Selecting ecosystem indicators for fisheries targeting highly migratory species

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SUMMARY

Several international legal agreements and guidelines have set the minimum standards and key principles to guide the implementation of an ecosystem approach for the management and conservation of highly migratory fish species. Since its creation IOTC has had the ability to assimilate some of these principles in the form of adoption of formal management measures. Yet these management measures have not provided practical guidance on how to make operational an Ecosystem Approach to Fisheries Management (EAFM) within its convention area. The Specific Contract N⁰ 2 "selecting ecosystem indicators for fisheries targeting highly migratory species-" under the Framework Contract - EASME/EMFF/2016/008 provisions of Scientific Advice for Fisheries Beyond EU Waters- addresses some scientific impediments and provides solutions that shall support the implementation of an EAFM in IOTC. Here, we present some preliminary results of this project with the objective of seeking collaboration and broad consultation with IOTC. First, we summarize properties of success from other regions of the world in operationalizing the ecosystem approach which could be transferred to IOTC. Second, we provide a list of candidate ecosystem indicators to monitor the broader impacts of IOTC fisheries on the pelagic ecosystem. Third, we propose two potential ecoregions within the Indian Ocean which could be used to guide region-based ecosystem plans, assessments and research. Fourth, we present the key elements of a pilot ecosystem plan to be developed for one case study region. Ultimately, the products created throughout this study aim to facilitate the linkage between ecosystem science and fisheries management as well as facilitate the process to operationalize an EAFM in IOTC.

KEYWORDS

Ecoregion, area-based management, ecosystem plan, ecosystem overview, ecosystem assessment, ecosystem risk assessment

1. Introduction

Several international legal agreements and guidelines such as the Convention on Biological Diversity (CBD) (United Nations, 1992), 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 for the management and conservation of highly migratory fish species (Meltzer 2009). The implementation of an EAFM in tuna 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. 2016). In IOTC, its Convention Agreement does not make reference to the principles of the precautionary or ecosystem approach, yet since its creation it has had the ability to assimilate some of these principles in the form of adoption of formal management measures. These management measures have not provided practical guidance on how to make operational an Ecosystem Approach to Fisheries Management (EAFM) within IOTC.

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 or area-based management units in marine pelagic ecosystems to guide ecosystem research, ecosystem planning and the operationalization of an EAFM in general, and (3) the lack of pre-agreed operational objectives and an ecosystem plan to ensure ecosystem and socio-economic considerations are accounted in fishery management advice and decision making.

The Specific Contract N⁰ 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 that shall support the implementation of an EAFM through collaboration and consultation with IOTC and ICCAT. The main purpose of Specific Contract N^0 2 is to provide a list of ecosystem indicators (and guidance for associated reference points) to monitor impacts of fisheries targeting tuna and tuna-like species on marine ecosystems. This contract also proposes area-based management units or ecoregions with meaningful ecological boundaries for tuna and tuna-like species and its fisheries in the Indian and Atlantic Oceans in order to facilitate the operationalization an EAFM in marine pelagic ecosystems. Finally, it also provides a pilot ecosystem plan using two ecoregions as case studies, one within the Indian Ocean Tuna Commission (IOTC) and one within the International Commission for the Conservation of Atlantic Tunas (ICCAT) convention areas. The Specific Contract started in December 2016 and will finalize in November 2018 and it is being conducted by several EU partners (AZTI, CEFAS, IEO, WMR, IPMA, IRD, MRAG). The project is organized around the following tasks:

- Task 1. Revision and description of how an EAFM is being implemented in different areas of the work and establishment of best practices and lessons.
- Task 2. Proposal of candidate ecosystem indicators with its data requirements to monitor the impacts of ICCAT and IOTC fisheries on tuna and tuna-like species and the broader pelagic ecosystems
- Task 3. Proposal of area-based management units or ecoregions in the Atlantic and Indian Ocean to guide the operationalization of an EAFM.
- Task 4 Provide guidance of how reference points should be set for the selected ecosystem indicators and a framework to better facilitate the link between ecosystem science and fisheries management
- Task 5. Develop a pilot ecosystem plan for the two case study regions, one in the ICCAT and one in IOTC
- Task 6. Identify issues and gaps of information and provide recommendations to facilitate the implementation of the ecosystem plans
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2. Scope of the present study

Here we present an overview and preliminary results of task 1, 2, 3 and 5 relevant for IOTC with the objective of seeking collaboration and a broad consultation with IOTC. We highlight that any of the products created during this project should be adapted to the needs of IOTC. First, we summarize properties of success, best scientific practices and lessons that have facilitated the operationalization of EAFM in other areas of the word and that could potentially be transferred to IOTC. Second, we provide a list of candidate ecosystem indicators to monitor the broader impacts of IOTC fisheries on tuna and tuna-like species and the broader pelagic ecosystem. Third, we present two potential ecoregions within the Indian Ocean which could be used to guide region-based ecosystem plans, assessments, research and management advice. Fourth, we present the key elements of a pilot ecosystem plan to be developed for one case study region, the Indian subtropical ecoregion. These results should be treated as preliminary as they are currently being developed by the Consortium within the EU project.

