Pre-workshop analysis in preparation for the 2022 IOTC Ecoregions Workshop :

"Identification of regions in the IOTC convention area to inform the implementation of the ecosystem approach to fisheries management"

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Abstract

The Indian Ocean Tuna Commission (IOTC) has committed in principle to operationalize an Ecosystem Approach to Fisheries Management (EAFM) in accordance with internationally agreed standards. Accordingly, the IOTC Working Party on Ecosystems and Bycatch (WPEB) has been working to assess the feasibility of and developing several ecosystem products to inform EAFM implementation in the region. However, in the context of managing highly migratory species such as tunas, billfishes and sharks in the Regional Fisheries Management Organization (RFMOs), the spatial scale at which these ecosystem products should be developed remains largely unexplored. Regionalization of the IOTC convention area into areas or ecoregions that make ecological sense and are large enough to be practical can provide a foundation for developing a wide range of ecosystem products to assist in the production of more integrated ecosystem-based advice to the Commission. The WPEB14 recommended convening a workshop to provide advice on the identification of draft ecoregions to foster discussions on the operationalization of the EAFM in the IOTC convention area. The first IOTC ecoregion workshop took place in September 2019 with the participation of CPC national scientists and external experts. This process resulted in a draft proposal of seven ecoregions within the IOTC convention area which were presented to the WPEB15. The WPEB15 recommended a second IOTC ecoregion workshop to refine the process of ecoregion delineation while considering the expert advice and feedback received in the first workshop and the draft proposal of ecoregions. The second IOTC ecoregion workshop is planned to take place from January 19 to 21 2022. This report summarizes the main preparatory work that has been carried out prior to the second IOTC Ecoregion workshop, and it presents the main tasks and expected outputs of this second workshop.

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Introduction

The ecosystem approach to fisheries management (EAFM) has been adopted within a wide range of policy instruments including the Food and Agriculture Organization (FAO). The FAO advises that Regional Fisheries Management Organizations (RFMOs) implement an EAFM to account for the impacts of fisheries on marine ecosystems and the effects of marine ecosystems on fisheries (FAO 2002, FAO 2003). The EAFM is a spatially-explicit approach for the integrated management of fisheries that incorporates ecosystem knowledge and uncertainties, considers multiple external influences and endeavors to account for diverse societal objectives (NOAA 2004). It attempts to account for the connectivity between species, their habitats and the physical environment, and their connection with humans (Rice et al 2011).

The Indian Ocean Tuna Commission (IOTC, one of the tuna RFMOs) has the mandate to manage 16 pelagic fish species (Table 1), among which are three species of tropical tuna, two species of temperate tuna (though in practice *Thunnus maccoyii* is managed by CCSBT), six species of neritic tuna, and five species of billfish. For most of these species, single-species stock assessments are performed every two to three years in IOTC. In addition, fisheries interactions with vulnerable species and the ecosystem are also recognised, and management measures are applied to minimize the interaction of tuna and billfish fisheries on vulnerable species groups (e.g. seabirds, turtles, sharks). Yet there is not a holistic and integrative EAFM framework within the IOTC convention area (Figure 1) for the management of assemblages of interacting species and fisheries and the trade-offs that inevitably emerge.

Table 1. Species under the management of the IOTC (taken from https://iotc.org/about-iotc/competence).

FAO English name	FAO French name	Scientific name	FAO Code	Habitat type
Yellowfin tuna	Albacore	*Thunnus albacares*	YFT	Tropical oceanic
Skipjack	Listao; Bonite à ventre rayé	*Katsuwonus pelamis*	SKJ	Tropical oceanic
Bigeye tuna	Patudo; Thon obèse	*Thunnus obesus*	BET	Tropical oceanic
Albacore tuna	Germon	*Thunnus alalunga*	ALB	Temperate oceanic
Southern bluefin tuna	Thon rouge du sud	*Thunnus maccoyii*	SBT	Temperate oceanic
Longtail tuna	Thon mignon	*Thunnus tonggol*	LOT	Neritic
Kawakawa	Thonine orientale	*Euthynnus affinis*	KAW	Neritic
Frigate tuna	Auxide	*Auxis thazard*	FRI	Neritic
Bullet tuna	Bonitou	*Auxis rochei*	BLT	Neritic
Narrow barred Spanish Mackerel	Thazard rayé	*Scomberomorus commerson*	COM	Neritic
Indo-Pacific king mackerel	Thazard ponctué	*Scomberomorus guttatus*	GUT	Neritic
Blue Marlin	Makaire bleu	*Makaira nigricans*	BUM	Tropical oceanic
Black Marlin	Makaire noir	*Makaira indica*	BLM	Tropical oceanic
Striped Marlin	Marlin rayé	*Tetrapturus audax*	MLS	Tropical oceanic
Indo-Pacific Sailfish	Voilier de l'Indo-Pacifique	*Istiophorus platypterus*	SFA	Tropical oceanic
Swordfish	Espadon	*Xiphias gladius*	SWO	Subtropical oceanic

An EAFM is a place-based approach rather than a species-based approach (Fogarty 2014). EAFM implementation creates the need to think, plan and act in terms of ecosystems. This process requires a move away from an emphasis on individual species and elements that comprise an ecosystem to a more integrative and holistic perspective, requiring a spatial context within which ecosystems can be described, monitored and reported on (Trenkel 2018). Therefore, one of the fundamental requirements to effectively implement an EAFM is the delineation of spatial units or ecologically meaningful regions (ecoregions) to guide ecosystem-based research, planning and management (Staples et al. 2014, Fletcher et al. 2010). Ecoregions are defined as areas exhibiting relative homogeneous ecosystems, and are designed to be units of analysis to support environmental assessments and decision-making in the management of natural resources (Ormerik and Bailey 1997). Ecoregions are used for a variety of purposes and applications depending on the intended purpose. Ecoregions may be practically useful for the implementation of an EAFM because they are delineated at the scale at which most species within that ecoregion will respond to management actions (Waltner-Toews et al 2008). Within ecoregions, a fisheries management body could monitor both the status of stocks and their corresponding 'ecosystems', but also implement management measures tailored to those species and fisheries interactions in the system. As such, ecoregions could be used to facilitate the planning, design and implementation of regionalised fisheries conservation and management measures (Rice et al 2011). Likewise, they can be used to monitor the status, trends, and threats to these regionalised ecosystems and any effects of region-specific management measures. Furthermore, they can be used as a framework for research purposes, for example, in ecosystem and habitat modeling.

Ecoregion mapping is an interdisciplinary endeavor that requires the integration of knowledge of multiple disciplines including but not limited to geography, ecology, climatology, and resource management. In practice, the derivation of ecoregions requires the classification or regionalization of the seaspace into a number of regions to reduce complexity to a manageable and understandable number of units. Ecological regionalizations or biogeographical regionalizations are processes that generally use biological and physical data to identify broad patterns of co-occurrence of species, habitat and ecosystem processes (Spalding et al 2007). These are then used to delineate geographically distinct units of homogenous ecological characteristics at a specified scale that are relatively distinct from adjacent areas (UNEP-WCMC 2006). There are several international organizations that have successfully derived and used ecoregions as tools to guide ecosystem-based research, planning and management advice (e.g. North Atlantic Fisheries Management Organization (NAFO), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), International Council for the Exploration of the Sea (ICES), the North Pacific Fisheries Management Council in Alaska, USA). The use of ecoregions as a tool to provide more integrated and ecosystem based advice is now being explored in IOTC (Figure 1) and also in ICCAT (Juan-Jordá et al. 2021).

Though highly migratory with wide spatial distributions, tuna and tuna-like species have been shown to have distinct, geographical assemblages in response to broad oceanographic patterns and processes occurring at ocean-basin scales (Reygondeau et al 2012); and thus, ecoregions could be used as a tool to advance research and guide planning and advice to support the application of the EAFM. Recent efforts have been made to develop ecoregions for the IOTC convention area (i.e. Juan-Jordá et al 2018, Juan-Jordá et al 2019a). In 2018, initial work towards a broad-scale delineation of the IOTC convention areas (Figure 1) was presented to the IOTC 14th Session of the Working Party on Ecosystems and Bycatch (WPEB), as a conceptual scientific exercise to discuss its potential utility and to explore avenues for future work. The ensuing discussion of the WPEB group led to the recommendation that a workshop be convened in 2019 to provide advice on the identification of draft ecoregions based on a revised set of criteria and to foster discussions on the operationalization of EBFM in the IOTC convention area (IOTC 2018).

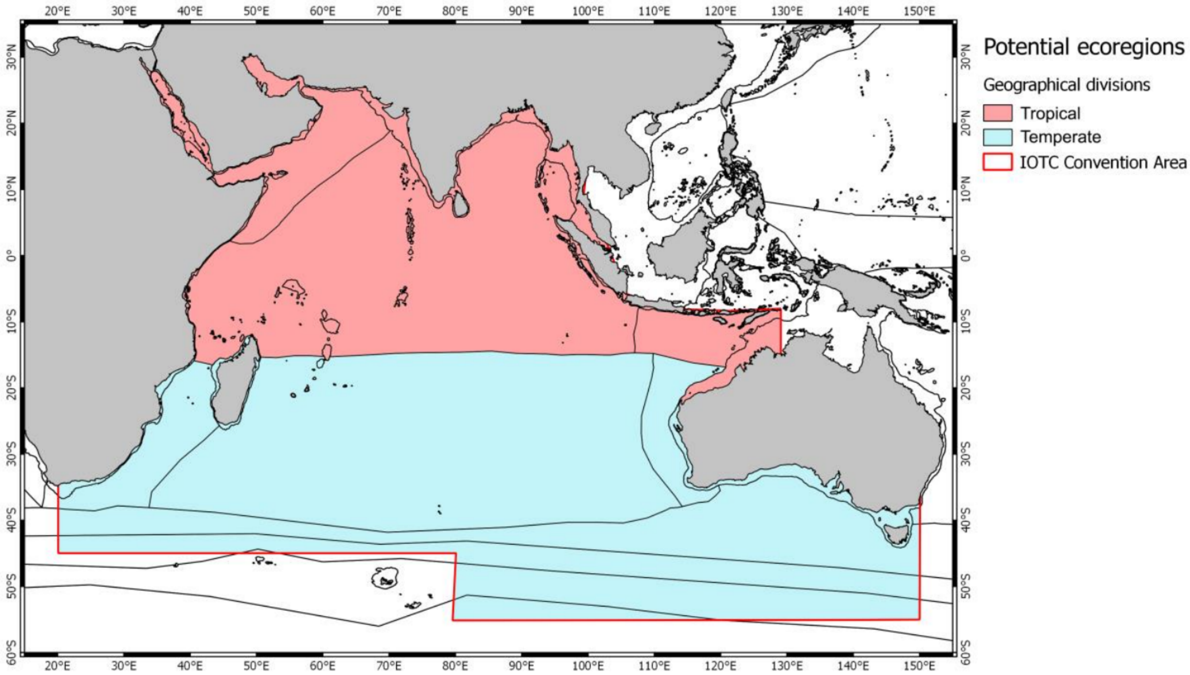


Figure 1. The IOTC convention area (red line) and the candidate ecoregions proposed by Juan-Jordá et al. 2018.

