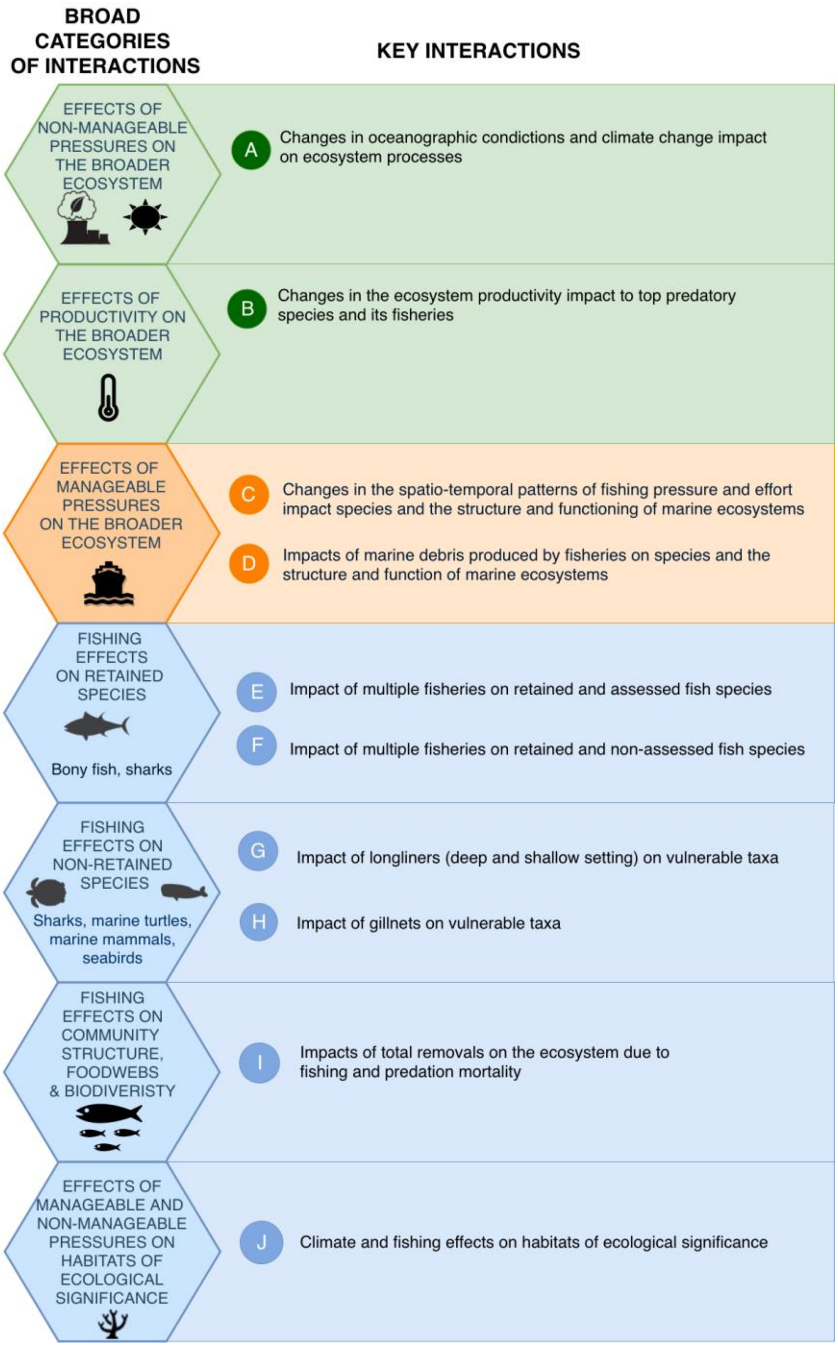


Figure 20. Key interactions considered relevant in the Temperate Ecoregion to be monitored by the Commission.

It is recognized that there are many more ecological interactions operating in the ecosystem within each of the main broad interaction categories identified. It is expected that the importance of these and complementary interactions will be re-evaluated in future updates to this ecosystem plan. At this stage, we are only identifying and defining the relevant ecological interactions in the Temperate Ecoregion and we are treating them as equally relevant to monitor changes in the ecosystem and avoid undesired ecosystem states. However, some interactions might be more relevant than others, either because they are more prevalent and have a higher probability to occur or because their level of impact might be relatively higher which might be imposing a high cost to the fishery or the ecosystem. Therefore, it is not only important to identify the existing ecological interactions, but also their importance to assess their relative risks (NPFMC, 2007). In the future, an ecosystem risk assessment should be conducted to determine the degree of importance of each interaction to the Commission. An ecosystem risk assessment aims to quantify the strength of each interaction, its risk, based on two sources of information, their probability of occurrence as well as the level of impact to the current ecosystem state. Defining these interactions and their relative importance and risk in the system, can provide the Commission with a tool to prioritize potential issues, make choices between different risks and trade-offs or take actions to avoid unwanted risk through appropriate management actions (NPFMC, 2007).

4.3 Matching key ecological interactions with management objectives

Monitoring the key interactions with ecosystem indicators allows to provide feedback to IOTC about the state of each interactions, as well as identify the research and data gaps than hinders the monitoring of specific interactions. Ecosystem indicators as well as management objectives are key to monitor key interactions as well as to determine how a well an interaction is managed (or simply monitored by surveillance indicators) in relation to management objectives. Consequently, next we propose a series of candidate management objectives which can be used to measure the performance of indicators (proposed in section 5) towards achieving specific goals within each broad interactions categories (Figure 21).

The management goals for each broad interaction category ideally should be discussed and agreed by the Commission. The management goals should encapsulate key principles of the ecosystem approach such as the sustainable use of fish resources, the conservation of biodiversity and the maintenance of resilient ecosystems. Until the Commission defines and adopts specific management goals for each broad interaction category, this pilot ecosystem plan will be based on the proposed management goals which intends to express IOTC aspirations reflected in its Convention mandate, on-going negotiations for a Convention Amendment, and adopted recommendations and resolutions as well as relevant internationally agreed standards (Garcia *et al.*, 2018).

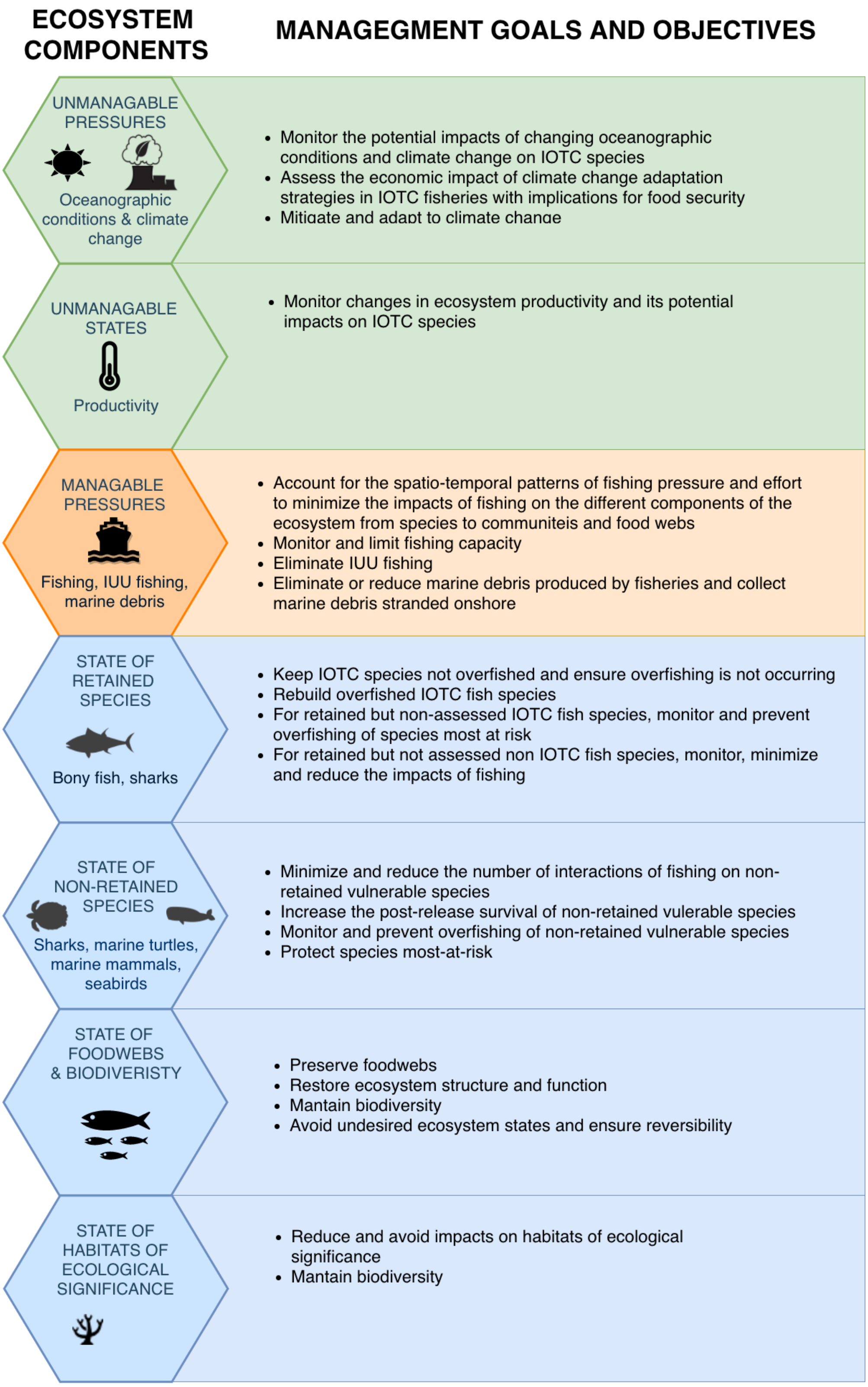


Figure 21. Ecosystem components linked to management goals.