3. Preliminary results

Task 1 – The ecosystem fisheries management approach in the world - properties of success, best practices and lessons

Under task 1 we examined and analyzed how different areas of the world are implementing an EAFM with the objective of identifying properties of success, best practices and lessons that potentially could be transferred and used in IOTC. We picked areas of the work that have proven experience using ecosystem science and advice to influence fisheries management decisions. Specifically, we examined: (1) North Pacific Fishery Management Council in the United States (Zador et al. 2016), (2) the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), and (3) the North Atlantic Fisheries Management Organization (NAFO). The chosen areas are at different stages of implementing an EAFM, which allows highlighting best practices and effective approaches from different states of the EAFM implementation process. We also reviewed and learnt from relevant projects and programs that have worked extensively on the development and use of a wide range of ecosystem indicators to monitor the impact of fisheries and climate on the status of marine ecosystem around the world and inform the EAFM. These programs include: (1) EU projects DEVOTES (http://www.devotes-project.eu/), and EcApRHA (www.ospar.org/work-areas/bdc/ecaprha) and (2) the IndiSeas Programme (http://www.indiseas.org) supported by UNESCO-IOC. We also reviewed the Marine Strategy Framework Directive (MSFD) established by the EU Commission.

From the different reviewed areas and programs, we identified properties for success (and failures) as well as best practices and lessons that have fostered and are facilitating the implementation of an EAFM in these regions. These are summarized below:

Properties of success

1. Clear framework of implementation
2. Transparent and trusted participatory and consultative process
3. Well-articulated needs and vision
4. Mechanisms for setting ecosystem objectives and priorities
5. Flexible and adaptive process
6. Fluid and strategic communication

Best scientific practices

1. Setting area-based assessment units or ecoregions to guide ecosystem assessments and plans
2. Monitor selected ecosystem indicators to track the impacts of pressures (fishing and climate) on the state of the ecosystems
3. Analysis of trade-offs
4. Cumulative impacts of fishing
5. Development of multispecies, ecosystem and climate models
6. Quantification of ecosystem production and thresholds
7. Development of ecosystem risk assessments
8. Establishment of bycatch reduction, protections of habitats and monitoring food web dynamics
9. Development of tools, specific software, to visualize indicators and integrate information in support of ecosystem assessments

Lessons

1. Ecosystem focused fisheries management can be done without full knowledge of the ecosystem and making use and integrate of all available knowledge is crucial
2. Get to know well the annual management cycle to optimize the opportunities to better link ecosystem science and information to the fisheries management cycle
3. Be flexible and adaptive in the process of selecting a small number of key ecosystem indicators and start the process with a pilot case study
4. Stakeholders need to be involved in the development of ecosystem products from the beginning
5. Development of ecosystem indicators and assessments that are area-based can be the catalyst for stronger regional collaboration
7. Effort to develop standardize guidelines for data collections and estimation of indicators (to override data confidentiality issues) leads to stronger outputs, higher participation and more regional collaborations

Task 2 – Candidate ecosystem indicators to monitor the impacts of IOTC fisheries on tuna and tuna-like species and the broader ecosystem

Under task 2, we delivered a list of potential ecosystem indicators of relevance to IOTC that are suitable to track the impacts of IOTC fisheries on tuna and tuna-like species and the broader pelagic ecosystem. These candidate indicators could be used and inform the development of ecosystem assessments in IOTC. For this, we examined the ecosystem indicators developed and used in the world case studies and programs reviewed under task1. Then, we identified those that have the most potential to support the development of ecosystem assessments in IOTC.

The initial list extracted from all the reviewed case studies and programs consisted of more than 200 ecosystem indicators that aimed to track the impacts of fisheries on marine ecosystems. Initially all the indicators were cataloged into broad categories those tracking pressures and those tracking changes in the state of the ecosystem. Pressure indicators are used to monitor the activities/mechanisms that cause change in the state, for example fishing, and the environment or climate change. State indicators are used to monitor the change in state of the ecosystem. In order to monitor changes in the state of the ecosystem, the ecosystem state indicators were divided and catalogued to describe four broad components of the ecosystems, (1) main target species, (2) bycatch species including vulnerable, protected or threatened species, (3) foodwebs and trophic relationships and (4) habitats.