This first IOTC ecoregion workshop took place in September 2019 with the participation of CPC national scientists and external experts (Juan-Jordá et al. 2019b). Prior to the workshop, a baseline draft proposal of ecoregions was prepared, which was presented and discussed at the workshop by all the participants (Nieblas et al. 2019). The baseline proposal was used in the workshop to present preliminary analyses and guide discussions towards deriving draft ecoregions within the IOTC convention. This process resulted in a draft proposal of seven ecoregions (Figure 2) within the IOTC convention area (Juan-Jordá et al. 2019b). Another important output of this workshop was the constructive and technical discussions that took place in framing the general process of ecoregion delineation (Figure 3), from defining the main purposes and uses, main principles, rules and criteria to guide the regionalizations, to evaluating data inputs and analytical methods, and examining and refining candidate ecoregions based on expert knowledge within the Indian Ocean. During the workshop, the participants provided valuable feedback on the data sets and methods used to delineate the ecoregions to be considered in future revisions of the work. The draft proposal of seven ecoregions derived in this first IOTC ecoregion workshop were presented at the WPEB15 in September 2019. The WPEB15 recommended a second IOTC Ecoregion workshop to refine the process considering the expert advice and feedback received in the first IOTC ecoregion workshop (IOTC 2019).

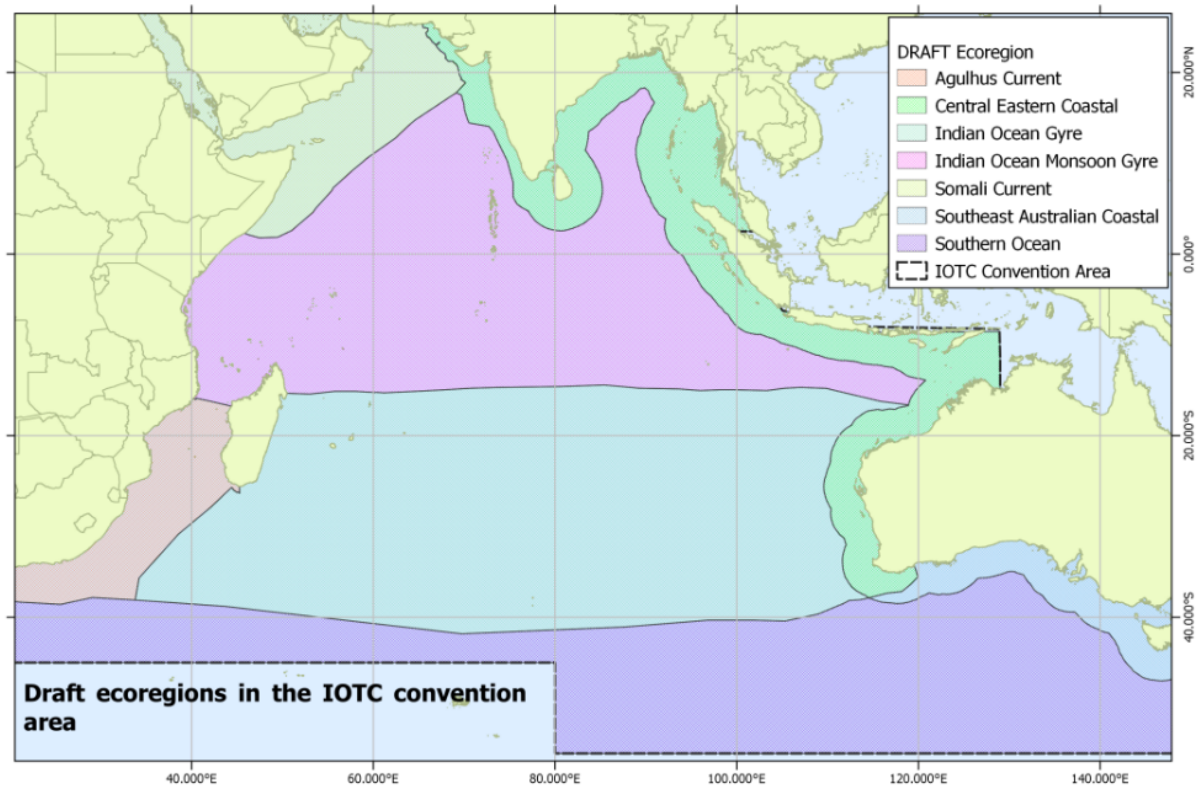


Figure 2. The IOTC convention area (dashed black line) and the draft ecoregions proposed by Juan-Jordá et al. 2019b.

Objectives

The current work has been performed in preparation for the second IOTC Ecoregions workshop, “Identification of regions in the IOTC convention area for supporting the implementation of the ecosystem approach to fisheries management”, to be held online from January 19 to 21, 2022. The overall aim of the second IOTC ecoregion workshop is to refine the process of ecoregion delineation considering the expert advice and feedback received at the first IOTC ecoregion workshop, and also prepare a refined draft proposal of ecoregions in the IOTC convention area. This report summarizes the preparatory work carried out prior to the second IOTC Ecoregion workshop, and also presents the main tasks to be carried out during the second IOTC ecoregion workshop.

Report structure

This report is structured following the framework of the approach taken to derive the ecoregions described below (Figure 3). For each major step in this framework, first, we briefly describe the actions taken during the first IOTC ecoregion workshop and we summarize the group recommendations and advice received. Next, we describe actions taken in preparation of the second IOTC ecoregion workshop to address the group’s advice and present our findings. Finally, we propose areas to be addressed in the near future.

Framework to guide ecoregion delineation

During the first IOTC ecoregion workshop it became apparent the importance for improved understanding and replicability of a well-structured **framework to guide the process of ecoregion delineation** that clearly and explicitly states **the main principles and procedural rules *a priori*** (Figure 3).

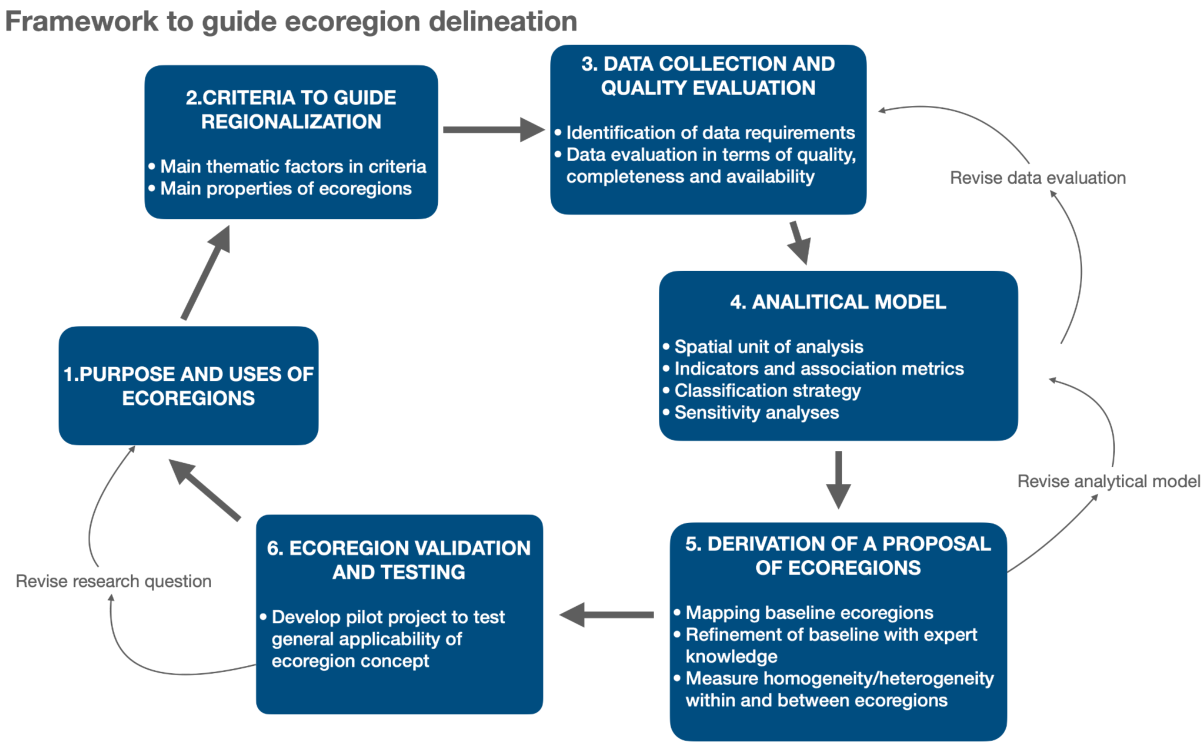


Figure 3. Approach taken to derive ecoregions to support EAFM implementation in IOTC.

This framework follows a stepwise process, with several feedback loops to incorporate lessons learned and new knowledge:

1. Purpose and uses of ecoregions

- Ecoregions should be designed to **serve a specific purpose** and satisfy specific user requirements, which should be discussed and defined a priori (Loveland and Merchant 2004), i.e., the purpose and use of the ecoregions in support of EAFM implementation in IOTC must be specified.
- The intended use and applicability of the ecoregions must be used as a guide to identify their expected qualities and guide the approach taken to delineate them.

2) Criteria to guide regionalization

- A set of **criteria for guiding the delineation of ecoregions** needs to be established in advance (ICES 2021). The criteria need to include the **main thematic factors** (e.g.

oceanography, biogeography, taxonomy, fisheries, socio-economics, etc..) that will be used to inform the delineation of ecoregions.

3) Data collection and quality evaluation

- The **collection and requirements of data** to address and characterize each thematic factor for ecoregion delineation should be identified and **well documented,** and the extent to which currently available datasets satisfy such requirements need to be assessed (Loveland and Merchant 2004). The data used to inform the delineation of ecoregion boundaries must be carefully evaluated for their **quality, completeness, and availability**.

4) Analytical model

- The analytical methods to carry out the ecoregion analysis and mapping should be selected. There is a **wide range of quantitative and qualitative approaches** to classification and their choice must be driven by the intended purpose and application of ecoregions and the nature and availability of data and information at hand. Quantitative methods (e.g. factor-based classification approach), qualitative methods (e.g. weight-of-evidence approach, expert knowledge) or a hybrid of both methods have been used to derive ecoregion classifications.
- It is important to note that both quantitative and qualitative approaches to **classification are inherently subjective** and may have elements of subjectivity, including expert opinion and judgment. However, this does not imply a reduction of the rigor or validity of results (Loveland and Merchant 2004).
- **Sensitivity analyses** should be performed to determine the influence of different parameters informing the ecoregion delineation.

5) Interpreting results and deriving proposal of ecoregions

- **Baseline ecoregions** resulting from the classification analysis should be mapped and refined with expert knowledge to derive the draft **proposal of ecoregions.**
- The results should be analyzed to determine the **heterogeneity between** and the **homogeneity within** the resulting classification groups, or candidate baseline ecoregions, so their regional structure can be objectively evaluated (Bailey 1983).
- **Expert knowledge** applied to refine the ecoregion classification must be **objective, robust and defensible** and, when possible, supported by literature and analysis.

6) Validation and testing

- Ecoregions should be considered as **working hypotheses to be tested and validated** (Baily 1983, Loveland and Merchant 2004). The ecoregions delineated are hypotheses that have arisen from knowledge of the thematic factors (e.g. oceanography, biography, taxonomy, fisheries) that are believed to be important for the intended use of the ecoregion. Therefore, ecoregions are expected to be validated and tested (Bailey 1983) before they are used for planning and resource management.
- The ultimate test of utility of ecoregion may be the extent to which they meet the end user needs (Loveland and Merchant 2004). Pilot studies and products must be developed to test their utility.