5 SKELETON OF AN INDICATOR BASED ASSESSMENT FOR MONITORING ECOSYSTEM INTERACTIONS

Key message

- For each of the ecological interaction identified, we list candidate management objectives and ecosystem indicators with their potential data sources and research needs, expose the risks of not monitoring these interactions, and how the commission is (or should be) addressing the risks.
- Of the proposed ecosystem indicators, only a small number are routinely monitored by ICCAT. Many indicators could potentially be developed in the short term using the data available in ICCAT, the data collected from the observer programs, and data from external sources. Ecosystem indicators ,for which data are not currently and readily available for their estimation, are still included in the proposal, to guide future data collection and research efforts.
- The identified interactions and proposed indicators intend to be an interim step towards developing a comprehensive ecosystem status assessment in the Tropical ecoregion to provide the Commission with an integrated overview of the health ecosystem, and provide early signals that might warrant management interventions.

5.1 Tracking ecosystem indicators between ecosystem components and implications for management, priorities and considerations for the Commission

Ecosystem indicators can be used to monitor ecological interactions between ecosystem components which can be used to inform the Commission about ecological processes and the linkages between human pressures and the state of ecosystem components. Monitoring key interactions with ecosystem indicators provides feedback to the Commission about the state of each interaction and the research and data gaps. Therefore, the ecosystem indicators proposed in this section can have two main purposes under this ecosystem plan: (1) to help assess the state of the ecosystem components and their relevant interactions, and (2) to assess how well a fishery is managed in relation to objectives (NPFMC, 2007).

Next, for each broad category and interaction identified (Figure 20), we describe each interaction and the risk of not monitoring it. We also present management objectives and a series of candidate indicators to track the state of the interaction. The proposed indicators are divided into three categories depending on the on-going work in IOTC and data availability to estimate them: (1) Indicators currently estimated and/or monitored in IOTC; (2) Indicators for which data is potentially available (or partially available), but are not currently estimated and/or monitored by IOTC; (3) Indicators for which data is not currently and readily available for their estimation, but are included to guide future data collection and research efforts. Notice that we merely propose a list of candidate indicators and we do not go through the process of estimating them or describing the time frame, mechanisms and costs for monitoring these indicators. However, for each interaction and candidate indicators, we discuss their data sources, data gaps and research needs, if relevant, in order to provide qualitative guidance about their feasibility to be used in the future for monitoring purposes. In the future, when some of these indicators are estimated, their performance also should be monitored against some reference points (or thresholds). The determination of critical thresholds to achieve management target is fundamental as well as determining the appropriate management actions that should take place. While these elements are not covered in the present pilot ecosystem plan, we refer to the guidelines developed as part of this SC02 project for setting reference points for a wide range of ecosystem indicators (see Task 4 of SC02 final report).

Last, we also provide a synopsis of what the Commission is doing to monitor (and potentially address the potential risks) for each of the interactions. We also identify actions that the Commission may need to initiate to monitor and address the potential risks associated with the interactions. Recommendations actions include suggestions of research needs to fill data and analysis gaps as well as specific Commission level analysis and actions (NPFMC, 2007).

5.2 Effects of non-manageable pressures on the broader ecosystem

5.2.1 Changes in oceanographic conditions/climate change impact ecosystem processes

Description

There are well known relationships between environmental variables such as temperature, pH, current speed and O2 concentration on the biological rates (growth, feeding, spawning, migration, etc.) of marine species (Dell'Apa *et al.*, 2018). Some of them have proven direct impacts on primary productivity and thus the forage base (Brown *et al.*, 2010). Given this, strong direct (exotherms and their habitat) and indirect (shift in distribution and abundance of species) dependency on oceanographic conditions, it is clear that environmental variability may greatly affect the dynamics of IOTC species and ecosystem processes in general, both in the short-medium- and the long-term.

What is the risk of not monitoring this interaction

The abundance/biomass, horizontal and vertical distribution and reproductive capacity of species most vulnerable to environmental variability might change due to natural variability in the marine environment, which can be aggravated by climate change. This might lead to a dangerous decrease of IOTC species abundance and/or a horizontal migration of species to more temperate waters, that could end up having socio-economic impacts for IOTC fisheries as well as mismanagement based on current knowledge.

Management objectives

-Monitor the potential impacts of changing oceanographic conditions and climate change on IOTC species

-Assess the economic impact of climate change adaptation strategies in IOTC fisheries with implications for food security

-Mitigate and adapt to climate change

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in IOTC	Indicators currently not monitored in IOTC for which data are potentially available	Indicators currently not monitored in IOTC for which data are not available
• Sea surface temperature (SST)* • Water column descriptions (e.g. mixed layer depth-MLD)*	• Sea surface temperature (SST) • Water column descriptions (e.g. mixed layer depth-MLD) • Chlorophyll concentrations/primary production • Chlorophyll concentration and seas surface temperature gradients (Fronts) • Sea level anomaly • Eddie Kinetic Energy • Dissolved oxygen concentration • Tropicalization index for a community of species	

*Collected in some observer's programs but not widely used.

Data sources, data gaps and research needs

Some environmental data is collected by some CPCs as part of their observers programs in the IOTC area (mainly SST and wind speed from which MLD can be derived). Current speed and direction may also be measured in each fishing operation. However, all these variables are not being currently processed and used widely, and it is not known the extent of their existence and their quality. Alternatively, the proposed environmental indicators can be estimated based on data derived from existing remote/in situ sensing and model products from open-access data bases, such as the Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/), the NOAA Environmental Research Division's Data Access Program (ERDDAP) (http://coastwatch.pfeg.noaa.gov/erddap/) and Bio-ORACLE - Marine data layers for ecological modelling (http://www.bio-oracle.org/).

More research is required in investigating how potential changes in current oceanographic condition might directly and indirectly affect the dynamic of IOTC species. Identifying most vulnerable species to these environmental changes is fundamental. Using habitat modelling and forecasting approaches as in other tuna RFMO areas (mainly in the WCPFC and IATTC) could help forecasting these effects and providing some scientific advice for a more precautionary management of these species (Lehodey *et al.*, 2010; Lehodey *et al.*, 2011; Arrizabalaga *et al.*, 2015a).

Recommendation for indicator development

- Identify and monitor those species most vulnerable to environmental changes and climate change.
- Identify and prioritize those environmental indicators that could more likely cause relevant effect on the dynamics of IOTC species.
- Explore the potential of using environmental data derived from observer programs.
- Identify remote sensing real time environment monitoring systems to collect the environmental data.

Relevance and implications for management

(c) How is the Commission addressing the risk now?

- The Commission is not monitoring or accounting for the effects of the environmental variability on IOTC fisheries and species, though some research has been conducted and accounted in some individual species assessments.

(d) What other actions might the Commission put in place to address and mitigate the risk?

- Conduct a series of ecological risk assessments to identify those fish species most-vulnerable to changes in oceanographic conditions and climate change.
- Produce a coherent and revised list of species that are vulnerable to oceanographic conditions and climate change for monitoring purposes.
- Identify and monitor environmental variables that could more likely cause relevant effect on the dynamics of IOTC species.
- Develop annual environmental conditions report.
- Model and forecast the potential impacts of climate change on most vulnerable species to climate change.
- Assess the economic impact of climate change and climate change adaptation strategies for IOTC fisheries and its implications for food security.

5.3 Effects of productivity on the broader ecosystem

5.3.1 Changes in ecosystem productivity impact top predatory species and its fisheries

Description

The amount of biomass of primary producers, and so, the energy at low trophic levels in an ecosystem, limits and controls the productivity of the systems in terms of the biomass of higher trophic level predators that are mainly caught in IOTC fisheries. These bottom up changes are often linked to the climate and physical interactions. In addition, some external stressors (for example, nutrient runoff fertilizing freshwater systems) may also cause changes in energy pathways from lower to higher trophic level triggering other ecosystem processes that might result in changes in species biomass and trophic relationships. Reductions in energy flow from lower trophic levels may lead to precipitate competition for scarce resources at higher trophic levels; and increases in energy flow on the contrary, could favor certain higher trophic level species in one pathway, allowing them to outcompete predators relying on another pathway.

What is the risk of not monitoring this interaction

A reduction in primary production may negatively affect the production of the commercially important IOTC species and might contribute to a non-intended overfishing of stocks before the signal is completely clear. Bottom-up changes are likely to favor some species over others in competition for shared resources, potentially resulting in economic trade-offs.

Management objectives

-Monitor changes in ecosystem productivity and its potential impacts on IOTC species

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in IOTC	**Indicators currently not monitored in IOTC for which data are potentially available**	**Indicators currently not monitored in IOTC for which data are not available**
None	• Primary production • Zooplankton biomass and/or abundance • Zooplankton biomass and size structure • Low trophic level biomass (e.g. small pelagic fishes biomass)	

Data sources, data gaps and research needs

There are different data sources that provide this type of information to different users worldwide. The most effective and widely used method of measuring primary production is by measuring *Chl-a* concentrations with remote sensing (see final SC02 report Task 2.3). But there are also other sources, such as the Continuous Plankton Recorder (CPR) that could provide information about phyto- and zooplankton biomass and size structure. However, the amount and quality of data obtained with the CPR in the Temperate Ecoregion needs to be investigated and similar programs could be promoted in the Temperate Ecoregion.