At this stage, a first level of screening for the more than 200 indicators identified was also done (1) to remove duplicate indicators (e.g. different case studies used the same type of indicators), (2) to exclude indicators that reflected conventional single species indices (such as the biomass, size structure or demographic parameters calculated for single species) as our focus was to select more integrative and community-level indicators, and (3) exclude those that were still at the developing stage and we felt that further testing was required before they could become operational. We valued more ecosystem indicator that capture the cumulative impacts of fisheries on the broader ecosystem by monitoring the cumulative impacts of fisheries on whole communities (including targeted and non-targeted species) and captured the indirect impacts of fisheries on food webs. While single-species indicators (such as the biomass, size structure or demographic parameters of single species), which are commonly examined through conventional singles fisheries management, are still required and are part of an ecosystem approach, we stress additional information can be gained by incorporating more integrative and community-based ecosystem indicators into assessments indicators of biodiversity and ecosystem function. This screening resulted in 32 pressure and state indicators.

These 32 indicators were then evaluated in great detail using a criteria consisting in a ranking procedure to create an ordered list of indicators. This ranking procedure aims to guide the choice of indicators, as well as where to place efforts to develop the them (Queiros et al. 2016). We applied the Indicator Quality (IQ) evaluation method, with the pelagic food web specifically in mind, developed by Queirós et al. (2016). Queirós et al. (2016) uses 8 quality criteria to quantify the strength and weaknesses of indicators, assigns scores to each indicator according to each quality criteria, and finally a final score is determined per indicator, which allow their final ranking. The 8 quality criteria include: 1. scientific basis, 2. ecosystem relevance, 3. responsiveness to pressure, 4. possibility to set targets, 5. precautionary capacity/early warning, 6. Concrete, measurable, accurate, precise and repeatable, 7. Cost-effective, and 8. Existing/ongoing monitoring data.

No single indicator was scored with a maximum potential score of 8 (if it met all the quality criteria) (Figure 1). Even no single indicator was considered to have all relevant data available, since even simple indicators such as those based on catch and catch-at size data suffer from incomplete information for target and non-target species. High performance indicators (scores >6) monitoring key attributes (biomass, size structure and spatial distribution) for species of relevance to IOTC included: (1) the integrative indicator for the assessment of the biomass of multiple stocks of commercially fished species relative to management reference points (such as B_{MSY}), (2) total biomass of specific feeding guilds (which might include target and non-target species) can also demonstrate how biomass is accumulating and changing within the food web as a result of predator prey interactions, and (3) distributional indicators capturing changes in the extent of a species range or change in patterns within their range.

Indicators of pelagic habitat and trophic relationships scored mid-range (score >5), either due to a lack of clear responsiveness to pressures, due to the difficulty of setting acceptable targets, or due to limited data availability. Nevertheless, an ecosystem assessment would not be complete without indicators capturing these ecological components. Simple biomass and abundance metrics for planktonic groups were considered the best indicator of pelagic habitats. Trophic interactions were considered equally well captured by specific indicators of production (e.g. primary production), or based on multi-species indices such as predation mortality. Developing measures of total ecosystem productivity or by guild groups can be used to set limits of the total catch that can be taken by fisheries to avoid ecosystem-over-exploitation.

Indicator of incidental mortality of bycatch ranked among the lowest (score >=4.5) since there are few data on bycatch to estimate them with good spatial and temporal coverage, and biomass estimates with which to determine targets are also not available. The temporal and spatial coverage of observer programs which can provide the data on the incidental mortality of bycatch species are often incomplete due to low observer coverage for most member states. 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 publically available. Trend based assessments of incidental mortality (i.e. acceptable if decreasing) may not acceptable for bycatch species without absolute target values because, for example, a recovery of the abundance of a depleted species may result in an increase in bycatch rates and on the contrary the decrease of the population in a decrease of bycatch rates.

The 32 pressure and state indicators listed as candidate ecosystem indicators to populate potential ecosystem assessments in IOTC should be considered as preliminary, as the full analysis has not been completed yet.

Task 3 – Proposal of area-based management units or ecoregions to guide the operationalization of an EAFM

Under task 3 we proposed potential ecoregions within the Indian Ocean which could be used to guide region-based ecosystem plans, assessments and research to ultimately provide ecosystem management advice. The definition of EAFM specifies that it is place-based and its operationalization requires the choice of spatial units that are ecologically and biologically meaningful (CBD 2004, Grant et al. 2006, UNESCO 2009). Spatial units that are ecologically meaningful can help to highlight potential differences in environmental drivers, biological attributes and productivities among regions that in turn could explain differences in species composition or fishery production potential among regions (NAFO, 2014). They can also provide a framework to develop ecosystem assessments to monitor the status, trends and threats of specific ecosystem components by region with similar characteristics where the environmental drivers and fisheries impacts on each region would be presumably different. Furthermore, they could facilitate the planning for ecosystem management, the design of fisheries conservation and management of measures at the scale of specific regions. This would allow focusing management actions on specific regions and species, and it would provide a framework for monitoring and measuring success of specific spatially based management measures. Finally, the ecologically-based spatial units could also be used as a basis for ecosystem research including the development of ecosystem models (Rice *et al.*, 2011).