7) Revise and refine

- Ecoregions must be **refined and updated as needed** at regular intervals to account for changes in data availability and quality and changes in user needs.

- Similarly ecoregions may change over time; for example in response to the effects of climate change and environmental variability. Therefore, it is important that additional research be directed to assess what constitutes significant change in order to inform the best timing for their update (Loveland and Merchant 2004).

Step 1 - Purpose and uses of ecoregion

Actions taken during first workshop and Group advice

During the first IOTC ecoregion workshop in 2019, the experience in developing and using ecoregions in the Northwest Atlantic Fisheries Organization (NAFO), International Council for the Exploration of the Sea (ICES), the Commission for the Conservation of Antarctic Marine Living Resources (CAMLR) and the North Pacific Fisheries Management Council (NPFMC) in the USA were presented to the Group. Each organization had the opportunity to provide (1) an overview of how spatially explicit units or ecoregions have been identified to support EAFM implementation in their convention areas, (2) the main drivers to delineate them, (3) their main uses with examples, (4) experiences on the strengths and weaknesses of using ecoregions as an EAFM implementation tool, (5) and insights into lessons learned from the process.

The Group discussed **potential strengths and weaknesses** in the use of ecoregions as tools for guiding EAFM implementation in the context of these organizations and in the context of IOTC species and fisheries. These regional examples showed that **a strength** of using ecoregions is that they are a useful foundation to structure ecosystem advice for fisheries management bodies, and also provide a useful foundation for developing a wide range of research products (e.g. ecosystems overviews, fisheries overviews, integrated assessments, ecosystem models). These regional examples also showed that **a weakness** of using ecoregions is that they may add a level of complexity and abstraction to discussions with very few concrete examples of implementations that fisheries managers may not be willing to deal with.

Based on these regional examples, the Group discussed how ecoregions are being used as tools (1) for regional planning of resources and information, (2) to develop regional research products (e.g. ecosystem overview reports, ecosystem models) which help to simplify indicators and advice by making them context and region specific, (3) and to structure advice to better understand the connection between their fisheries and the state of the ecosystem and emerging trade-offs between multiple fisheries and taxa interactions.

The Group advised on the importance of providing a strong rationale of what might be the potential benefits and uses of ecoregions in the context of IOTC species and fisheries and suggested testing examples of their applicability in order to validate them. The Group also noted the importance of involving the Commission early, to build an inclusive and iterative process. The Group further noted the use of ecoregions to structure advice is not a revolutionary idea since it does not impose a new management system on managers, and it does not impose additional burdens in terms of resources or new data collection or monitoring. Therefore, the Group suggested that when communicating this work to the IOTC community it is important to reassure them that the use of ecoregions to structure ecosystem-based advice is not going to change the status quo, and instead the focus should be on showing the potential added benefits of using them.

Action taken in preparation for the second workshop, findings and proposed solutions

Based on the Group's advice and the discussions that took place during the first IOTC ecoregion workshop, we provide **a list of potential uses of ecoregions as tools** to guide EAFM implementation in IOTC to be discussed at the workshop. We note that the following potential uses of ecoregions is not going to change the current practice of management advice applied at the species level or fishery level, and instead the focus should be on showing the potential added benefits of using them.

- **Planning and prioritization tool** - Ecoregions can provide a spatial framework for assessing needs and risks at the scale of specific regions which can be used to inform planning and prioritization of resources, data collection and research.
- **Research and monitoring tool** - Ecoregions can steer research for the development of multiple concrete **scientific products and integrated approaches** (e.g. ecosystem overviews, fishery overviews, integrated ecosystem assessments, ecosystem models, etc…). The ecoregion units can provide a regional framework for assessing status, trends and threats and for addressing multi-fishery and multi-taxa interactions and emergent trade-offs. This may include (1) monitoring and reporting the state and trend of the environment and possible ecosystem responses to climate change, (2) monitoring and reporting the state and trends of bycatch and vulnerable species and responses to mitigation measures, (3) support broad-scale ecological modeling to enhance understanding of ecosystem structure and function and predict cumulative responses derived from fishing and the environment, (4) identification and visualization of emerging trade-offs in multi-species and multi-fishery interactions, (5) planning and directing future research in poorly-understood regions, among others.
- **Advice tool**: Ecoregions can provide a spatial framework for **structuring advice** (integrated advise) to address regional management challenges. The ecoregion can provide a spatial framework for integrating scientific and socio-economic information and visualize emerging trade-offs between multiple management objectives.

Based on the Group feedback, we also added an additional step in the main framework for guiding the ecoregion delineation (Figure 3) which consists of **validating and testing the draft ecoregions** by developing a **pilot product** to test its general applicability, potential usefulness, benefits and challenges. This is further developed under Step 6 in this report.

To engage the Commission early in the process, we also recommend presenting outputs of this workshop to the WPEB and request its diffusion to the SC and Commission to build an inclusive and iterative process, and consult potential purposes and uses with the wider IOTC community as early as possible.

Step 2 - Criteria to guide ecoregion delineation and the expected qualities of ecoregions

Actions taken during first workshop and Group advice

During the first IOTC ecoregion workshop, evaluation criteria were presented to the Group to discuss what thematic factors, including both ecological and social factors, should be considered to inform and guide the delineation of the ecoregions.

Some thematic factors were considered and their relevance discussed, including :

1. the oceanography and biogeography of the region,
2. the knowledge of the spatial distributions and co-occurrence of main IOTC species (tuna, billfishes, neritic species, sharks, and other bycatch species),
3. the spatial dynamics of the main fisheries (including coastal artisanal, semi-industrial and industrial fleets) and their spatial overlaps,
4. relevant socio-economic and geopolitical factors, and
5. compatibility with other regional initiatives (e.g. SWIOFC).

The Group agreed on the expected qualities of the ecoregions and that thematic factors including (i) major oceanographic and biogeographic patterns, (ii) the spatial distribution of main IOTC species (tunas, billfishes, neritics), and (iii) the spatial distribution of IOTC fisheries (coastal and industrial fisheries) should be the primary factors to be considered as part of the evaluation criteria for guiding the ecoregion classification. The Group recommended excluding the rest of thematic factors proposed.

Action taken in preparation for the second workshop, findings and proposed solutions
Based on the Group's advice and the discussions that took place during the first IOTC ecoregion workshop, we have updated and described the criteria that will be used for guiding the present ecoregion classification. The criteria now include three thematic factors to guide the ecoregion classification, including the major oceanographic patterns, the spatial distribution of tunas and billfishes (oceanic and neritic species), and the spatial distribution of the fisheries targeting them (Table 2).

Table 2. Refined criteria for evaluating and guiding the delineation of ecoregions and their expected qualities.

#	Criteria
	Oceanography/Biogeography
1	The boundaries of proposed ecoregions appropriately demarcate areas with a clear oceanographic justification
	Spatial distributions of main IOTC species
2	The boundaries of proposed ecoregions appropriately demarcate the core distribution of IOTC tuna and billfish species (neritic and oceanic) and the biogeography of tuna and billfish communities
	Spatial distribution of main IOTC fisheries
3	The boundaries of proposed ecoregions appropriately demarcate the core distribution of major IOTC fisheries (artisanal and industrial) operating in the IOTC convention area, including coastal and oceanic pelagic waters

Furthermore, the intended use and applicability of the ecoregions (summarized in step 1) are used as a guide in dealing with issues of scale and ecoregion extent, since the spatial scale at which ecoregions are defined and their expected qualities can have an important impact on their potential uses. Based on Group discussions and best practices in developing and using marine biogeographic classifications for resource planning and management, we summarize here a list of properties of ecoregions which are used to guide all the steps in the delineation of ecoregions in IOTC (Figure 3). These are:

- **Ecoregions should be considered static** in order to become a practical tool for resource assessment and management. It is also a common practice to differentiate between the **core and periphery** of an ecoregion (Loveland and Merchant 2004). The homogeneity of

ecoregion will be most manifested at the core, by contrast transition areas will be most manifested at the periphery. Therefore, ecoregions have boundaries that are generalized and not precise, and should be interpreted more often as gradients and transition zones rather than sharp edges. Boundaries of ecoregions should not be interpreted as 'hard' management lines (Rice et al 2011).
- **Ecoregions must be relatively few in number** to make them a practical tool to inform EAFM implementation. The spatial scale at which ecoregions are defined can have an important impact on their potential uses, therefore the ideal versus practical number of ecoregions may be considered to inform the delineation of ecoregions.
- Ecoregion classifications may consider involving some type of **nested hierarchy** to account for issues of scale and ecoregion extent (Loveland and Merchant 2004). The intended use and applicability of the ecoregions must be used as a guide in dealing with issues of scale and ecoregion extent, including whether hierarchical subdivisions are needed.
- Ecoregions for EAFM implementation purposes should be **geographically distinct**. Ecoregions with similar characteristics, but in geographically diverse areas should be treated separately.

Step 3 - Data collection and quality evaluation

Actions taken during first workshop and Group advice

During the first IOTC ecoregion workshop several existing datasets were revised, presented and discussed in terms of availability, quality and completeness to guide the choice of key data inputs to characterize each of the main thematic factors included in the criteria (Table 2) for guiding the delineation of ecoregions.

Criteria 1 - Oceanography/biogeography of the Indian Ocean

To address the first criteria that requires that there is clear oceanographic justification for demarcation of ecoregions, information on the broad scale oceanographic processes in the Indian Ocean were investigated via existing pelagic biogeographic classifications for the Indian Ocean (i.e., Longhurst, Pelagic Provinces of the World (PPOW), Marine Ecosystems of the World (MEOW) and Large Marine Ecosystems (LME) biogeographic classifications). A qualitative examination of their overlap with the species distribution data layers found that the combination of PPOWs and MEOWs biogeographic classifications (Figure 4) best represented and covered the distribution of coastal and oceanic IOTC species and the fisheries targeting them (Nieblas et al. 2019). The combination of the MEOW coastal provinces and the PPOW provinces enables the incorporation of the diversity of fisheries in coastal and island nations in addition to oceanic pelagic zones in the Indian Ocean. Furthermore, the MEOW coastal provinces ensure that neritic species habitats are represented. The combined MEOW and PPOW classification scheme resolved to 24 provinces in the IOTC convention area (Figure 4).

The Group concurred with the representation of oceanography and biogeography of the region as derived from the combination of the MEOW and PPOW biogeographic classifications and recommended its use as an input layer for the classification analysis for delineating the ecoregions.