Recommendation for indicator development

-Make use of existing databases (for example, remote sensing products and CPR) to monitor ecosystem productivity.

-Develop ecosystem models that are able to include these low trophic levels in the system and analyze their evolution in time and space, linking them with the dynamic of the higher trophic levels of that system.

Relevance and implications for management

(c) How is the Commission addressing the risk now?

- There is no action taken by the Commission to address this issue at the moment.

(d) *What other actions might the Commission put in place to address and mitigate the risk?*

- Integrate the remote sensing and low trophic level information available in public data sources with the information collected by IOTC, both from the fisheries and also from the observers programs, to analyze potential links between system productivity and productivity of IOTC species.
- Explore the interaction between primary and secondary production and non-IOTC species (e.g. small pelagics) and IOTC species dynamics.
- Develop ecosystem models and integrated methods to produce scenarios of low and high productivity for forecasting potential effects of changes in ocean productivity on top predators (IOTC fisheries).

5.4 Effects of manageable pressures on the broader ecosystem

5.4.1 Changes in the spatio-temporal patterns of fishing pressure and effort impact species and the structure and functioning of marine ecosystems.

Description

The overall extent of fishing pressure and effort and the associated spatio-temporal patters of fishing are important to be monitored in order to draw sounds conclusions regarding the impacts of fishing on the different components of the ecosystems as well as inform management strategies to minimize and avoid impacts. It is essential to consider the spatial extent and patchiness of the fishing activity, as well as to have information about the consistency with which areas are fished in the same regions from year to year. Furthermore, it is important to monitor fishing capacity. Excess capacity might contribute to overfishing, declines in food production potential as well as economic waste.

What is the risk of not monitoring this interaction

Not taking into account the spatio-temporal patterns of fishing activity limits the potential of defining area-based plans to minimize regional impacts of fishing on main target species, as well as protect vulnerable taxa (e.g. avoid localized depletions).

Management objectives

-Account for the spatio-temporal patterns of fishing pressure and effort to minimize the impacts of fishing on the different components of the ecosystem from species to communities to foodwebs.

-Monitor and limit fishing capacity.

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in IOTC	Indicators currently not monitored in IOTC for which data are potentially available	Indicators currently not monitored in IOTC for which data are not available
• Number of active IOTC vessels operating in the area annually, and type and size of vessels • Total catch spatially and over time • Total catch and effort (and size) distribution spatially and over time for all gears • Number of hooks deployed by longliners spatially and over time	• Total fishing activity as hours fished per square km by vessels with AIS or VMS systems • Vessel track intensity measured with AIS or VMS systems • Mean Trophic Level Indicators (catch data)	

Data sources, data gaps and research needs

The submission of annual catches (IOTC form1) for each species per fleet, gear and year (which includes retained catches and discards), the submission of fishing vessel statistics (IOTC form 2) which refers to the number of vessels operated by fleet, type of vessel, size class, gear and year, the submission of catch and effort data (IOTC form 3) which refers to the fine scale data reported by fleet, year, gear, month, spatial grid and species), the submission of length-frequency data (IOTC form 4), which refers to individually body lengths of IOTC species per fleet, year, gear, month and spatial grids, is mandatory for each IOTC CPC. However, the compliance by CPC, especially, with the submission of length-frequency and catch-and effort data is far from being completed and in most of the cases catch-and-effort data is not submitted for the complete fleet covering all the annual catches reported by CPC in form I (IOTC, 2017).

IOTC does not maintain a database of catch distribution by gear raised to total landings by time-area strata (5x5 degrees squares, quarter and gear) for all the IOTC species, only is done for main commercial tuna species and swordfish. A georeferenced dataset for catches would allow monitoring and analysing total catches spatially over time for IOTC species within IOTC convention area, which could be used to develop region-based indicators. This limits the estimation of some of the proposed indicators since it would not be possible to extract and analyze the fisheries data relevant to the Temperate Ecoregion.

IOTC maintains a database of catch and effort distributed by time-area strata (month and 5x5 degree square), similar to the one maintained in ICCAT. However, ICCAT has also estimated the overall Atlantic longline- and purse seine effort by time area strata (5x5 degrees squares and quarter) which IOTC has not. However, there are ongoing discussions about the adequacy of the scales used in this dataset, which uses 5 degrees squares and months as the minimum spatial and temporal resolution, which is too poor to inform any type of area-based management responses.

IOTC monitors the total number of active IOTC vessels operating in the convention area. It is believed that the number of vessels fishing for IOTC species in the Indian Ocean is known with more accuracy in the recent years thanks to information collected after the implementation of IOTC Resolutions that call for countries to report yearly lists of domestic and foreign fishing vessels, information collected through the IOTC Transhipment Programme and market data provided by the International Seafood Sustainability Foundation (IOTC, 2017). However, the vessel statistics are generally available only for industrial fleets whose catches are available, and vessels statistics are not available, are incomplete or inaccurate for many artisanal fleets (IOTC, 2017).

The recent expansion of the automatic identification system (AIS) presents an opportunity to monitor fishing activity at fine spatio-temporal scales to quantify the behavior of global fishing fleets, including fleets targeting tuna and tuna-like species, down to the individual vessels (Kroodsman *et al.*, 2018). However, not all of the vessels, both large and small, have AIS and, thus, before using this potential information an analysis of the strengths and weaknesses of the tool by gear and member countries should be carried out. Similarly, VMS systems have been implemented in IOTC vessels for many years for all commercial fishing vessels exceeding 24 meters length overall and for those smaller than 24 meters but operating outside its EEZs. But it is mostly a compliance tool and the data belong to the member countries, so it is not usually shared for scientific purposes at the IOTC scientific committee level (at least on a region wide scale). In fact, VMS has actually been implemented for much longer than AIS and could also be very useful for monitoring the spatio-temporal dynamics of fishing fleets.

Recommendation for indicator development

- Develop a georeferenced catch dataset and georeferenced effort dataset for all IOTC species, gears and countries.
- Determine the best unit of effort for each gear.
- Develop complete catch-and-effort datasets by gear/country.
- Develop a complete database for active IOTC vessels and its characteristics.
- Explore the utility of AIS and VMS to monitor the spatio-temporal dynamics of IOTC fishing fleets.

Relevance and implications for management

(c) *How is the Commission addressing the risk now?*

- It monitors the number, type and size of vessels fishing IOTC species in the Indian Ocean, but it remains incomplete.

(d) *What other actions might the Commission put in place to address and mitigate the risk?*

- Improve compliance with catch, size, effort and fishing vessels statistics.
- Develop a georeferenced catch and effort dataset for all IOTC species, gears and countries.
- Request countries to make available VMS data for the scientific committee and scientific use.
- Explore the AIS and VMS data to estimate indicators and monitor fishing activity at finer spatio-temporal scales in IOTC fisheries.

5.4.2 Impacts of marine debris produced by fisheries on species and the structure and function of marine ecosystems

Description

Abandoned, lost and discarded fishing gear, here referred as marine debris, can cause ecological problems for marine species when floating gears continue catching and killing organisms (known as ghost fishing). It can also have an impact on sensitive habitats when stranded offshore as well as cause socio-economic problems for the fishing fleets by increasing costs when lost unintentionally. Potentially fishing boats operating in the Temperate Ecoregion may lose gear (or associated), discard gear or abandon gear, yet the extent and magnitude of the marine debris derived by longliners (the major gear operations in this region) is unknown or poorly known. While the purse seine fishery is small in the Temperate Ecoregion, some drifting FADs and GPS buoys lost may impact some coastal areas (e.g. Madagascar coast) in the northern area of the Temperate Ecoregion.

What is the risk of not monitoring this interaction

Not accounting for the mortality due to ghost fishing in population and stock assessment models has the potential to make less effective the harvest strategies of managed species as well as affect the state of the most vulnerable species such as sea turtles, marine mammals, seabirds and some sharks and bony fishes (Coggins *et al.*, 2007; Gilman *et al.*, 2013). Accumulation of marine debris produced by fisheries along the coast can also impacts the health of coastal ecosystems and their utilizations by coastal communities.

Management objectives

-Eliminate or reduce marine debris produced by fisheries

-Collect marine debris stranded onshore

Candidate Indicators to evaluate whether objectives are met:

Indicators which are currently estimated and/or monitored in IOTC	Indicators currently not monitored in IOTC for which data are potentially available	Indicators currently not monitored in IOTC for which data are not available
• FAD losses	• Number of drifting FADs lost outside fishing grounds • Number of FADs/GPS buoys stranded on the coast • Number of drifting gear (derived from longliners) lost and stranded on the coast	

Data sources, data gaps and research needs

IOTC has started to collect and held a database with the number of drifting FADs lost outside fishing grounds but not for the number of FAD/GPS buoys stranded on the coast or for any gears and fleets operating in the Temperate Ecoregion or elsewhere in the Indian Ocean. Instead individual CPCs might have access to this type of information for their individual fleets, as shown by the EU French purse seine fleet operating in the ecoregion (Maufroy *et al.*, 2015; Zudaire *et al.*, 2018). More large-scale examinations of the spatio-temporal patterns of drifting FADs deployed by the different purse seine fleets operating in the ecoregion will be crucial to understand the cumulative effects and impacts of drifting FADs-GPS lost on the pelagic environment. It would be more challenging to examine the spatio-temporal patters of gear abandoned, lost or discarded by longliners and gillnets in the Ecoregion.