IOTC has not yet defined its own ecoregions or area-based management units to guide the development of ecosystem plans, assessments and research. Nevertheless, IOTC has its own spatial delineations within its Convention Area including some statistical areas for data reporting and single stock area delineations. These statistical areas were not developed with the intent of creating spatial assessment units with meaningful ecological boundaries to inform the development of area-based ecosystem plans and ecosystem assessments. Therefore, here, we identify and propose area-based management units or ecoregions within the IOTC convention area that make sense ecologically, and also account for the spatial patterns and dynamics of the main IOTC species and their fisheries. The area-based management units or ecoregions proposed are based on three pillars of information (1) the biogeography and oceanographic characteristics of the pelagic waters in the Indian Ocean, (2) the spatial distributions of tuna and tuna-like fish species in the Indian Ocean, (3) and the spatial patterns of the main fishing fleets targeting them. In doing so, first, existing biogeographical classification systems developed for marine pelagic ecosystems were reviewed and their potential relevance for the management and conservation of highly migratory tuna and tuna-like fish species in the high seas are discussed. Of the six biogeographical classifications reviewed, the Spalding's Pelagic Provinces of the World (PPOW) (Spalding et al. 2012) had the most qualities to inform the choice of ecologically meaningful spatial units for the management and conservation of tuna and billfish species (Figure 2). Second, the spatial distribution of catches of tuna and tuna-like species in the Indian Ocean were examined, and their spatial partitioning into communities and degree of overlap with the PPOW biogeographic classification was analyzed. Despite tunas and billfishes having a very broad tolerance for a wide range of environmental conditions, we find they form unique communities, which are associated to specific pelagic provinces with specific 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 (Figure 3). This suggests the environmental conditions captured by the Spalding's provinces might be controlling to some extent the spatial distribution and co-occurrence of tuna and billfish communities in the Indian Ocean. Third, the spatial dimensions of the main fleets and fisheries targeting tuna and tuna-like species in the Indian Ocean was also examined, as well as their overlap with the PPOW biogeographic classification. We find that purse seine fleets mainly operate in the tropical provinces targeting tropical tuna species. While longline fisheries operate throughout the entire Indian Ocean and can be divided on two main modes. While longline deploying their gear on the more surface waters target more temperate species such as albacore in the most subtropical temperate provinces, longliners deploying their gear at deeper depths target more tropical tuna species such as yellowfin and bigeye tuna in the most tropical provinces.

Based on the three aforementioned pillars of information, we propose two potential broad ecologically meaningful area-based management units or ecoregions in the Indian Ocean (Figure 4):

1) **Tropical Ecoregion** – It includes the Somali Current, the Indian Ocean Monsoon Gyre and Indonesian Through-Flow Provinces. This region is characterized by the monsoon. The currents in the northern Indian Ocean are mainly controlled by the monsoon winds and are dominated by a large circular clockwise current. The summer monsoon winds produces localized 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 the catch of these species is mainly caught 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 a well some areas of the subtropical Convergence, Subartic and Antartic 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 characterized 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 other tuna RFMOs, the CCSBT.

This proposal of ecoregions aims to create and foster discussion in IOTC on what could be considered the ideal versus practical ecologically meaningful spatial units to facilitate the operationalization of an EAFM in IOTC. The operationalization of an EAFM within the IOTC Convention areas requires the development of ecosystem plans and ecosystem assessments that in our view need to be region based, if our aim is to provide sound ecosystem advice for the distinct realities, fisheries, species and environments existing within the IOTC convention area.

Task 5 – A pilot ecosystem plan for Subtropical and Temperate ecoregion

Under task 5 we aim to develop a pilot ecosystem plan for one case study area, the Subtropical and Temperate Ecoregion. Effective management needs effective planning. Therefore, operational plans are needed to link higher level policies and objectives into actions (Staples et al. 2014). There are multiple purposes and benefits in development of an ecosystem plan to guide the implementation of an EAFM in a region (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 prioritize 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) helps the Commission to understand the cumulative effects of fisheries and emergent trade-offs between multiple objectives; and (5) serve as a communication tool to better link ecosystem science and policy (NPFMC 2007, Staples et al. 2014).

The development of an ecosystem plan requires the use of multiple tools and the preparation of multiple elements and processes. Here, the pilot ecosystem plan being developed for the Indian Subtropical and Temperate ecoregion is including the following elements, which we described briefly 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, the conservation of biodiversity and maintenance resilient ecosystems. Until the Commission defines and adopts a strategic vision for ecosystem plans, we are basing the vision and the goals of this pilot ecosystem plan on the IOTC aspirations reflected in its adopted recommendations and resolutions.