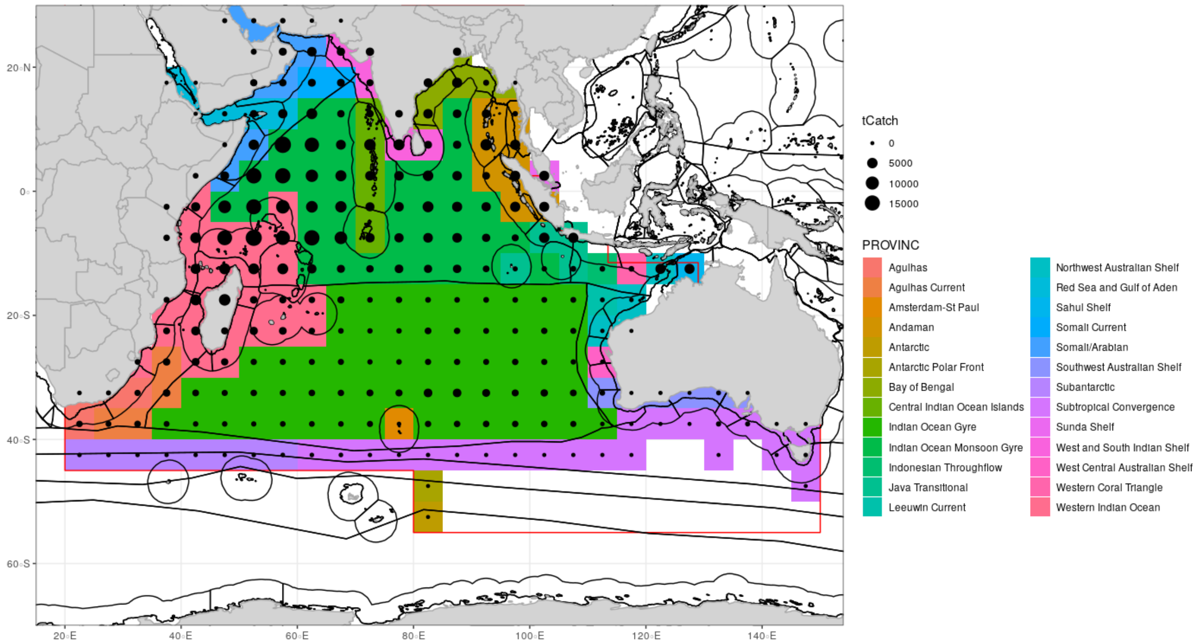


Figure 4. The combined MEOW and PPOW biogeographic classification scheme resolving into 24 provinces within the IOTC convention area. The raised total catch (MT) of the main IOTC species (YFT, SKJ, BET, ALB, SWO) distribution (black circles) overlaid on merged MEOW-PPOW provinces (black lines) is also shown. IOTC convention area is outlined in red. The number of provinces (24 provinces) used in the first spatial analysis are indicated by the colored squares.

Criteria 2 - Spatial distribution of species

To address the second criteria that boundaries of proposed ecoregions should appropriately demarcate the distribution of IOTC neritic and oceanic tuna and billfish species, the Group examined the IOTC georeferenced raised fishery catch data for the main IOTC species (Table 1) and catch and effort data of other species caught in IOTC fisheries (e.g. sharks, sea turtles) to determine their potential to infer species distribution patterns.

The Secretariat estimates the georeferenced raised catch data using a combination of different techniques, mostly involving proxy fleets / gears to fill the gaps where catch and effort data are not reported, or are reported with very coarse spatial resolution (e.g. at the level of the CPC's EEZ). These data are a mix of 1°x1° and 5°x5° resolutions, which is due to the reporting requirements of the different fisheries in the IOTC. As in 2019, we regridded the data to 5°x5° in correspondence with the official 5°x5° IOTC reporting grids (shapefile). To avoid biasing distributions toward extreme high catches, data were filtered to remove catches greater than the 95th percentile. Data were further filtered to remove potentially erroneous reporting errors, specifically catches of tropical tuna (SKJ, YFT, BET) captured below 45°S.

Georeferenced catch data were used as proxies of species distribution instead of catch per unit effort as this analysis aimed to include diverse species caught from diverse gear types. Combining catch per unit effort indices across the numerous different gear types included here is a difficult task, and not within the scope of this study. The catch data analyzed here are fisheries dependent, which is not ideal for inferring ecological processes (Reygondeau et al 2012); however, fisheries-independent data are few. We believe, and the Group agreed, that these catch data can be a useful proxy of species distributions.

The georeferenced raised catch data for the **five main IOTC species** (SKJ, YFT, BET, SWO and ALB) were provided by the IOTC Secretariat, and available from 1952-2017. For our analyses, we investigated the last 15 years of data (i.e. 2003-2017), as agreed by the 1st workshop, which we found to be of good quality, were easily available and had a high degree of completeness. These were therefore sufficient to represent species distributions and the Group recommended their use as an input layer for the classification analysis for delineating the ecoregions.

Contrary to the raised catch data for the main five IOTC species, georeferenced catch data of **neritic and shark species** were found to be of low to medium quality and to have a low degree of completeness. Therefore, these data were not used as an input layer in the first spatial analyses. The Group agreed the distribution of neritic tunas (with reported catches for kawakawa *Euthynnus affinis*, longtail tuna *Thunnus tonggol* and Spanish mackerel *Scomberomorus commerson* only) and the distribution of sharks (with reported catches of blue shark *Prionace glauca*, silky shark *Carcharhinus falciformis*, oceanic whitetip shark *Carcharhinus longimanus* and porbeagle *Lamna nasus*) formed a data layer that was influenced by major problems with reporting and statistics and recommended that these not be retained as a data layer for the spatial analysis. For porbeagle, the Group identified misreporting in the tropical region, as this species is only distributed south of 35°S. They noted that sources of information other than IOTC (e.g. national reports) could be consulted as they likely hold better information on neritic and shark species (e.g. the WIOFish database). Furthermore, the Group advised that the catch data be revised for **neritic species and shark species** held in IOTC to check whether updated data should be incorporated into a refined and updated spatial analyses (step 4 in Figure 3). It is only during the past 10 years that reporting shark catches became mandatory at the IOTC. When revising the shark data, the Group recommended that the data from the last five years should be considered for the analyses, rather than the period 2003-2017 initially selected for analysis, to check whether updated data should be incorporated in the refined/updated analysis. The Group also recommended that the fishery observer data sets of the IOTC could be used for sharks in order to complement the information of the IOTC catch/effort datasets. For instance, the EU PS fleet has maintained a high observer rate since 2016, with good estimates of shark bycatch, especially for silky shark, which could be used to inform distribution maps. They also noted that better shark distribution maps could be obtained from a combination of the data available at IOTC (nominal catches, georeferenced catches and observer data) coupled with expert knowledge. If the completeness of the neritic and shark catch data remains low after revising and updating the datasets, the Group advised to use the layer of the EEZ (as used in the MEOW classification) as a proxy to account for coastal species/fisheries into the spatial analyses.

In 2019 we also investigated as a potential information layer the **size distribution of main IOTC species**. The IOTC size data were considered to be low-quality due to strong bias by the different selectivity of gears. These data were not considered to adequately reflect the spatial distributions of the different size classes and the Group agreed that size data should not be considered for onward analyses.

Lastly, we also investigated the availability of fisheries catch data in the IOTC datasets for **other bycatch species** caught in IOTC species (turtles, seabirds and marine mammals). The bycatch data were sourced from IOTC observer data, which were insufficient to inform the distribution of these species and were not further analyzed. However, the Group discussed whether bycatch species (e.g. sea turtles, marine mammals and seabirds) should be a layer of information to inform the delineation of ecoregions. The Group viewed these bycatch species as the “end users” of the ecoregions, rather than being important for informing the ecoregions, since ecoregions could be used as a framework to conduct regional bycatch assessments.

Criteria 3 - Spatial distribution of IOTC fisheries

To address the third criteria that requires that ecoregion boundaries demarcate the spatial distribution of major IOTC fisheries, in the 2019 analysis, IOTC georeferenced total raised catches by each major fishery and fleet were used as a proxy to determine the main fishing grounds of each fishery, including the 10 most important fisheries determined by their catch, e.g., purse seine, longlines, gillnets, and other major coastal and high seas fisheries.

The method of using IOTC catches to inform the spatial distribution of the main fisheries was approved by the Group, though an important comment to improve understanding was to distinguish between deep and shallow setting longliners, as they may operate in different fishing grounds and target different species, and may help in the delineation of ecoregions. Furthermore, the group recommended that the fisheries be by gear type (e.g. coastal fisheries, high seas longline fisheries, high seas purse seiner fisheries) to help differentiate coastal vs high sea fisheries by region in the analysis and improve visualization of the results.

Action taken in preparation for second workshop, findings and proposed solutions

Criteria 1 -Oceanography/biogeography of the Indian Ocean

We revised the groupings and the number of biogeographical provinces derived from combining the MEOW and PPOW biogeographic classifications. We found that the 24 provinces proposed by the MEOW-PPOW combined classification added to the difficulty in visualizing and interpreting the spatial analyses, a key concern raised by the Group (see in the next section - Step 4). Furthermore, the area of many of the 24 provinces overlapped with only one 5°x5° grid cell (the spatial resolution of the catch data), and contributed to the Group's concerns about the calculation of the fidelity indicator (see in the next section below - Step 4). Therefore, we further grouped the MEOW-PPOW biogeographic provinces according to some objective rules:

1) That PPOW coastal provinces take precedence over MEOW coastal provinces (leading to larger provinces that are biologically sensible for IOTC species as PPOWs are based on pelagic biogeographic conditions appropriate for both neritic and open ocean IOTC species, while still allowing the coastal zone to represent neritic habitat);
2) The single-grid provinces be combined with neighboring provinces following PPOW delineations where possible (for example the province Amsterdam-St Paul was combined with the Indian Ocean Gyre; Figure 5);
3) Provinces with zero catches are excluded.

With these objective rules, we reduced the number of provinces from 24 to 15 (Figure 5).

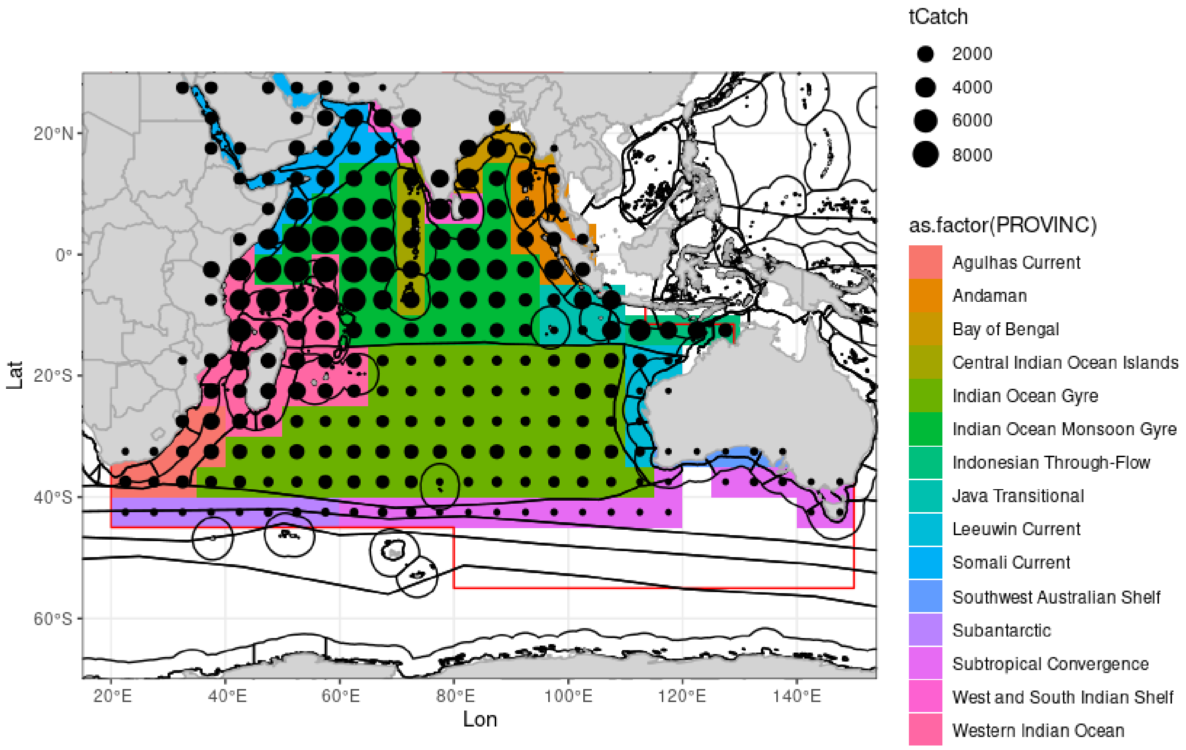


Figure 5. The newly regrouped MEOW and PPOW provinces.The black circles indicate median catch in tonnes for major IOTC species (SKJ, YFT, BET, SWO and ALB) for each 5°x5° pixel of the IOTC convention area (red polygon).