Recommendation for indicator development

- Examine the spatio-temporal patters of gear abandoned, lost or discarded by longliners and gillnets in the Ecoregion.

Relevance and implications for management

(c) How is the Commission addressing the risk now?

- It does not monitor or maintain a database with the extent and magnitude of marine debris produced by IOTC fisheries, however, it has a requirement to mark fishing gear to identify ownership and increase visibility of passive gear (Gilman, 2015) .
- Some CPCs have their own agreements and protocols to monitor and control lost, abandoned and discarded fishing gear(Gilman, 2015).

(d) What other actions might the Commission put in place to address and mitigate the risk?

- Encourage all CPCs to establish protocols for data collection and monitoring for the lost fishing gear of its fleets and report to IOTC to facilitate the quantification of cumulative effects across all gears and fleets
- Promote preventive measures such as the use of technology to track gear position for their retrieval and reduce the incidence of gear loss
- Implement measures to reduce the abandonment and discarding of fishing gear at sea
- Establish port reception facilities and compensation schemes for recycling unwanted gears.

5.5 Fishing effects on retained fish species

This broad interaction aims to monitor the impacts of fishing on the fish species retained by IOTC fisheries. Each fleet preferentially targets a species or set of species but also catches incidentally other fish species that may be retained because of their commercial value (Figure 15-17). IOTC fisheries retain a large number of fish species, including the main commercial tunas, billfishes, small tunas and other bony fishes, and some sharks.

However, it is important to distinguish between those fish species that are part of IOTC convention mandate (Table 1), or extended list fish species which make an important component of bycatch and retained catch (Table 2) for which CPCs are requested to report fishery statistics. For those fish species not included in Table 1 or 2, IOTC has still the responsibility, at least, to monitor the interaction of its fisheries on those fish species (Table 3 and 4).

This ecosystem plan addresses the impacts of fishing effects on retained and assessed fish species (interaction 5.5.1) and retained but not assessed fish species (interaction 5.5.2), separately, because it is presumed the data availability for indicator development differs for those two types of interactions.

5.5.1 Impacts of fisheries on retained and assessed fish species

Description

This interaction is the most monitored in IOTC of all, as IOTC was created to ensure the sustainable use of species under its mandate (Table 1). IOTC has the responsibility to assess on principle the state of 16 species, of which part of the core distribution of 9 of them are found at the Temperate Ecoregion. Those species are targeted by multiple fisheries and fleets (see conceptual model figures in section 4) and to date, IOTC has conducted fishery stock assessments for all of them and the exploitation status is known for 12 of them. While IOTC extended the list of fish species under Table 1 to include those species, largely oceanic sharks, which make an important component of bycatch and retained catch (see Table 2), from this extended list only blue shark has been assessed for which exploitation status is known. For these species and stocks, for which fisheries stock assessment are available, there are a number of indicators that are routinely produced to monitored and track the state of the species in response to fishing.

What is the risk of not monitoring this interaction

Not monitoring the impacts of fisheries on retained fish species can lead to overfishing of the stocks which can drive stocks bellow acceptable levels of productivity and risk (overfished and/or overfishing status), followed by depletion and collapses if overfishing is not addressed.

Management objectives

- Keep IOTC species (those in Table 1) and some key species affected by IOTC fisheries (some of Table 2 such as shark species) not overfished ensure overfishing is not occurring

-Rebuild overfished IOTC species (in Table 1 and extended Table 2)

Candidate indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in IOTC	Indicators currently not monitored in IOTC for which data are potentially available	Indicators currently not monitored in IOTC for which data are not readily available
• Single species total or spawning stock biomass relative to a reference level (e.g. Bmsy, SSBmsy or proxies) • Single species fishing mortality relative to a reference level (e.g. Fmsy or proxies) • Single species size based indicators (e.g., mean length, 95th percentile of the length distribution, proportion of fish larger than the mean size of first sexual maturation) • Single species age-based indicators • Single species relative indices of abundance (e.g., standardized CPUEs)	• Fish condition (length-weight residuals) for main commercial species • Distributional range (including extent, center of gravity, pattern within range at different depths, and pattern along environmental gradients) • Species size at first sexual maturation and whether it changes over time • Sex ratio	• Population genetic structure • Ichthyoplankton abundance indices

Data sources, data gaps and research needs

Some of the indicators proposed are routinely estimated and monitored for some IOTC species assessed as part of the stock assessment evaluations. Those indicators include single species total and/or spawning stock biomass and fishing mortality rates. Depending on the model and information available and used, stock assessments can also estimate a myriad of size and age based indicators that are usually estimated by fleet, combination of fleets or area. Other IOTC species are assessed with much simpler stock assessment models or data-limited methods, and therefore a smaller set of indicators are routinely produced such as size based indicators by fleets or combination of fleets and areas. Some data-limited methods, especially Bayesian methods that can take advantage of *prior* biological information, can also provide relative biomass and fishing mortality trends and indicators.

On top of the most widely used indicators aforementioned, there are also multiple indicators to monitor the impacts of multiple fisheries on fish stocks that can be estimated based on the datasets hold by IOTC (mainly the catch, catch-effort and size datasets) and datasets collected by the Regional observer program (ROS) or the various National observer programs from each CPC. For example, monitoring the distributional range of species by measuring changes in the extent and center or gravity in their distributions, and their longitudinal and latitudinal trends can provide information about the impacts of fishing on these species, as well as their responses to climate change. Changing distribution in major tuna and tuna-like species distributions can alter biological relationships between species at local scales. Furthermore, fish condition, measured for example as the residuals of the length weight relationship, can be used as an indicator of somatic growth in fishes. This indicator monitors the weight of the fish per unit of body length, when the residuals are positive indicates that fish are in better condition, while when negative indicate poorer conditions. The condition of fish might be altered by fishing pressures or also environmental effects as well as density dependent effects. This indicator does not only monitor the condition of individual stocks, but when combined across stocks, it can provide information about the ecosystem productivity. This indicator could be potentially estimated with the data sets obtained by the observer programs. Last, monitoring species size at first sexual maturation overtime, or their sex ratio, and their genetic population structure can also provide information about the fishing pressure upon specie. High fishing pressures shifts populations towards younger, smaller and more quickly maturing individuals, which ultimately can reduce the resilience of fishes to ecosystem changes and environmental variations. Yet the data needed to estimate and monitor these indicators are not regularly collected in IOTC.

Recommendation for indicator development

- Fish condition and maturity measures over time,
- Age and length structure of the populations
- Fishery independent abundance estimates (for example, using close-kin abundance estimates for small size populations, etc…)
- Joint CPUEs for multiple fleets to improve the fishery dependent abundance indices.
- Changes in the distributional range of species which might result from fishing or climate change responses

Relevance and implications for management

(c) How is the commission addressing the risk now?

- It has conducted fishery stock assessments and monitors the exploitation state for the majority of stocks under its mandate (Table 1).

(d) *What other actions might the Commission put in place to address and mitigate the risk?*

- Conduct fishery stock assessments using data-poor assessment methods or indicator-based analysis for the rest of IOTC species and key species of Table 2.
- Continue improving the data reporting and compliance of catch, effort and size data which currently forms the basis for all stock assessments conducted in IOTC.
- Research the potential of the data collected by the observer programs to support indicator development.
- Increase compliance of the data collection and reporting requirements for all gillnet fleets, so they can be incorporated in stock assessments. Develop standardized CPUE series for gillnets (e.g. Andrade (2017)).

5.5.2 Impacts of fisheries on retained and non- assessed fish species

Description

There is a large number of fish species which are retained by IOTC fisheries that are not currently assessed in IOTC and therefore their status is unknown. However, it is important to distinguish those that are considered IOTC species, for which IOTC is responsible to assess and manage them (Table 1), those extended lists of species making an important component of the bycatch of IOTC fisheries (Table 2) and other fish species which interact with less frequency with IOTC fisheries (Table 3 and 4). Those species not formally included in the Convention mandate under Table 2, 3 and 4, IOTC has still the responsibility, at least, to monitor the interaction of its fisheries on those fish species and minimize its impacts. For those non-assessed species, ecological risk assessments (ERA) are crucial to identify species most vulnerable to fisheries which allows focusing resources on a few set of species for monitoring purposes.

IOTC has conducted a preliminary ecological risk assessment for shark and some ray species, as determined by a susceptibility and productivity analysis (Murua *et al.*, 2012), in order to rank their relative vulnerability to logline and purse fisheries in the IOTC area. This exercise has been updated in 2018 including the gillnet fisheries as well. The preliminary ecological risk assessment in 2012 allowed identifying the 17 most vulnerable shark and ray species to longline and purse seine fisheries, which has been used to set research and provide advice on shark management to the Commission. An ecological risk assessment for sharks and rays for other fisheries is still missing driven by a lack of data availability. IOTC conduced an ERA for teleost fishes caught by purse seine fisheries but not for other fisheries (Murua *et al.*, 2009a).

What is the risk of not monitoring this interaction

The abundance of fish species most vulnerable to IOTC fisheries, those being highly susceptible to being caught by IOTC fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Monitor and prevent overfishing of fish species (retained but not assessed) most at risk.