2. **Ecosystem overview** – Once the region has been chosen for the development of the ecosystem plan, it is important to define the scope of the region and to bring together all the relevant background information together. The ecosystem overview aims to integrate and synthesize our current knowledge of the main pressures and drivers that contribute to the state of the ecosystem in the Indian Tropical ecoregion. The overview starts with a short description of the main oceanographic and physical process operating in the area which may have an effect on the productivity and ultimate the fisheries production in the region. The overview also describes the main manageable threats and resultant pressures, being fisheries and the production of marine debris by fisheries, on the state of the ecosystem. It describes the main gears operating in the area and those fish species being targeted and exploited commercially. Moreover, the overview also describes the state and the changes in state of the different components of the ecosystems and describes those pressures accounting for the changes in state. It will describe the state of the main exploited fish species (retained and non-retained), and also the state of non-retained vulnerable species including some sharks, seabirds, marine turtles and marine mammals. In order to understand the potential indirect impacts of fishing on the marine foodweb, it also includes a section where the foodweb and known predatory-prey relationships is described.

3. **Ecosystem conceptual model** – While the ecosystem overview facilitates the integration of all the fisheries and ecological knowledge of the region, at the same time it also allows to identify how the different ecosystem components interact and relate to each other, raising up those emergent issues that we would like to monitor. Different visualization tools are being used to visualize those ecosystem components and their interconnectedness. The conceptual model allows to frame the scope ensuring that no critical components are missed and facilitating the targeting of specific research. Therefore, the conceptual model allows to identify and raise a manageable number of issues that may need to be research separately or as a whole. Eventually, the issues raised will need to be prioritize and risk assessment methods are available to prioritize them, to identify those issues of high priority for which research is needed or are needed to be managed as a priority. The conceptual 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 model 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.

4. **Ecosystem assessment framework including main ecosystem interactions, and a proposal of objectives, ecosystem indicators and reference points** – The ecosystem overview and conceptual model of the ecosystem for the case study 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, we identify and list issues and interactions that the Commission may wish to monitor in order to ensure the sustainable fisheries and avoid undesired changes of the ecosystem state or that the Scientific Committee may wish to monitor in order to base its ecosystem advice. In this ecosystem plan, an "interaction" if defined as a component (or group of components) that has an impact on another component (or group of components). At this stage, we are listing and defining the relevant ecosystem interactions, a later exercise will be to determine the degree of importance to the Commission based on their probability of occurrence as well as the level of impact to the current ecosystem state (the two pillars informing an ecosystem risk assessment). Defining these interactions and their relative importance and risk in the system, provide managers with a tool to either make choices between different risks and trade-offs or take actions to avoid unwanted risk through appropriate management actions.

   Relevant interactions are being categorized within eight general categories:
   A. Climate/physical impacts on the broader pelagic ecosystem
   B. Effects of productivity on the broader pelagic ecosystem
   C. Impacts of manageable pressures (fishing and marine debris) on the broader pelagic ecosystem
   D. Fishing effects on retained fish species
   E. Fishing effects on non-retained fish species
   F. Fishing effects on non-retained vulnerable taxa
   G. Fishing effects on community structure and function, food webs, and biodiversity
   H. Climate and fishing effects on habitats of ecological significance

   Ecosystem indicators can be used to monitor interactions. Ecosystem indicators have two main objectives under this ecosystem plan: (1) to help assess the status of the ecosystem components and their relevant interactions, (2) to monitor how well a fishery is managed in relation to objectives.

   A list of candidate indicators is being identified to monitor each of the interactions. These are divided in two categories: (1) Currently available and developed in IOTC derived from the work conducted by the Scientific Committee; (2) Those for which data is available (or partially available) but which are not currently monitored by IOTC; (3) those for which data is not currently available, but are included to guide future research efforts. Together with indicators, potential management objectives are also proposed to track the state of each relevant interaction. Furthermore, each indicator should be associated with reference points (or thresholds). When the reference points are reached, they should also trigger a management action. The determination of critical thresholds is an essential research topic as well as determine what are the appropriate management actions that should take place. While reference points could also be proposed for each candidate ecosystem indicators, here we will make reference to decision framework to set reference points developed under task 4, since the setting of reference points depends on the type of indicator and data available to estimate them. Not until these indicators are calculated we will be able to suggest specific reference points for each of them.

5. **Ecosystem advice and communication framework** – Once the ecosystem plan is finished it will need to be shared and communicated to different audiences including the scientific committee and the Commission. A communication strategy provides a clear process for sharing results in a logical and strategic way (Staples et al. 2014). A communication strategy will be developed for the pilot ecosystem plan and will include (1) identifying the target audience, (2) the communication methods (how and where), (3) the key messages and (4) timing. Additionally, the project will also propose a series of products and activities that aim to better link ecosystem science and fisheries management advice in the short and long terms. The products will be presented and described how they are interconnected, their main purpose, and targeted audience and their timelines. Ecosystem products include the development of ecosystem plans, ecosystem overviews, ecosystem conceptual models, ecosystem risk assessments, indicator-based assessments, and ecosystem report cards. Some of this product have been partially

developed in this project, other have been presented but not fully developed, and other could be developed in the near future.