Criteria 2 - Spatial distribution of species

We updated the catch datasets used to inform the species distribution for oceanic tunas and billfishes, neritic tunas and sharks, and revised them in terms of availability, quality and completeness. This revision seeks to refine the choice of key data inputs for analyses and in deriving a new proposal of draft ecoregions.

We requested georeferenced raised catches of the main target species, including albacore, yellowfin, bigeye, skipjack and swordfish from the IOTC Secretariat for the latest data (up to 2019), and processed and filtered the data as in the 2019 analysis, i.e. data were regridded to the 5°x5° IOTC reporting grid, catches >95th percentile were removed, as were catches of tropical tuna captured below 45°S.

Catch and effort data for neritic and shark species were updated from the data publicly available in the IOTC webpage. Following the recommendations from the Group, we investigated the coverage of shark catch data over time to identify if the most recent 5 years had substantially better reporting than other years in the previous 15 years.

Five main oceanic tuna and billfish species (ALB, YFT, SKJ, BET, SWO)

As in 2019, we find the updated georeferenced raised catch data for the five main open ocean species "good" in terms availability, quality and completeness (Table 5), and they **will be retained to represent the spatial distribution and abundance of oceanic tuna and billfish species in the IOTC** (Table 5; Figure 6, Figure 7)**.**

Catches for tropical species BET, SKJ, and YFT are concentrated in the western Indian Ocean north of the Seychelles and west of Somalia (Figure 6). Substantial catch occurs south of India, in Sri Lankan waters and off Indonesia for these species. Catches of ALB are highest south of 20°S and around the Western Indian Ocean islands (i.e. Madagascar, Réunion, Mauritius). Catches for SWO are relatively widespread, including areas south of 20°S, in the Agulhas current region, in the north western Indian Ocean, the Bay of Bengal, and around Indonesia (Figure 6). We find that in general, the tropical species YFT, BET and SKJ are primarily found north of 20°S and that the subtropical (SWO) and temperate species (ALB) are found primarily south of 20°S, though SWO appears widespread, particularly in the north east basin (Figure 7).

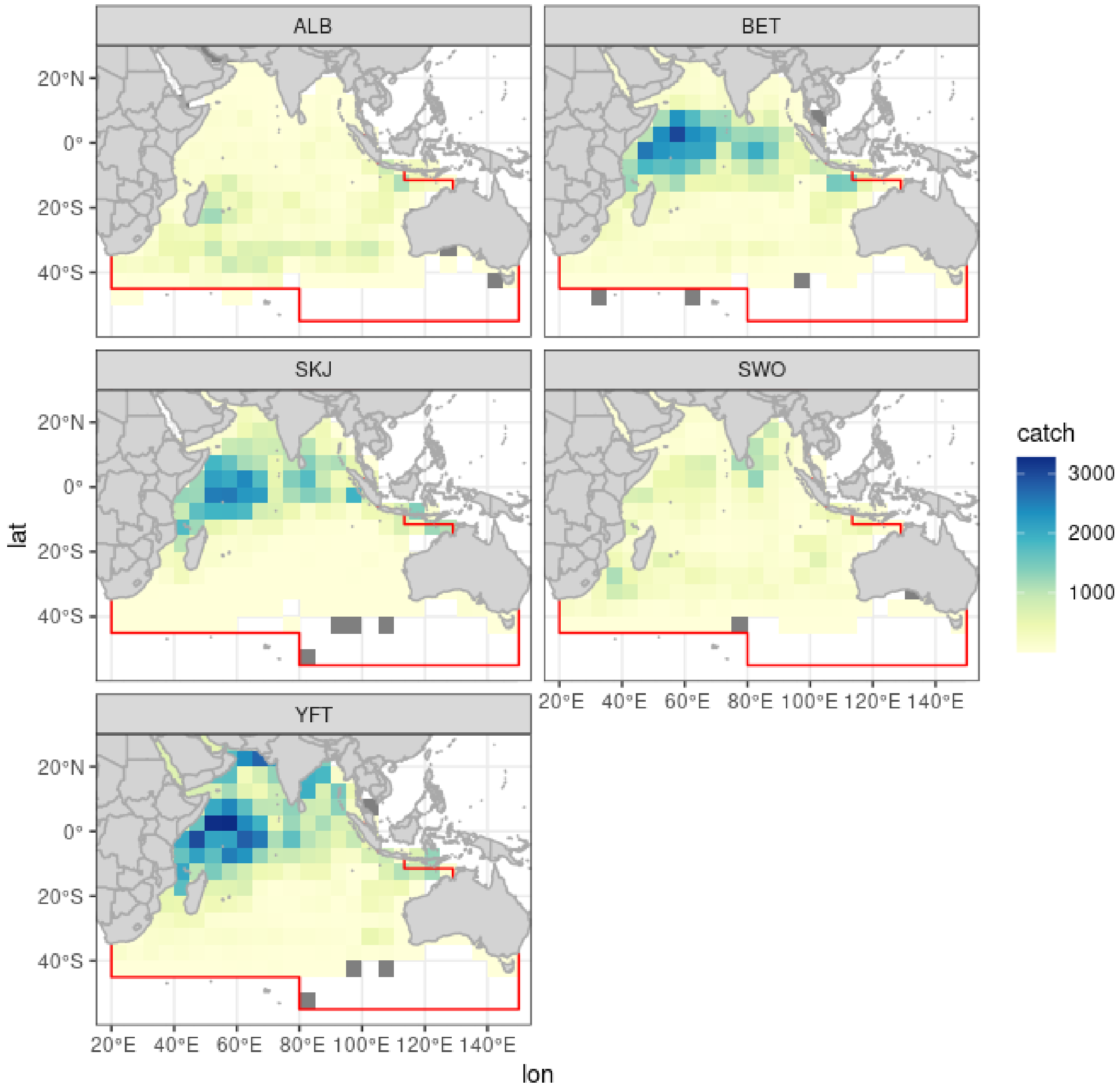


Figure 6 The spatial distribution of the median annual raised catch (MT) over 2005-2019 for each of the main IOTC pelagic species, including ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes) in the IOTC convention area. Blue indicates higher catch and yellow indicates lower catch. Gray pixels indicate zero catch.

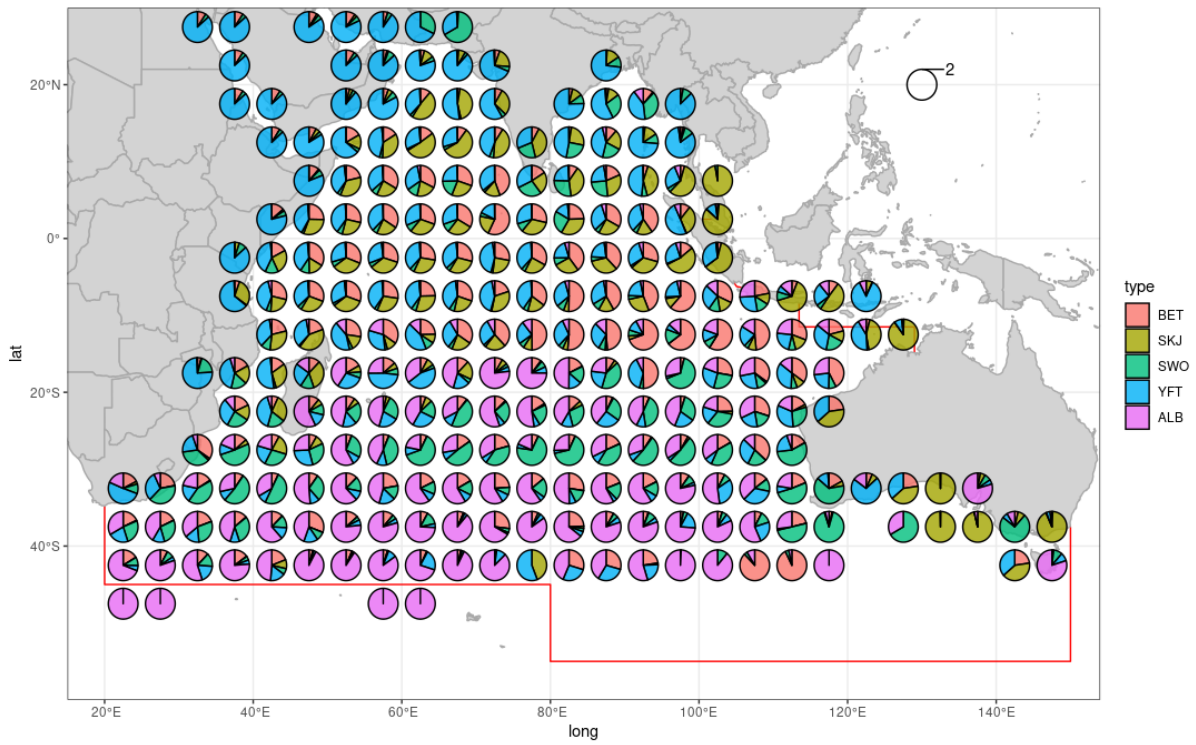


Figure 7 The spatial distribution of annual raised catch of the main IOTC pelagic species, including ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes) in the IOTC convention area averaged over 2005-2019. Pie chart sizes are not representative of the quantity of catch, but display the proportion of the total catch of each species in each grid cell.

Neritic species

Upon examination of the updated georeferenced catch and effort data, we find the majority of the reported catches for neritic species are either zero or very close to zero, with only one or two coastal pixels accounting for the vast majority of the reported catches (Figure 8). Low quantities of catch are often reported in the offshore PS fishery (Figure 9); however, neritic catches happen near the coast, where the BB, GILL, GIOF, HAND, RNOF, and TROL fisheries operate. These fisheries also show reported catch of neritics, but much lower than for the PS fishery (Figure 9). The patchy catch reports with very few coastal grid cells accounting for the majority of the catch from these fisheries potentially indicates that catches are un- or under-reported.