-Monitor, minimize and reduce the impact of fishing on fish species (retained but not assessed) most at risk.

Candidate Indicators to evaluate whether objectives are met

Priority species by fishery to develop the indicators:

Bony fish – Unknown for most IOTC fishery, except for purse seiners. ERA for bony fishes not conducted except for purse seine fisheries.

Sharks – Blue shark, bigeye thresher, shortfin mako and hammerheads for longline fleets. Unknown species for gillnets, noting that most shark species are likely to be retained in the gillnet fisheries.

Rays – Rays are not retained in longliners. Unknown species for gillnets, noting that most ray species are likely to be retained in the gillnet fisheries.

Indicators which are currently monitored in IOTC	Indicators currently not monitored in IOTC for which data are available	Indicators currently not monitored in IOTC for which data are not available
• Total catches of retained and non-assessed IOTC species (Table 1). • Single species catch and catch rate indicators* • Single species size based indicators (e.g., mean length, 95th percentile of the length distribution, proportion of fish larger than the mean size of first sexual maturation) *	• Total catches of retained and non-assessed species interacting with IOTC fisheries (Table 2,3 and 4) • Number of retained and non-assessed species interacting with IOTC fisheries • Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients)	• Species size at first sexual maturation • Fish condition (length-weight residuals) for main commercial species

*while these indicators have been estimated for some of the bony fishes and sharks they are not necessarily updated regularly and monitored closely by IOTC.

Data sources, data gaps and research needs

Total catches for the non-assessed fish species under Table 1 and 2 remains underreported which limits its utilization for developing catch-based indicators. Similarly, the catch and effort and size-based datasets reported by CPCs to the Secretariat for these species also remains patchy and temporally and spatially fragmented for most species. Furthermore, the underreporting of catches of most species also limits the development of distributional range indicators based on catches. Therefore, the potential uses of the catch, effort and size datasets for indicator development needs to be examined for each species individually and especially if those indicators are to be monitored spatially. For the rest of fishes possibly interacting with IOTC fisheries covered in table 3 and 4, there is virtual no data hold in the Secretariat to estimate any type of indicators, noting also that at least some are demersal species and their interaction with IOTC fisheries is extremely limited.

The monitoring of the retained but not-assessed species relies on the data collected by the IOTC Regional observer program and National observers programs. .Monitoring the size at which species matured and its interannual variability as well as their potential response to fishing pressure might be difficult at this stage.

Recommendation for indicator development

- Focus on developing indicators for those species covered in Table 1 and Table 2.
- Identify and monitor those species most vulnerable to specific IOTC fisheries.
- Explore the potential of using data derived from IOTC and the various observer programs to develop size based and distributional range indicators.
- Explore the use of data-limited stock assessment models to monitor the status of these species.

Relevance and implications for management

(c) How is the commission addressing the risk now?

- It is focusing on developing indicators for those species covered in the IOTC convention mandate (Table 1) and species of the species covered un Table 2 but progress has been slow due to quality and availability of catch, effort and size data
- It has conducted a series of ecological risk assessments to identify species of sharks most-vulnerable and at risk from longline and purse fisheries, and preliminary gillnet and of bony fishes for purse seiners.

(d) What other actions might the Commission put in place to address and mitigate the risk?

- In addition to monitoring those species covered in the IOTC convention mandate, it should also monitor closely those bony fish, sharks and ray species of Table 2, 3 and 4 most vulnerable to longline, purse seine, gillnet fisheries and other fisheries identified in the ecological risk assessment.
- Urge CPCs to provide accurate statists, including catches (and discards dead and alive) as well as catch and effort and size data from all IOTC fisheries
- Increase compliance of the data collection and reporting requirements for all gillnet fleets is especially relevant, so they can be incorporated in stock assessments. Develop standardized CPUE series for gillnets.
- Conduct an ecological risk assessment to identify those bony fish and ray species most vulnerable to IOTC fisheries.

5.6 Fishing effects on non-retained vulnerable (fish and non-fish) species

Multiple species interact and are caught by IOTC fisheries that are not retained and are therefore, discarded (bony fish, sharks) or release (sea turtles, seabirds, marine mammals) back into the water. Bony fishes and sharks might be discarded because of their low commercial value or because there are non-retention measures in place by IOTC (for some sharks), and sea turtles, seabirds and marine mammals are released following the non-retention measures. The IOTC fisheries operating in the Temperate Ecoregion are diverse (mainly surface setting longliners, deep setting longliners in the open ocean and gillnets in the most coastal areas off the African coast) (section 3.1.1). These fisheries are known to interact, catch and subsequently discard or release a large number of species across a wide range of taxonomic groups (bony fishes, sharks, rays, sea turtles, marine mammals and seabirds) (sections 3.3.2). Driven by the different types of fisheries (longliners and gillnets) and different fishing strategies within the same gear (e.g. deep vs surface setting longliners) targeting different species and therefore having a distinct impact on species and the marine ecosystem, this ecosystem plan addresses the impacts of fishing effects on non-retained species for each type of fleet separately.

5.6.1 Impacts of longliners (shallow and deep setting longliners) on vulnerable taxa

Description

In order to monitor and reduce the impacts of longline fisheries on vulnerable taxa, setting both on shallow or deep waters, it is important to distinguish between interactions and mortality rates. Some fisheries employ mitigation measures as they attempt to decrease the mortality rates of vulnerable species (Clarke *et al.*, 2014). Longline fisheries interact with a wide range of taxa that are non-retained and therefore are released back into the sea dead or alive (bony fish, sharks, rays, sea turtles and marine mammals). In general terms, the cumulative magnitude and regional extent of the longline interactions (across all the fleets) with the different taxa (bony fish, sharks, rays, sea turtles and marine mammals) and post-mortalities is poorly known in the Temperate Ecoregion. There are some exceptions since some national fleets monitor and report their level of interactions with vulnerable taxa (see section 3), yet the spatial and temporal scale of the reporting remains poor and the observer coverage used for the reporting also remains low. Initially, there was an intent to differentiate between the impacts of deep setting longliners and surface longliners on the different taxa since these fleets target different species at different depths and therefore it is expected they might have different impact on the type of vulnerable taxa, extent of interacting and mortality rates. Yet it was not possible to assess the differential impact of both fishing strategies for most taxa groups because data is not disaggregated to the type of longline fishing strategy. Therefore, the impacts of both types of longline fisheries were combined, even though, and when available, specific details on those differential impacts are provided.

Some ecological risk assessment identifying those taxa and species most vulnerable to longline gears have been conducted relevant to the Temperate Ecoregion. The seabird ecological risk assessment reveals impacts of longline fisheries on seabirds are large in the Temperate Ecoregion (Wanless & Misiak, 2016). Nineteen of the 22 species of albatross and petrels found in the IOTC area have a high behavioural susceptibility to being caught by longliners, especially in their northernmost areas of distribution, while the reminding 3 have a low behavioural susceptibility to being caught. Most vulnerable seabirds main areas of distribution in the southern Oceans therefore also need to be considered jointly with the longline fleets targeting southern bluefin tuna, in the area of competence of CCSBT. An ecological risk assessment of sharks to longline fisheries also revealed that thresher sharks, silky shark and porbeagle were among the most vulnerable species (and non-retained under Resolution 12/09) to longline fisheries (Murua *et al.*, 2012; H. Murua *et al.*, 2018). Ecological risk assessment of sea turtles to longline, gillnet and purse seine fisheries indicated that all sea turtles present in the Indian Ocean were found to be medium to highly vulnerable to the three types of gears (Williams *et al.*, 2018). In general, sea turtles were found to be more vulnerable to gillnets and longline fisheries than purse seine fishing, driven by the large spatial area and depth distribution of longline fishing in the Indian ocean, and also the high post-capture mortality of sea turtles in gillnets. With regards to sea-turtles, it is important to note that the rate of interactions is higher in shallow setting longlines compared to deep setting longliners (as well as surface gillnets). On the other hand, the mortality rates are higher in deep setting longlines as, contrary to shallow longlines, in deep sets the captured turtles do not have access to the sea surface for breathing. An ecological risk assessment for marine mammals to assess their relative vulnerabilities to IOTC fisheries has not been conducted. Still there is evidence that a number of species of marine mammals interact with longliners and gillnets in the Temperate Ecoregion. Further, some interactions with longlines refer to sighting and/or depredation events, where the marine mammals are not actually captured by the fishing gear but interact with the gear and often prey (depredate) the catch. The magnitude and regional extent of these mammal interactions with the different gears and post-mortalities is poorly known.

What is the risk of not monitoring this interaction

The abundance of species most vulnerable to IOTC fisheries, those being highly susceptible to being caught by IOTC fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Minimize and reduce the number of interactions of fishing on non- retained vulnerable species

-Increase the post-release survival of non-retained vulnerable species

-Protect species most at risk

Candidate Indicators to evaluate whether objectives are met

Priority species to develop the indicators:

Bony fish – There are not non-retention measures in place for any species.

Sharks – Bigeye thresher and porbeagle caught by longliners.

Rays - Interactions of Manta and devil rays with oceanic longlines are limited. The pelagic stingray has the largest number of interactions, and it is usually discarded due to low commercial value.

Sea turtles - Green turtle southwest population, the loggerhead southwest population, the hawksbill southwest population and olive ridley west population are the most vulnerable to longliners.

Marine mammals – Extent of interactions and most vulnerable species unknown. Some species are known to interact with longline fisheries. Ecological risk assessment has not been conducted.