We consider the development of these elements to be the first steps towards the development of an ecosystem plan, but do not consider this list to be complete. Future revisions of this preliminary ecosystem plan could also envision to conclude a section with management actions needed to meet each specific objective, as well as identify continuous financial support for the implementation of the plan, to name a few. Additionally, the current state and formulations of these elements should be seen as preliminary as they are still under development. With this pilot ecosystem plan we intent to create awareness about the need for ecosystem planning, create discussion about what elements need to be part of a planning process, and intent to be the foundation for future participatory and consultative ecosystem plans in IOTC.

4. Conclusions

Two of the main objectives of the EU project to facilitate the operationalization of an EAFM in IOTC are (1) identify candidate ecoregions or area-based management units within the Indian Ocean to guide the development of ecosystem products such as ecosystem plans and assessments to inform advice, and (2) develop a pilot ecosystem plan for one case study region. In IOTC, the EU Consortium carrying out the project chose to develop the pilot ecosystem plan for the Indian Subtropical Temperate Ecoregion. The proposal of ecoregions aims to create and foster discussion in IOTC on what could be considered the ideal versus practical ecologically meaningful spatial units to facilitate the operationalization of an EAFM in IOTC. The pilot ecosystem plan aims to create awareness about the need for ecosystem planning, create discussion about what elements need to be part of a planning process, and intent to be the foundation for future participatory and consultative ecosystem plans in the IOTC convention area. Ultimately, the products created in this study aim to facilitate the linkage between ecosystem science and fisheries management as well as facilitate the process to operationalize an EAFM in IOTC.

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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
Spawning Stock Biomass relative to MSY Btrigger	7	1	1	1	1	1	1	0.5	0.5	target species
Distributional range (including extent, centre of gravity, pattern within range and pattern along environmental gradients)	6.5	1	1	0.5	0.5	1	1	1	0.5	target and non-target species
Community size based indicators (mean length, size spectra, 95th percentile of the fish length distribution)	6.5	1	1	0.5	0.5	1	1	1	0.5	target and non-target species
Biomass indicators (total, guild/community) including fish, marine mammals and seabirds	6.5	1	1	1	1	0.5	1	0.5	0.5	target and non-target species
Mean Trophic Level Indicators (catch)	6	1	1	1	1	0	0.5	1	0.5	target species
Age-frequency distribution (AFD) of fish	6	1	0.5	0.5	0.5	1	1	1	0.5	target and non-target species
Proportion of non-declining exploited species	6	1	1	0.5	1	0.5	1	0.5	0.5	target and non-target species
Group Fishing mortality	6	1	0	1	1	1	1	0.5	0.5	target and non-target species
Predation mortality from multispecies models	6	1	1	1	0.5	1	1	0.5	0	target and non-target species
Mean maximum length of fish and elasmobranchs	6	1	1	1	0.5	0	1	1	0.5	target and non-target species
Abundance-Biomass Comparison (ABC) curves	5.5	1	1	1	0.5	1	1	0	0	target and non-target species
Species diversity indices (Shannon/Simpson/Evenness/Richness)	5.5	1	1	1	0.5	0	1	0.5	0.5	target and non-target species
Plankton biomass and/or abundance	5.5	1	1	0	0.5	1	1	0.5	0.5	pelagic habitats
Proportion of fish larger than the mean size of first sexual maturation	5.5	1	0	0.5	0.5	1	1	1	0.5	target and non-target species
Productivity (production per unit biomass) of key species or trophic groups (including production of phytoplankton)	5.5	1	1	0	0.5	1	1	0.5	0.5	trophic relationships
Multivariate Seabird Indices	5.5	1	1	1	0.5	1	1	0	0	trophic relationships
Recovery in the Population Abundance of Sensitive Fish Species	5	1	1	1	1	0	1	0	0	target species
Proportion of predatory fish or "Large Species Indicator"	5	1	1	1	0.5	0.5	1	0	0	target and non-target species
Ichthyoplankton abundance indices for most abundant larval taxa	5	1	1	0	0.5	1	1	0.5	0	target and non-target species
Length-frequency of catch (including bycatch) per year and subarea	5	1	0	0.5	0.5	1	1	0.5	0.5	target and non-target species
Species size at first sexual maturation	5	1	0	0	0.5	1	1	1	0.5	target and non-target species
Mean Trophic Level Indicators (survey)	4.5	1	1	1	1	0	0.5	0	0	target and non-target species
Incidental mortality of marine mammals / seals	4.5	1	1	0.5	0.5	0	0.5	0.5	0.5	non-target vulnerable species
Incidental mortality of seabirds	4.5	1	1	0.5	0.5	0	0.5	0.5	0.5	non-target vulnerable species
Incidental mortality of marine turtles	4.5	1	1	0.5	0.5	0	0.5	0.5	0.5	non-target vulnerable species
Incidental mortality of sharks	4.5	1	1	0.5	0.5	0	0.5	0.5	0.5	non-target vulnerable species
Plankton biomass and size structure	4.5	1	1	0	0.5	1	1	0	0	pelagic habitats
Catch sex and maturity composition	4.5	1	0	0.5	0.5	0	1	1	0.5	target and non-target species
Disease Ecology Indicator	4.5	1	1	1	0.5	0	1	0	0	target and non-target species
Fish condition (length-weight residuals)	4.5	1	1	0.5	0.5	0	1	0.5	0	target and non-target species
Large Fish indicator for demersal fish	4	0	1	0.5	1	0	1	0	0.5	not applicable
Population genetic structure (single species)	0.5	0	0.5	0	0	0	0	0	0	target and non-target species