We find the updated catch data for neritic species, while easily available, are still incomplete and of low quality, and **they will not be retained for further analyses.**

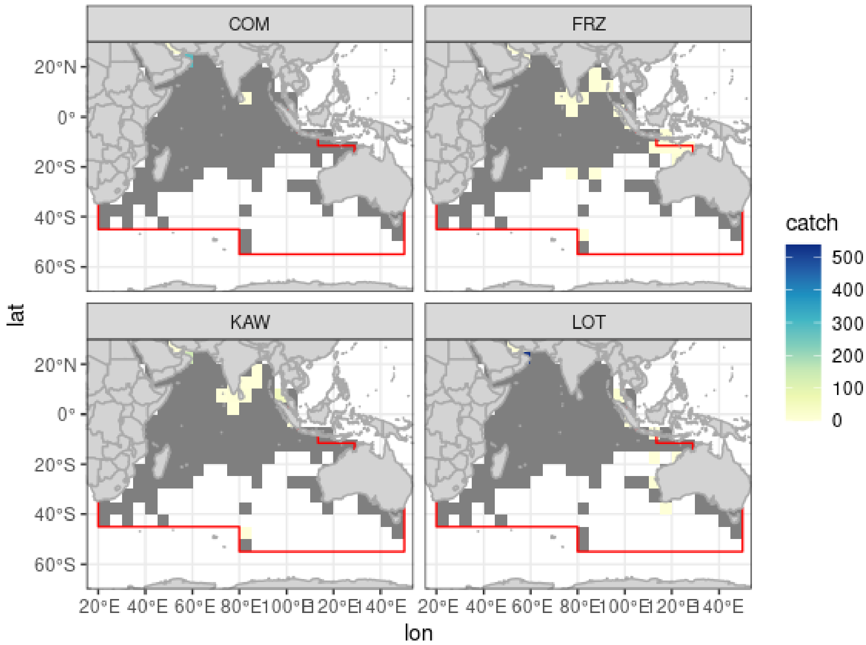


Figure 8. The spatial distribution of the median annual catches (MT) over 2005-2019 for each of the four neritic species/species groups found in the IOTC online database (Table 5 for data information, Table 1 for species codes). FRZ indicates frigate and bullet tuna.

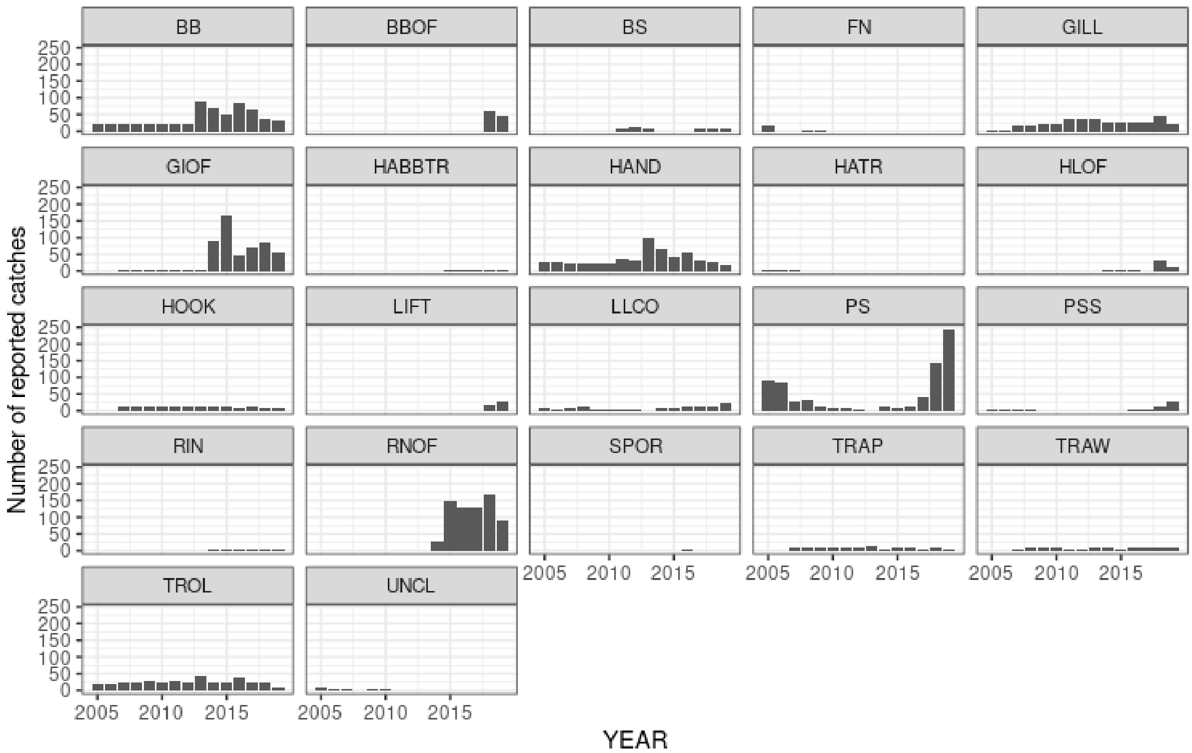


Figure 9 The number of times each fishery reported catches of neritic tuna greater than zero per year for the period 2005-2019.

Shark species

We find that the most recent five years have a somewhat higher number of reported catches, but that the total catch reported (in MT) is much lower than in earlier years (Figure 10).

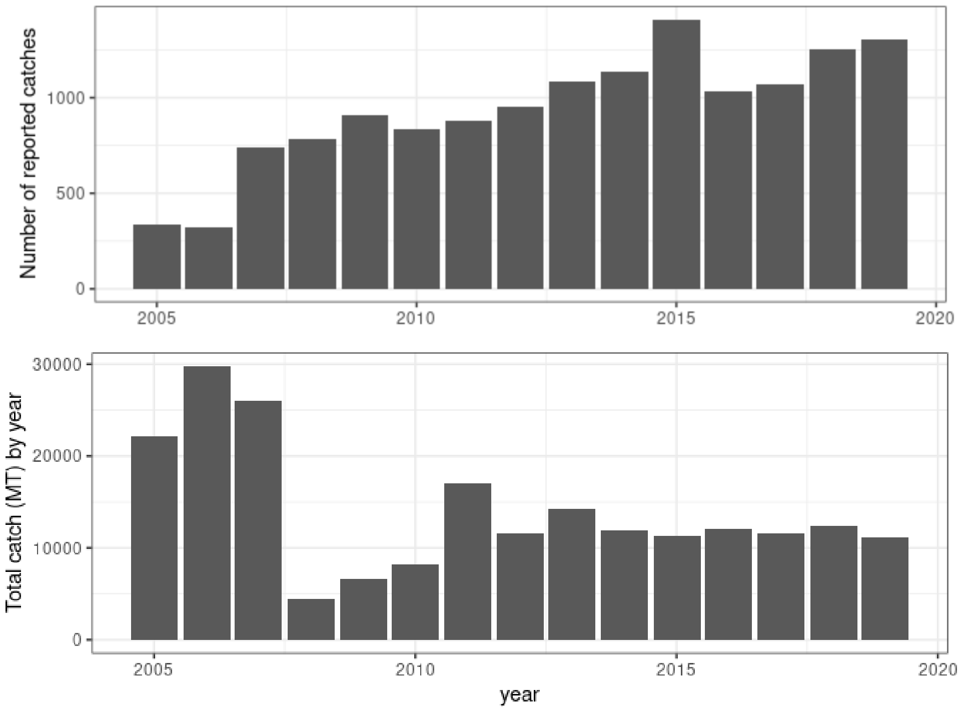


Figure 10 The number of reported catches greater than zero (top) and total catch (MT; bottom) of shark catch data from 2005 to 2019.

When investigating shark catch by species, we find that most individuals are reported as “SKH” in the years 2005-2019 (Figure 11 top), which indicates that catches have not been identified to species. We find that in the more recent period, a greater number of blue sharks (BSH) were reported than unidentified sharks (SKH) (Figure 11 bottom panel). This may indicate better identification to species, or that proportionally more blue sharks (BSH) were being caught in this period than previously.

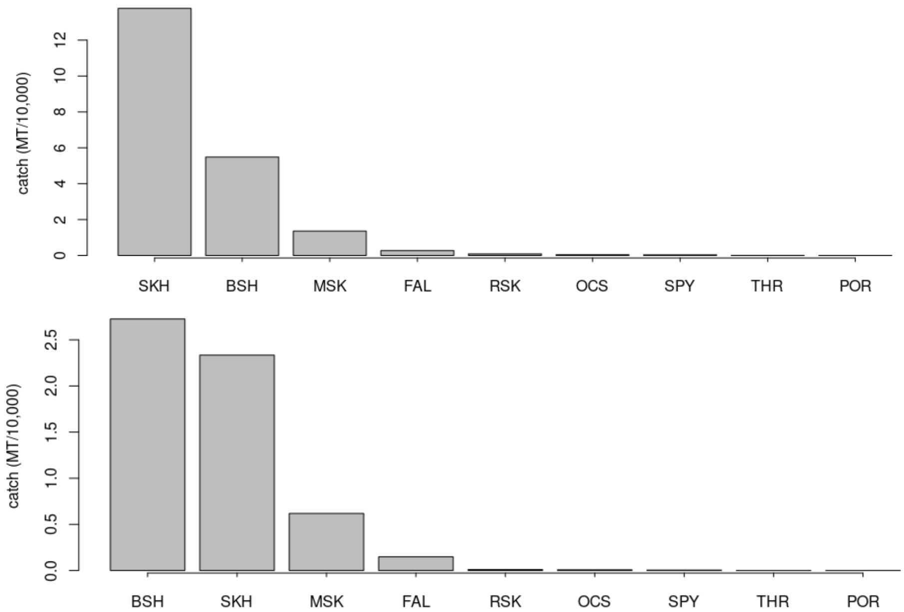


Figure 11 The total catch (MT/10,000) by shark species from 2005-2019 (top) and from 2015-2019 (bottom) within the IOTC convention area.

We further investigate the distributions of the three species with the highest catches that have been identified to species or family level (blue shark BHS, Lamnidae mackerel sharks MSK, and silky shark FAL) (Figure 12). We find blue shark (BSH) distributions are reasonable, though patchy, in that they are known to be distributed throughout the Indian Ocean basin, but are found mostly south of Africa and in the purse seine fishing grounds in the northwestern Indian Ocean. Silky sharks (FAL) shows almost no catch, except in the offshore area of the Bay of Bengal, and Lamnidae sharks (MSK) distributions are reasonable in terms of their biology, but highly patchy and almost completely missing in the west of the basin.

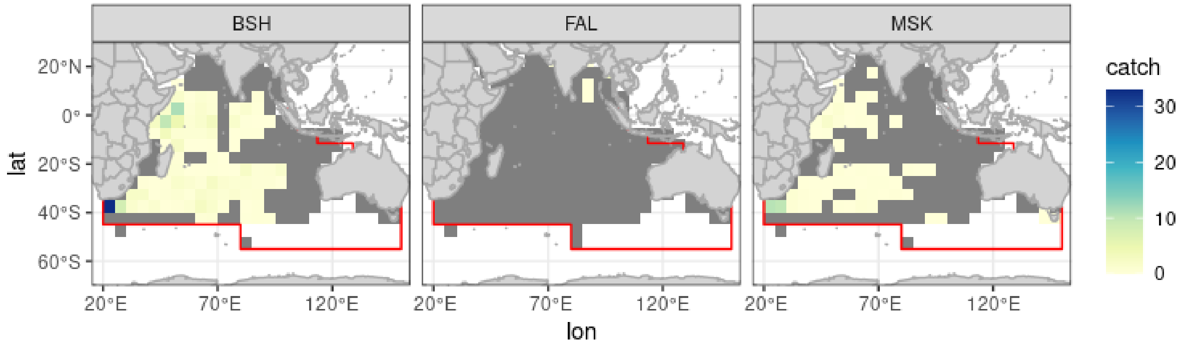


Figure 12 The spatial distribution of the median annual catches (MT) over 2015-2019 for the top 3 most commonly-caught shark species (excluding "SKH") found in the IOTC online database (Table 5 for data information, Table 1 for species codes) . Gray cells indicate zero catch.