Seabirds – Nineteen of the 22 species of albatross and petrels found in the IOTC area have a high behavioural susceptibility to being caught by longliners. Two species, the Amsterdam albatross and the Tristan albatross are listed by the IUCN Red List as Critically Endangered.

Indicators which are currently estimated and/or monitored in IOTC	Indicators currently not monitored in IOTC for which data are potentially available	Indicators currently not monitored in IOTC for which data are not available
• Number of interactions for some fleets with limited spatial and temporal coverage • Number of bycatch vulnerable species release dead and alive for some fleets with limited spatial and temporal coverage • Post release mortality for some species and fleets	• Bycatch per unit effort, including standardization to serve as proxies of abundance levels • Frequency of bycatch or total number of interactions of bycatch species across all fleets • Discard survival of bycatch species (total number of individuals release dead and alive per fleet) • For fish and sharks -single species size based indicators (mean length, 95th percentile of the length distribution, proportion of fish larger than the mean size of first sexual maturation) • For fish and sharks - Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) • For fish and sharks -Single species biomass/abundance/catch rate indicators • For fish and sharks -Single species catch	• Population level mortality of bycatch species • Population genetic structure • For sea turtles, marine mammals - Biomass/abundance of species • For sea turtles, marine mammals -Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients)

Data sources, data gaps and research needs

The most important indicators are bycatch rates (i.e. number of individuals caught per a given unit effort, for example sea turtles per 1000 hooks for longline fisheries) and total number of individuals captured per fleet. It important that both of these indicators should be used together as an overall indicator to monitor bycatch trends over time. Then, it would be important to scale those values to the actual mortality rates, including both at-vessel and post-release mortality rates. Changes in the abundance of a population might also affect the bycatch rates by increasing them (if population increasing) or decreasing them (if population decreasing). The estimation of these indicators depends on the observer data collected in the IOTC regional observer programs or National programs in the longline fleets, and while some CPCs collect and report these measures to IOTC, the majority do not collect and/or report it, and if reported, the spatial and temporal extent of the data is too fragmented and too coarse to compute reliable indicators that can be used to provide management advise. The post-release mortality for vulnerable taxa after being caught by longliners is poorly known even for individual fleets.

Furthermore, while the number of interactions of longliners with vulnerable taxa (and mortality rates) might be monitored and reported to IOTC by a number of fleets in the Temperate Ecoregion region, it remains poorly understood the total cumulative impacts across all fleets within the Temperate Ecoregion. This hinders any quantitative assessment to determine the impact of longline fisheries on the state of any species. Without concerned collaborative efforts by all CPCs to estimate total interactions and discard rates, as well as to estimate total dead discard rates, based on information collected in the observer programs of their fleets, quantifying total number of interactions and mortality for vulnerable taxa seems unachievable.

The lack of quantitative assessments is in part because these assessments as well as many of the proposed indicators above, rely on data collected by the observer programs and on the level of coverage of these programs. For longliners, while the minimum level of observer coverage is 5%, many countries are not achieving these levels. The use of electronic monitoring systems to increase the observer coverage in large scale longline fisheries should be further encouraged as well as supporting the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner.

Recommendation for indicator development

- Bycatch rates (total number of interactions per unit effort) as well as bycatch mortality rates (i.e. number of individuals death per a given unit effort)
- Total number of individuals death per fleet
- Total number of release alive
- Post release mortality for different species

Relevance and implications for management

(c) How is the Commission addressing the risk now?

- Contracting Parties have to collect, monitor and report to the Secretariat the level of interactions with vulnerable taxa, yet the reporting is low.
- The minimum level of observer coverage in fleets is 5%, but many countries are not even achieving these levels. And even if achieved, many times the data is not properly reported.
- Adoption of mitigation measures to reduce impacts of fisheries and encouraging further research and testing of more efficient mitigation methods to reduce the impacts of fisheries (e.g. use of artificial hook, smart-hooks, painted bait, etc.).

(d) What other actions might the Commission put in place to address and mitigate the risk?

- Encourage and fund collaborative efforts undertaken by Contracting Parties to quantify the cumulative impacts including total number of interactions, discard rates and mortality rates of vulnerable taxa based on information collected in the observer programs of their fleets.
- The level of observer coverage in longliners should be increased further and progressively to improve the reliability of the data collected in these programs.
- Encourage the use of electronic monitoring systems to increase the observer coverage and the development of electronic monitoring and electronic reporting standards to ensure data collected by different members can be collated and used in a sound manner.
- Conduct ecological risk assessments for those taxa and gear not yet available

Explore the utility of the data collected from observer programs to estimate alternative indicators such as the distributional range of the species.

5.6.2 Impact of gillnets on vulnerable taxa

Description

Gillnet fisheries account for a substantial amount of tuna and associated species catches in the Indian Ocean which might have a large impact on marine ecosystems, and the extent of these catches in the Temperate Ecoregion is unknown. Gillnets fisheries interact with a wide range of taxa that are mostly retained and also that are non-retained and therefore are released back into the sea dead or alive (bony fish, sharks, rays, sea turtles and marine mammals). In general terms, the cumulative magnitude and regional extent of the gillnet interactions (across all the fleets) with the different taxa (bony fish, sharks, rays, sea turtles and marine mammals) and post-mortalities is poorly known in the Temperate Ecoregion.

There are few studies identifying those taxa and species most vulnerable to gillnet gears using ecological risk assessments, which allows focusing resources on a few set of species for monitoring purposes. The impacts of gillnet fisheries on seabirds in the Temperate Ecoregion is negligible (Wanless & Misiak, 2016). Ecological risk assessment of sea turtles to longline, gillnet and purse seine fisheries indicated that all sea turtles present in the Indian Ocean were found to be medium to highly vulnerable to the three types of gears. In general, sea turtles were found to be more vulnerable to gillnets and longline fisheries than purse seine fishing, driven by the large spatial area and depth distribution of longline fishing in the Indian ocean, and also the high post-capture mortality of sea turtles in gillnets. A preliminary ecological risk assessment for sharks was carried out in 2018 (H. Murua *et al.*, 2018) showing that thresher, hammerheads and crocodile shark have higher vulnerability to the gillnet fishery in the region. An ecological risk assessment for marine mammals has not been conducted. Still there is evidence that a number of species of sharks and marine mammals are caught and interact with gillnets in the Temperate Ecoregion. The magnitude and regional extent of these shark and mammal interactions with gillnets and post-mortalities is poorly known.

What is the risk of not monitoring this interaction

The abundance of species most vulnerable to IOTC fisheries, those being highly susceptible to being caught by IOTC fisheries and well as having low intrinsic productivity values, might decline to low levels jeopardizing their reproductive capacity if not properly monitored.

Management objectives

-Minimize and reduce the number of interactions of fishing on non- retained vulnerable species.

-Increase the post-release survival of non-retained vulnerable species.

-Protect species most at risk.

Candidate Indicators to evaluate whether objectives are met

Priority species to develop the indicators: **Bony fish –** Unknown impacts on species **Sharks** – Thresher, hammerheads and coastal sharks **Sea turtles -** Unknown impacts on species **Marine mammals –** Unknown impacts on species **Seabirds –** Negligible		
Indicators which are currently estimated and/or monitored in IOTC	**Indicators currently not monitored in IOTC for which data are potentially available**	**Indicators currently not monitored in IOTC for which data are not available**
•	• Bycatch per unit effort • Frequency of bycatch and total number of interactions of bycatch species • Discard survival of bycatch species (total number of individuals killed per fleet) • Population level mortality of bycatch species • For fish and sharks -Single species size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) • For fish and sharks - Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) • For fish and sharks -Single species biomass/abundance/catch rate indicators • For fish and sharks -Single species catch	• For sea turtles, marine mammals - Biomass/abundance of species • Population genetic structure • For sea turtles, marine mammals -Distributional range (including extent, center of gravity, pattern within range and pattern along environmental gradients) •

Data sources, data gaps and research needs

Most CPCs with gillnet fisheries do not report data on the species caught in their fisheries. There are few studies describing species composition and impacts of gillnets on vulnerable species in the Temperate Ecoregion.

Recommendation for indicator development

- Bycatch rates (total number of interactions per unit effort or production of target species) as well as bycatch mortality rates (i.e. number of individuals death per a given unit effort or production of target species).
- Total number of individuals dead per fleet.
- Total number of release alive.
- Post release mortality for different species.

Relevance and implications for management

(e) How is the Commission addressing the risk now?

- IOTC has prohibited the use of large-scale driftnets on the high seas in the IOTC area (resolution 12/12), which will be extended to the entire IOTC area of competence by 1 January 2022 (IOTC Res. 17/07; does not apply to Pakistan).

(f) What other actions might the Commission put in place to address and mitigate the risk?

- Increase compliance of the data collection and reporting requirements for all gillnet fleets.
- Data on the gillnet fisheries must be collected and reported so they can be incorporated in stock assessments and impact assessments, as well as develop standardized CPUE series for gillnets and other ecosystem indicators.
- Identify relevant fisheries and regions where gillnet fisheries operate.
- Monitor the type of species and quantities captured by gillnet per fleet.
- Consider expanding resolution 12/12 on the prohibition of the use of large-scale driftnets on the high seas to within the exclusive economic zones of CPCs.