Figure 1. Ranked list of candidate ecosystem indicators evaluated using Queirós et al. 2016 criteria. The listed indicators should be considered preliminary as the full analysis has not been completed.

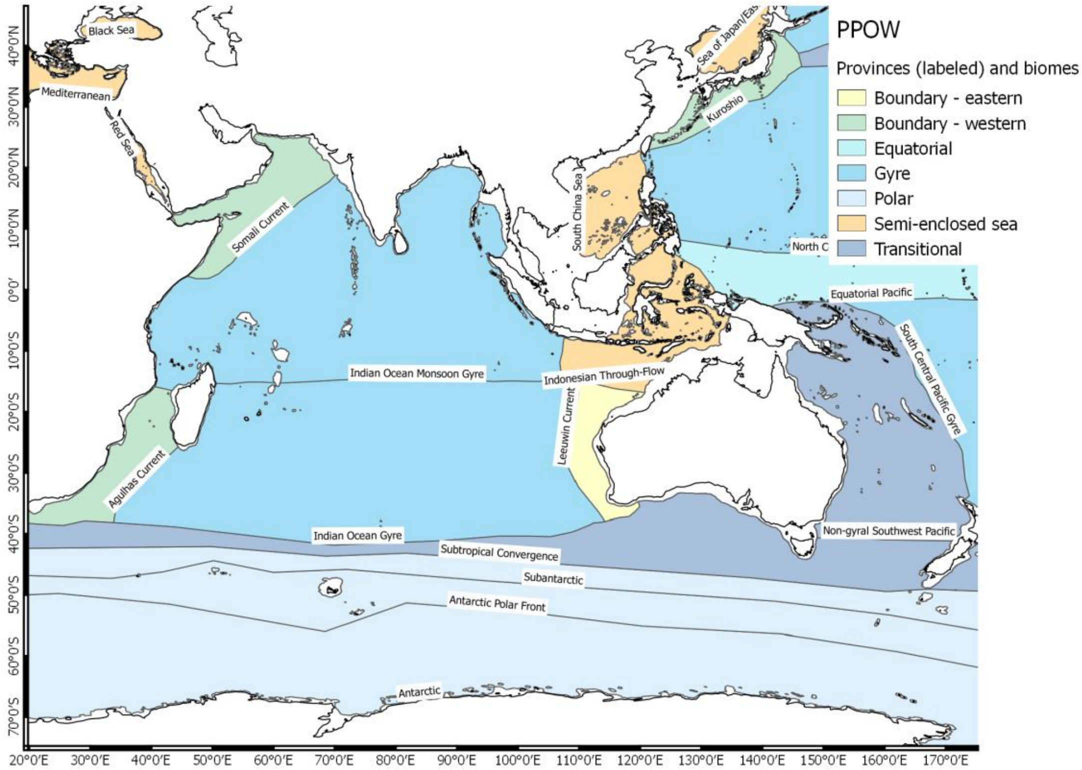

Figure 2. Spalding Pelagic Provinces of the World biogeographic classification.