The number of reported catch records per fishery shows that most records come from longline fisheries (Figure 13). From 2005, we find an increasing number of reports, but not particularly in the last 5 years. Of the other fisheries, offshore gillnets (GIOF) appear to have been reporting since about 2015, and not previously, in concurrence with the Group's comment.

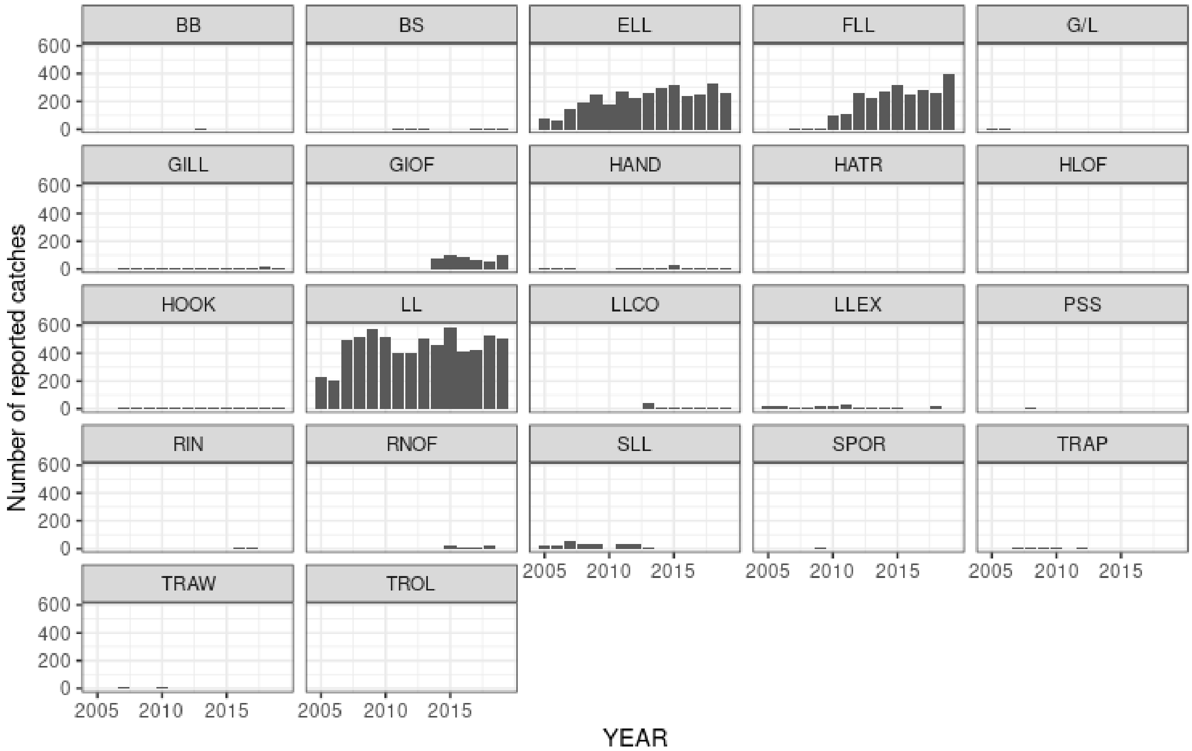


Figure 13 The number of observations of shark species reported by each fishery for the period 2005-2019.

Based on the examination of the shark catches above, we find that shark data are not significantly better in the most recent five year period than in the previous 10-15 year period. Most shark catch is primarily reported by the longline fisheries though increasingly by offshore gillnets (Figure 13). Though the number of records has gradually increased from 2005 (Figure 10 top panel), the quantity of catch was significantly higher in the first years of the selected time period (2005-2007; Figure 10 bottom). To our knowledge, there has been no significant change in the fisheries targeting sharks in this period; thus we find this decrease in catch inconsistent with increased reporting. We find that most of the catch is reported as SKH, i.e. unidentified to species (Figure 11), and potential misidentification of species is possible for FAL. The distribution of the highest reported species is reasonable for BSH; however, the data are patchy, in low quantities, and for these reasons, **shark data will not be retained for further analyses.**

Criteria 3 - Spatial distribution of the main IOTC fisheries

We examined the updated georeferenced raised catch data to describe the spatial distribution of the main IOTC fisheries and determine the main fishing grounds of each major fishery, including purse seines, longlines, gillnets, and other major coastal and high seas fisheries. We also investigated the coding system available for the different IOTC longline gears, which have recently been updated (Table 3) in order to identify whether we could distinguish the depth of setting in longline gears. In order to better understand the fisheries, their range, their impact on the analyses and to improve visualization and interpretability of the spatial analyses, we refined the grouping of the IOTC fishery codes from the first analysis and grouped them according to:

(1) the large gear groupings (LL, PS, GILL, LINE, BB, OT, and DSEI),
(2) the operation type (industrial or artisanal), and
(3) whether the fisheries were targeting specific species, i.e. swordfish and shark ("Analysis code", Table 3).

To simplify further analysis, we removed fisheries making up less than 0.1% of the catch (i.e. SLL). The refined fishery grouping seeks to include all major fisheries and the gear types operating in the IOTC (including coastal and high-sea fisheries), while limiting the number of different gear groupings that will be used in the spatial analyses. Finally, we end up with 14 different fisheries to be used in the spatial analysis (Table 3, Figure 14).

Table 3. The main fisheries in the IOTC convention area. Longline gear codes are further linked to the codes listed in Table 4.

Large group	Operation	Gear	Description	Analysis code
Longline (LL)	Industrial	ELL	Longline targeting swordfish	LL_IND_SWO
Longline (LL)	Industrial	FLL	Longline Fresh	LL_IND
Longline (LL)	Industrial	LL	Longline	LL_IND
Longline (LL)	Artisanal	LLCO	Coastal longline	LL_ART
Longline (LL)	Industrial	LLEX	Exploratory longline	LL_IND
Longline (LL)	Industrial	SLL	Longline targeting shark	LL_IND_SHK
Longline (LL)	Industrial	LG	Longline operated attached to a gillnet	LL_IND
Purse seine (PS)	Industrial	PS	Purse seine	PS_IND
Purse seine (PS)	Artisanal	PSS	Small purse seine	PS_ART
Purse seine (PS)	Industrial	RIN	Ring net	PS_ART
Purse seine (PS)	Artisanal	RNOF	Offshore ring net	PS_IND
Gillnet (GILL)	Artisanal	GILL	Gillnet	GILL_ART
Gillnet (GILL)	Industrial	GIOF	Offshore gillnet	GILL_IND
Gillnet (GILL)	Artisanal	GL	Gillnet operated attached to a longline	GILL_ART
Line (LINE)	Artisanal	HAND	Hand line	LINE_ART

Line (LINE)	Industrial	HLOF	Offshore hand line	LINE_IND
Line (LINE)	Artisanal	SPOR	Sport fishing	LINE_ART
Line (LINE)	Artisanal	TROL	Troll line	LINE_ART
Line (LINE)	Artisanal	TROLM	Mechanized troll line	LINE_ART
Line (LINE)	Artisanal	RR	Rod and reel	LINE_ART
Baitboat (BB)	Artisanal	BB	Baitboat	BB_ART
Baitboat (BB)	Industrial	BBOF	Offshore baitboat	BB_IND
Other (OT)	Artisanal	BS	Beach seine	OT_ART
Other (OT)	Artisanal	CN	Cast net	OT_ART
Other (OT)	Artisanal	FN	Fish net	OT_ART
Other (OT)	Artisanal	LIFT	Liftnet	OT_ART
Other (OT)	Artisanal	TRAP	Trap	OT_ART
Other (OT)	Artisanal	TRAW	Trawl	OT_ART
Other (OT)	Artisanal	HARP	Harpoon	OT_ART
Danish seine (DSEI)	Artisanal	DSEI	Danish seine	DSEI_ART

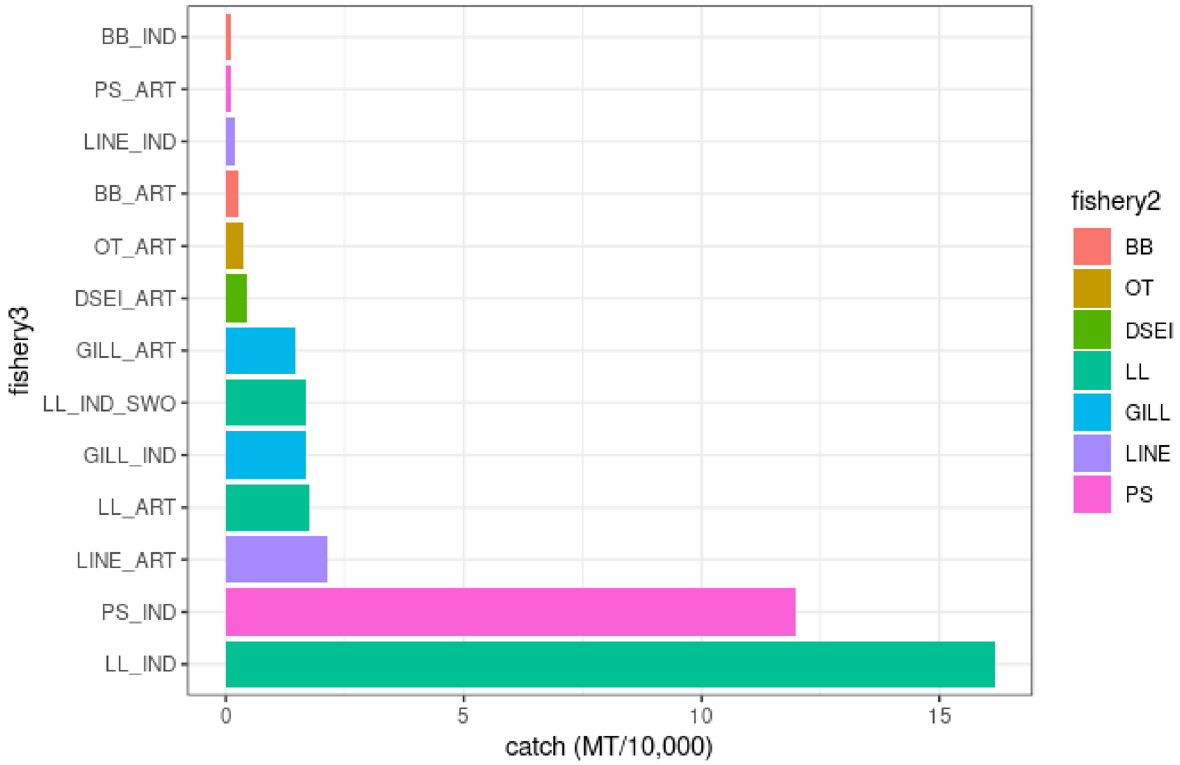


Figure 14. Median annual catch between 2005-2019 by the main gear types of the main target species in the IOTC convention area: ALB, BET, YFT, SKJ, and SWO (see Table 1 for species codes). Gear codes are as in Table 3.