5.7 Fishing effects on community structure and function, food webs and biodiversity

5.7.1 Impact of total removals on ecosystem components due to fishing and predation mortality

Description

Direct effects of fishing on targeted and bycatch species are in general well known in the scientific community (see sections 5.5 and 5.6 above about effects on retained and non-retained species). But the potential effects of fishing on the whole ecosystem due to direct and indirect cascading effects have also been recognized (Jennings & Kaiser, 1998). Fishing can affect trophic interactions and could lead to species replacement and shifts in community composition (Stevens, 2000). Since most of the fish species caught by IOTC fisheries have a high trophic level, any potential change in the status of one of these species might cascade down the food web (Myers *et al.*, 2007), getting different responses from other components. These responses will be different if the ecosystem is top-down, wasp-waist or bottom up controlled (Cury *et al.*, 2003). Properly understanding the ecosystem structure and functioning (directly related to biodiversity - (Strong *et al.*, 2015)) is therefore, key for implementing adequate management measures that would support a sustainable fishing activity in this Temperate Ecoregion of the Indian Ocean. Improving knowledge of the food-web dynamics and identifying key ecosystem components (apex predators usually play that role (Camphuysen, 2006)) will also be part of this process.

What is the risk of not monitoring this interaction

By ignoring the indirect effects of fishing we might not correctly assess the magnitude of deterioration of the structure and function of ecosystems. Without knowing the extent of these indirect impacts, we cannot design appropriate measures to fully mitigate against those impacts, affecting the goods and services that societies obtain from marine ecosystems.

Management objectives

-Preserve foodwebs

-Restore ecosystem structure and function

-Maintain biodiversity

--Identify/Preserve keystone species

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimate and/or monitored in IOTC	Indicators currently not monitored in IOTC for which data are available	Indicators currently not monitored in IOTC for which data are not available
	• Group spawning stock biomass relative to a reference level (e.g. Bmsy or proxies) • Biomass indicators (total, guild/community) • Proportion of non-declining exploited species • Recovery in the Population Abundance of Sensitive Species • Group Fishing mortality relative to a reference level (e.g. Fmsy or proxies) • Community size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation)(catch based) • Proportion of predatory fish or "Large Species Indicator" (catch data) • Abundance-Biomass Comparison (ABC) curve • Mean Trophic Level Indicators (catch data) • Mean maximum length of community (catch data) • Species diversity indices (Shannon/Simpson/Evenness/Richness) (catch data) for each major gear • Tropicalization index	• Community size based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (model based) • Mean Trophic Level Indicators (model derived) • Size spectra (total, by guild/community) (model based) • Mean maximum length of community (model derived) • Species diversity indices (Shannon/Simpson/Evenness/Richness) (model derived) • Proportion of predatory fish or "Large Species Indicator" (model derived)

Data sources, data gaps and research needs

The effects of fishing on the different ecosystem components in terms of both direct effects on retained and non-retained IOTC species and indirect effects on other components due to the trophic relationships existing between them, has been very scarcely evaluated in the Temperate Ecoregion.

Ecosystem models have not been developed for this are. The diet information to support the development of these models is scarce. Implementing research programs for analyzing the trophic dynamic of this temperate Indian system would be required to support the development of ecosystem models.

Recommendation for indicator development

- Support studies of fish diet, feeding ecology and food habits to support the development of ecosystem models and better understand trophic interactions and foodweb dynamics in marine ecosystems.
- Develop ecosystem/food web models to derive model/based indicators at community and/or ecosystem scale.
- Continue improving the reliability of catch and size statistics to support the development of ecosystem models.
- Increase observer's coverage to continue improving the reliability of observer data sets to support the development of ecosystem indicators.

Relevance and implications for management

(c) How is the Commission addressing the risk now?

- The Commission is not currently addressing, from an integrated perspective, the indirect impacts of fishing on marine food webs, however, at the single-species level, the Commission keeps improving the reliability of catch statistics, an important source of information for integrative approaches. For example, it has banned discards of target tuna in tropical tuna purse seine fisheries in 2017, which will improve the reliability of catch statistics.

(d) What other actions might the Commission put in place to address and mitigate the risk?

- The Commission should promote and support the use of multispecies and ecosystem models for producing both, tactical (short-medium term) and strategical (long-term) advice for management.
- The Commission should make use of the existing data collected by the observers' programs, evaluating their potential use for developing ecosystem and/or community scale indicators.
- Increase existing knowledge on ecosystem structure, trophic interactions and biodiversity in order to maintain the species interactions sustaining energy flow in the ecosystem and avoid crossing thresholds that might rapidly move the ecosystem into a new, unknown state.
- When developing an ecosystem-based fisheries management plan, consider apparent ecosystem-level risks and balancing trade-offs from an understanding of different ecosystem interactions.

5.8 Effects of manageable and non-manageable pressures on habitats of ecological significance

5.8.1 Climate and fishing effects on habitats of ecological significance

Description

Mapping habitats of ecological significance is important for determining the biological and ecological features of communities of special importance and determining areas of high biological value or diversity. Furthermore, knowledge of the spatial extent of the fishing impacts on these habitats is also needed to inform management strategies to minimize and avoid fishing impacts. New technologies such as satellite tracking are showing how highly migratory pelagic species use habitat hotspots as well as how these habitats hotspots overlap with fishing fleets. These technologies can be used to map habitats of special concern and inform ocean-scale spatial and dynamic management of fisheries (Hussey *et al.*, 2015; Dunn *et al.*, 2016; Queiroz *et al.*, 2016). The identification of habitats of special concern for species is also increasingly becoming an essential task to design effective responses to climate change as well as other marine threats (Brierley & Kingsford, 2009; Bell *et al.*, 2013). When this knowledge is available for multiple species, mapping areas of ecological significance for multiple taxa and their degree of overlap can be used to inform cross taxa area-based management. This can be done by allocating the spatial and temporal distribution of fishing activities to minimize their impacts and designing mitigation strategies for climate change.

What is the risk of not monitoring this interaction

Lack of good understanding of habitats of ecological significance can reduce the value of marine spatial planning, since the spatial planning will not be informed by management strategies to minimize and avoid fishing impacts as well as mitigation strategies for climate change.

Management objectives

-Reduce or avoid impacts of fishing on habitats of ecological significance

Candidate Indicators to evaluate whether objectives are met

Indicators which are currently estimated and/or monitored in IOTC	Indicators currently not monitored in IOTC for which data are potentially available	Indicators currently not monitored in IOTC for which data are not available
	• Mapping areas of special importance for life history stages of species (e.g. spawning areas, migratory corridors) • Mapping areas for vulnerable, threatened, declining species • Mapping areas of high biological diversity • Mapping habitat suitability of species and changes in habitat suitability due to climate change • Percent overlap of habitat of ecological significance by high fishing pressure • Percent area close to a specific gear	

Data sources, data gaps and research needs

Mapping habitats of ecological importance for species requires to know their spatio-temporal environmental and habitat preferences. This requires the collection and use of multiple sources of information, from spatial data collected by the fisheries (catch distribution) or on observers program (e.g. species absence/presence and catches, individual samples for reproductive studies) to the collation of physical and biological environmental covariates by the same fishing boats where the observers operate or from external sources that need to be matched to the observer data collection geolocations. At the end, these types of studies will require to make use of the existing data collected by the IOTC observer program and National programs, and evaluating their potential use for developing habitat-based indicators. It will also be critical to prioritize for what species the habitat mapping should be focused. It is recommended to use new technologies such as satellite tracking to identify how migratory pelagic species use habitat hotspots as well as how these habitats hotspots overlap with fishing fleets, which can be used to map habitats of special concern and to inform ocean-scale spatial and dynamic management of fisheries (Hussey *et al.*, 2015; Dunn *et al.*, 2016; Queiroz *et al.*, 2016).

The data derived from tagging programs also offers an opportunity to identify habitats of special ecological significance. Since 2002, IOTC has been coordinating the Indian Ocean Tuna Tagging Program (IOTTP) (IOTC, 2017). This tagging program has been mostly designed to increase the understanding on the population dynamics of tropical tunas and their basic life histories including estimates of longevity, growth, and natural mortality, and tuna movements and their interactions with fishing gears (Fonteneau & Hallier, 2015). The data derived from this tagging program is underutilized to support habitat research. Yet this tagging program is slowly revealing critical information of seasonal migrations, habitat utilization, breeding migration, migration corridors, hot spots, and physical oceanographic patterns that are important to understand how tunas use the open ocean environment.

Recommendation for indicator development

- Extend the use of the data derived from the IOTC observer program and National programs to identify habitat of ecological significance and encourage cross-taxa studies.
- Explore the use of data from tagging programs to identify habitat of ecological significance and develop these programs to include the most vulnerable bycatch species in IOTC fisheries.
- Identify the most vulnerable habitats of ecological significance.

Relevance and implications for management

(c) How is the Commission addressing the risk now?

- Some research studies on the habitats of ecological significance (e.g. reproduction, migration, feeding, hotspots) and habitat utilization and preferences for some relevant IOTC species are available. Yet their robustness still needs to be evaluated before they can be used to provide management advise to the Commission. The Commission has not formally identified, mapped or protected any habitats of special concern for relevant species.

(d) What other actions might the Commission put in place to address and mitigate the risk?

- Define clear operational objectives to address the importance of habitats of ecological significance and habitat utilization.
- Set a habitat research agenda and continue supporting habitat studies and the mapping of habitats of ecological significance for IOTC species as well as identify a list of priority species (e.g. most vulnerable, threatened species) to focus on.