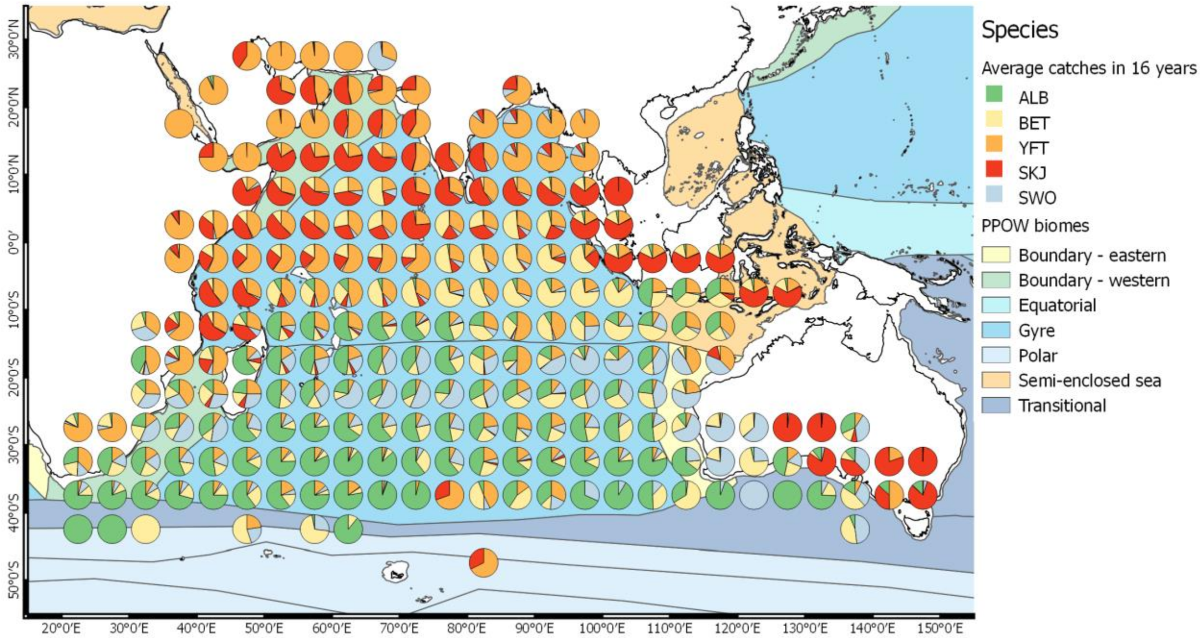

Figure 3. Spatial patterns of species catches overlaid on top of Spalding PPOW biomes and provinces. The PPOW provinces are represented by the black line divisions, and PPOW biomes are represented by colors. The area of each circle has been scaled to unity, and the size of each wedge represents the fraction of catch of each group. Values are averages for each 5X5 degree grid cell over the period 2000-2014.

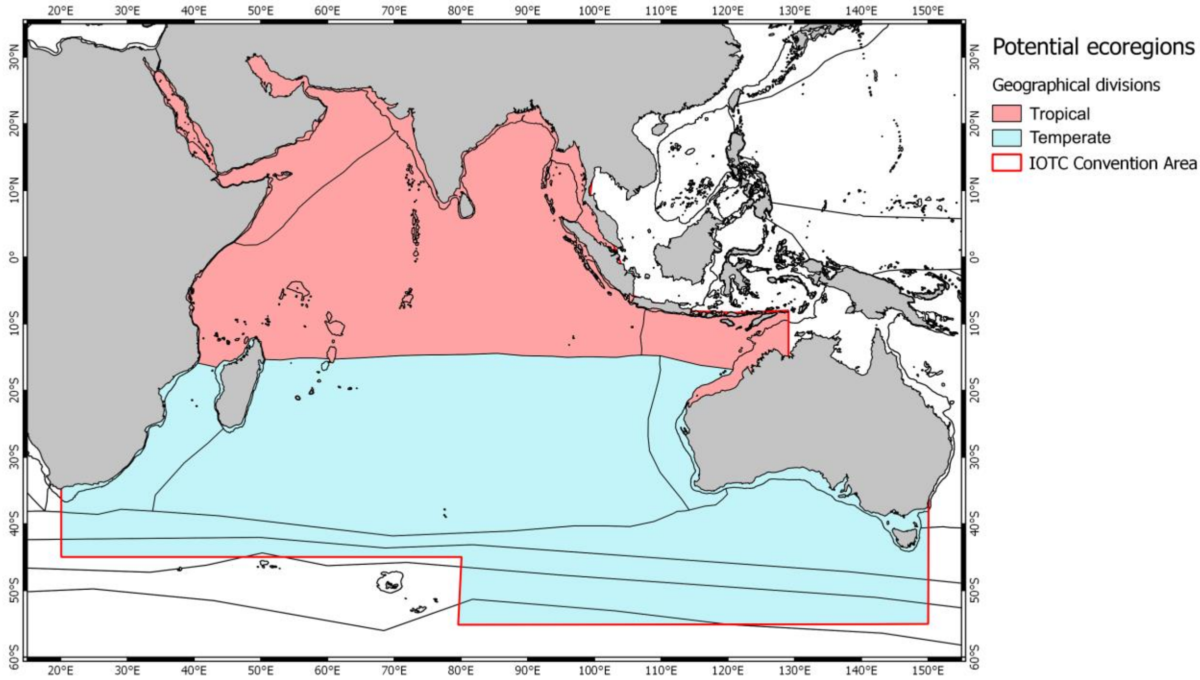

Figure 4. Preliminary proposal of area-based management units or ecoregions for the pelagic Indian ecosystem to support the operationalization of an EAFM in IOTC.