6 A STRATEGY FOR COMMUNICATION AND PRODUCING ECOSYSTEM ADVICE

6.1 A communication strategy to disseminate the ecosystem plan.

The pilot ecosystem plan needs to be shared and communicated to different audiences including the Scientific Committee and the Commission. A communication strategy is proposed for sharing the Pilot Ecosystem Plan in a logical and strategic way (Table 7).

Table 7. Proposal of a communication strategy to disseminate the ecosystem plan.

Communication strategy			
Target audience	**Communication method (how & where)**	**Key messages**	**Timing**
Scientists	-Presentation of Plan to the WPEB	-Plan needs to be revised by the WPEB -WPEB may request additional corrections and tasks	WPEB 2019
Scientists	-Presentation of Plan to the annual Scientific Committee Meeting	-Plan needs to be revised by the Scientific Committee - Scientific Committee may request additional corrections and tasks -Fit the plan within the current structures of the Scientific Committee	Scientific Committee 2019
Commission-Scientist	-Presentation of Plan to the Technical Committee on Management Procedures	-Plan needs to be revised by managers, as they may request additional corrections and tasks	IOTC Technical Committee on Management Procedures 2020
*Commission	-Presentation of Plan to the IOTC annual meeting	-Inform the Commission on the purpose and implications of the	IOTC Commission meeting 2020

		plan -Seek a request from the Commission to develop a formal plan	

*While we recommend the plan is not presented to the Commission until an ecosystem risk assessment is incorporated into the plan to rank priorities and action for the Commission, it is critical the Commission requests the development of an ecosystem plan.

6.1 A strategy to operationalize an ecosystem approach to fisheries management

An EAFM requires three major steps: ecosystem planning, ecosystem assessments and linking them to fisheries management (Figure 22). This ecosystem plan also proposes a series of steps and how they are connected to better link ecosystem science and fisheries management advice.

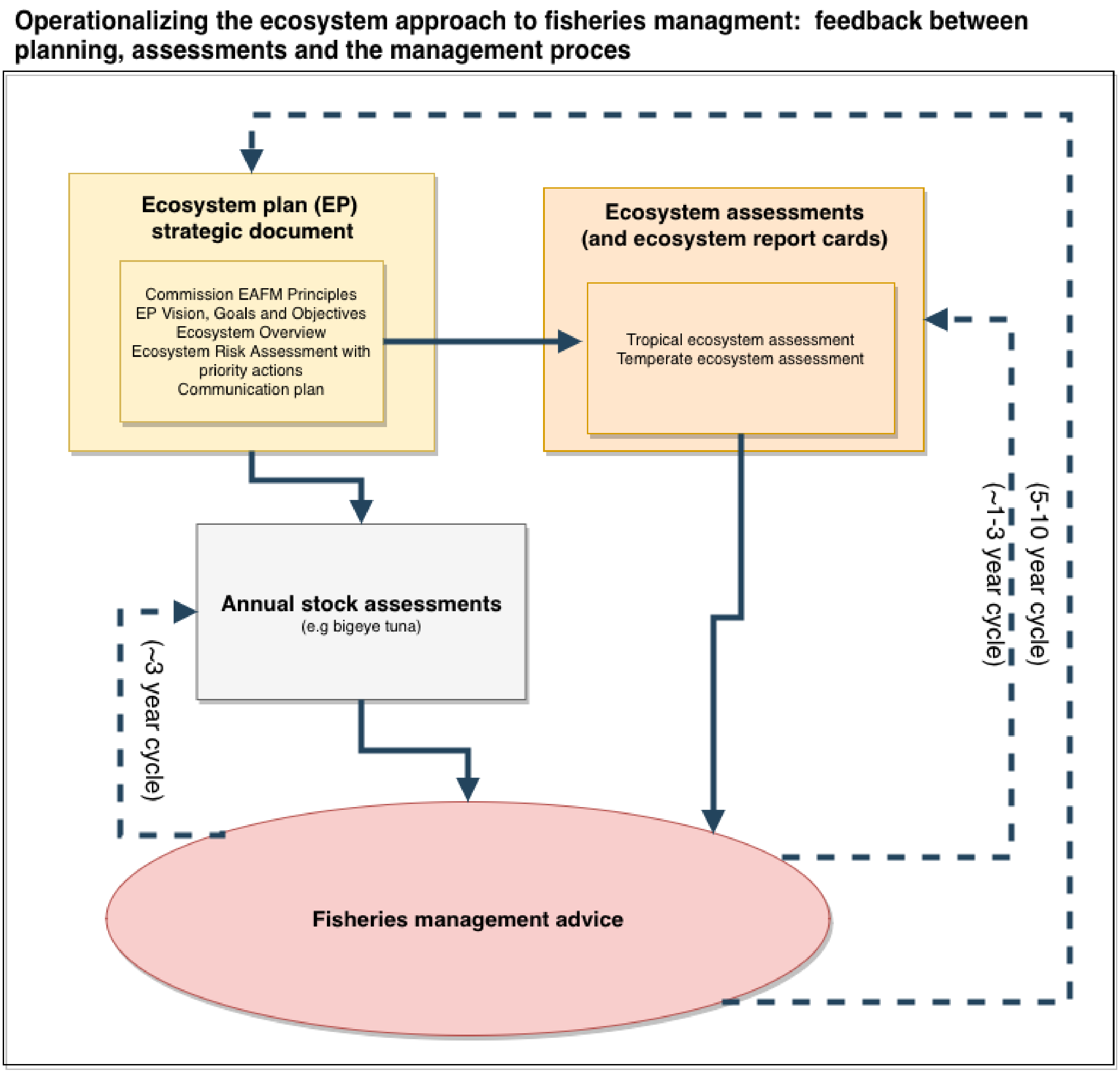


Figure 22. Operationalizing an EAFM requires the feedback between ecosystem planning, ecosystem assessments and fisheries management.

7 RECOMMENDATIONS TO FORMALIZE AN ECOSYSTEM PLAN IN IOTC

#	Recommendations/action item	Timing	Milestone
1	The pilot Ecosystem Plans should be presented, discussed and reviewed by the Working Party on Ecosystems and Bycatch (WPEB) and the Scientific Committee (SC) to evaluate its usefulness and promote further steps.	Short-term	Ecosystem plan presented at the IOTC WPEB and SC 2019 meeting
2	The regionalization of the ecosystem plan, its potential benefits and drawbacks, need to be further discussed and reviewed by the WPEB and the SC.	Short-term	Ecosystem plan and implications of regionalizing the ecosystem plan presented at the IOTC WPEB/SC 2019 meeting
3	Future versions of an ecosystem plan should incorporate an ecosystem risk assessment, which will become a cornerstone of the plans. An ecosystem risk assessment will determine the degree of importance of each of the interactions and issues identified in the pilot ecosystem plans. It will help prioritize the main issues and research actions that need to take place to avoid unwanted risk through appropriate management actions to the Commission.	Short-term	IOTC requests to the SC to develop formal ecosystem risk assessments to be developed as part of the pilot ecosystem plans
4	An EAFM engagement strategy and standardized EAFM road map materials for widespread use should be developed to communicate the importance of ecosystem planning and ecosystem assessments to the Commission.	Short-term	SC to develop outreach materials for Commission
5	The IOTC WPEB should continue the development of ecosystem assessments (and ecosystem report cards). The on-going assessments in IOTC can benefit from the current ecosystem plan and vice versa and both efforts should be coordinated. The pilot ecosystem plan identifies and proposes candidate indicators that can inform the current development of ecosystem assessments in IOTC.	On-going	The IOTC WPEB/SC develops the first version of an ecosystem assessment and ecosystem report card to be presented to the Commission
6	IOTC Commission need to agree on an ecosystem vision, goals and objectives for the pilot Ecosystem Plan (or any ecosystem plan). The Commission should request to the SC to develop a formalized Ecosystem Plan(s).	Medium-term*	IOTC Commission agrees on vision, goals and objectives for the Ecosystem Plans IOTC requests to the SC to develop a formal ecosystem plan
7	An Ecosystem Plan Team should be created in IOTC to oversight the development of the ecosystem plan(s) and to provide recommendations and guidance to the SC and the Commission.	Medium-term	Ecosystem Plan Team created by the SC or WPEB

8	An Ecosystem Plan Coordinator/Analysist at the IOTC Secretariat would facilitate the development of many of the activities proposed here.	Medium-long	Ecosystem Plan Coordinator/Analysist hired at the IOTC Secretariat
9	Future versions of an ecosystem plan should identify how the ecosystem plan interacts with other Commission processes as well as other SC activities and research programs.	Medium-term	Commission requests to the SC to develop a formal ecosystem plan integrated in its Science Strategic Research Plan
10	Future version of an ecosystem plan should consider including a section on skills and capabilities to support the implementation of the plan, as well as identify continuous financial support to ensure its implementation.	Medium-term	Commission requests to the SC to develop a formal ecosystem plan integrated in its Science Strategic Research Plan
11	Future versions of an ecosystem plan should consider including the socio-economic and governance aspects of fisheries in the region covered by the plan. Until the socio-economic and governance considerations are addressed properly, an ecosystem plan will only be partially guiding the operationalization of EAFM in the region.	Long-term	Socio-economic Working Group created at IOTC. Short term consultancy acquired to develop a strategy to develop the socio-economic components of an ecosystem plan. Each CPC develops a National Plant report on economic and socio-economic considerations of their tuna- and tuna-like fisheries.

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