To address the group's recommendation that depth of the set be investigated, we examined the recently-updated coding system available for the different IOTC longline gears (Table 4). These map to the codes in the raised catch data provided by the Secretariat following the Table 4 caption. It should be noted that there are no indications of depth by the gear codes, and the depth of sets are not reported to the IOTC.

Table 4 Recently updated IOTC gear codes, their description and the type of fishery (industrial, semi-industrial, or artisanal). The mapping to the raised catch data provided by the Secretariat is as follows: LL = LL ; ELL = LLSW/LLSI, SLL = LLSK, FLL = LLFR.

Gear code	Description	Fishery type
LL	LL-Drifting longline (over 1800 hooks)	Industrial
LLCO	LLCO-Small longline	Artisanal
LLEX	LLEX-Drifting longline (exploratory)	Industrial
LLFR	LLFR-Drifting longline (up to 1800 hooks)	Industrial
LLGI	LLGI-Longline (operated attached to Gillnet)	Semi-industrial
LLSI	LLSI-Swordfish longline (semi-industrial)	Semi-industrial
LLSK	LLSK-Shark longline	Industrial
LLSW	LLSW-Swordfish longline (Florida longline)	Industrial

We also discussed creating a “rule-of-thumb” whereby species that are commonly fished at depth (i.e. large YFT and BET) or at surface (i.e ALB) at certain latitudes. After discussion with the IOTC Secretariat, we determined that there is no information on the configuration of the longlines except in the regional observer data, but these cover very few years and only the Japanese and French fleets. There is indeed probably a link between longline depth and species targeting for ELL (fleets targeting swordfish), FLL (fleets targeting fresh tuna), and LL (large-scale longline vessels that freeze tuna to -60°C). However, it is difficult to identify this link, as the longline gear is defined by the species targeted and the conservation method, and not by any information on the targeted depth. Furthermore, we note that the depth of the longlines can be modified by the presence of a shooter, the speed of the boat, the number of hooks, the distance between buoys, and environmental conditions, among other reasons. In particular, the thermocline and currents play an essential role in the depth of the longline. Thus, it was determined that based on the data available, **it is not possible to distinguish between depth settings for longline gear in the IOTC.**

The main fisheries operating in the high seas are the industrial longline and purse seine fisheries (Figure 14). Relative to other gears, longlines dominate south of 20°S and in the southeast (Figure 15). Industrial purse seine vessels operate primarily in the north, especially in the fishing grounds in the northwest of the Indian Ocean (Figure 15).The coastal regions of continents and around island nations are more complex in their gear use, which are divided between coastal line fisheries, coastal longlines, gillnet, danish seine, coastal purse seine, baitboats, and other artisanal fisheries (Figure 15).

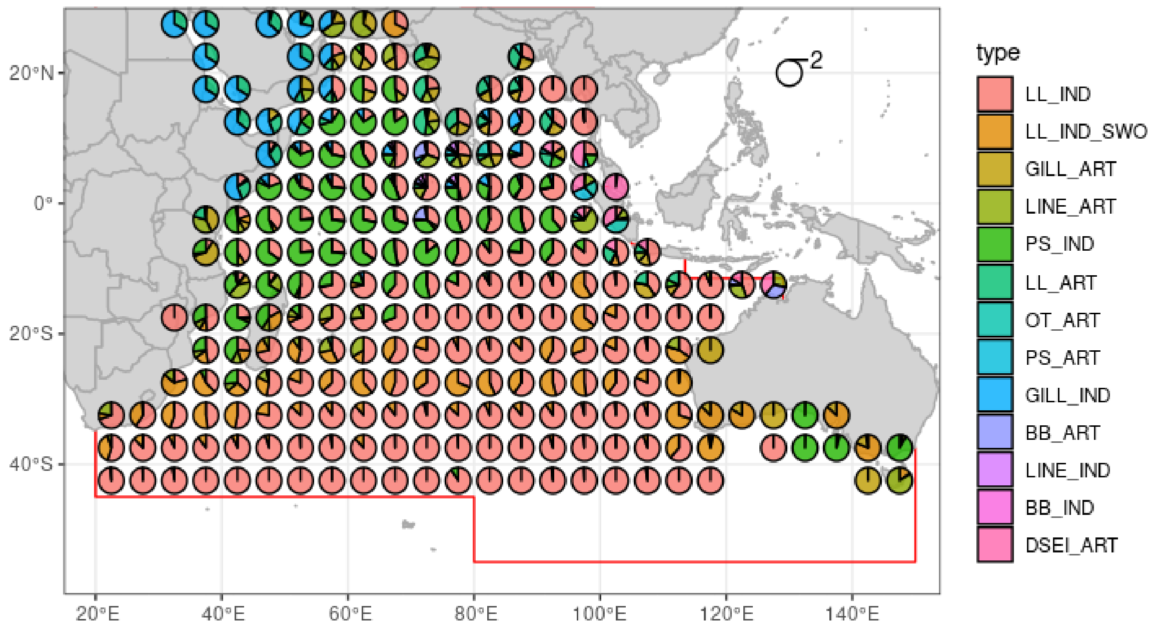


Figure 15. Spatial distribution of the main IOTC fisheries as inferred from the sum of the catch. Gear codes are as in Table 3. Pie chart sizes are not proportional to the quantity of catch (MT), but rather are meant to display the proportion of the catch that was due to each gear type for each grid cell. Catch data are derived from an average over 2005-2019 of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes).

Industrial longline fisheries “LL_IND” operate throughout the Indian Ocean (Figure 15, 16), with the majority of catch made by the drifting longline fishery (LL) in the northwest of the basin, and by fresh longliners (FLL) throughout the basin (Figure 15, 16). Industrial longlines targeting swordfish (“LL_IND_SWO”, i.e., ELL) operate in a longitudinal band primarily between 20°S and 30°S (Figure 15, 16) and into the Bay of Bengal. Longlines attached to gillnets (LG) operate in Sri Lankan waters, and are an old gear code that has not been reported since 2013 (Figure 16). The artisanal longline fishery (“LL_ART”) is made up of coastal longlines (LLCO), which operate in the northern basin, mostly around the Indian peninsula.

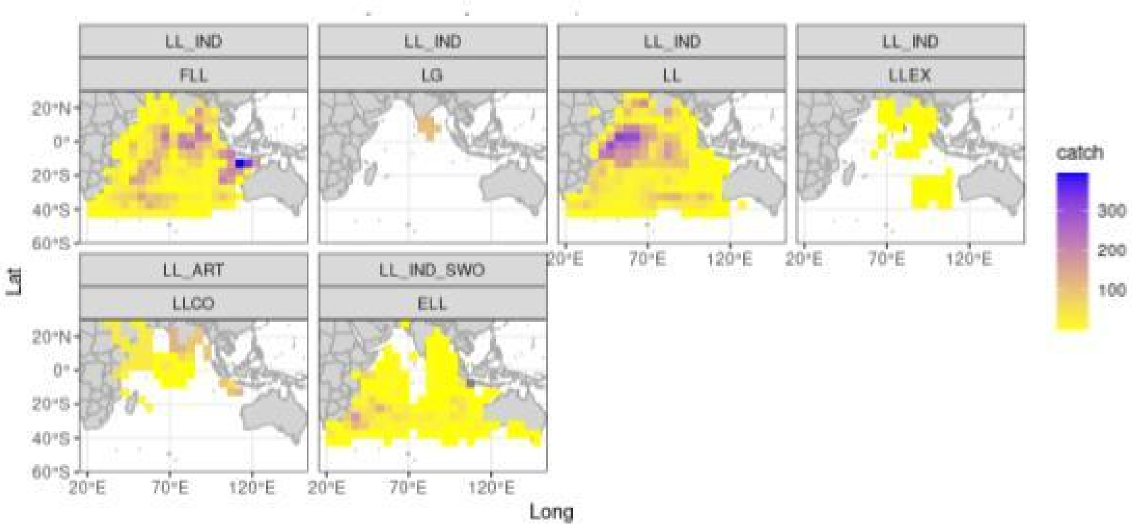


Figure 16. Spatial distribution of the median annual raised catches (MT) over 2005-2019 for the longline fisheries in IOTC including industrial longline fisheries (“LL_IND”, i.e., FLL, LG, LL, LLEX), longline industrial fisheries targeting SWO (“LL_IND_SWO”, i.e. ELL) and artisanal longline fisheries (“LL_ART”, i.e., LLCO); see Table 3). The median of the total annual raised catch per grid cell over 2005-2019 includes catches of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes).

Industrial purse seine ("PS_IND") is made up of two fisheries, purse seine (PS) and offshore ring net (RNOF). PS is one of the major fisheries in the IOTC (Figure 14) and operates primarily in the northwest basin (Figure 16, 17). RNOF also operates here, and in the northern central basin. The artisanal purse seine fisheries ("PS_ART") are coastal, and mostly operate around the Indian peninsula and in the Bay of Bengal (Figure 17).

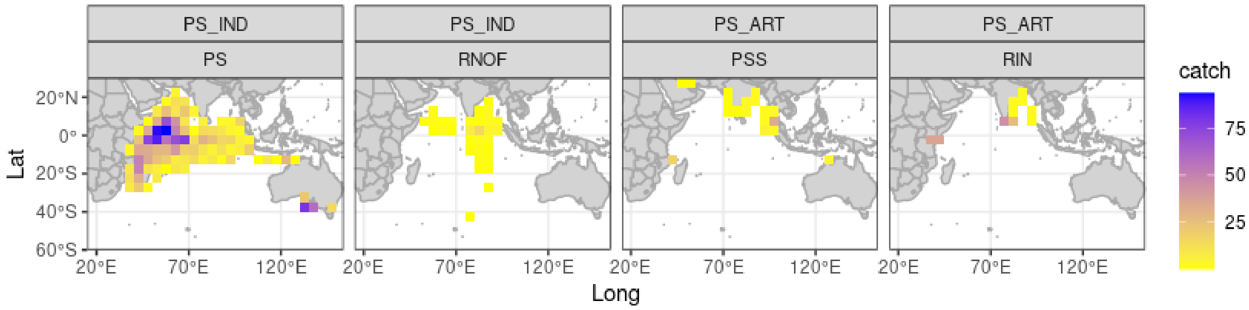


Figure 17. Spatial distribution of the median annual raised catches (MT) over 2005-2019 for the industrial purse seine fisheries ("PS_IND", i.e, PS and RNOF; see Table 3) and artisanal purse seine fisheries ("PS_ART", i.e., PSS, RIN). The median of the total annual raised catch per grid cell over 2005-2019 includes catches of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes).

After the industrial longline and purse seine fisheries, artisanal line fisheries (LINE_ART) is the most important fishery grouping (Figure 14), and includes a variety of different gears (Table 3), which operate in the coastal areas around the basin (Figure 15, 18). Handlines (HAND) and troll (TROL) fisheries have the most catch and are the most widespread of the LINE_ART fisheries, and the others are more scattered. The offshore handline (HLOF) of the industrial line fisheries grouping (LINE_IND) operates off the southern tip of the Indian peninsula and Sri Lanka (Figure 18).

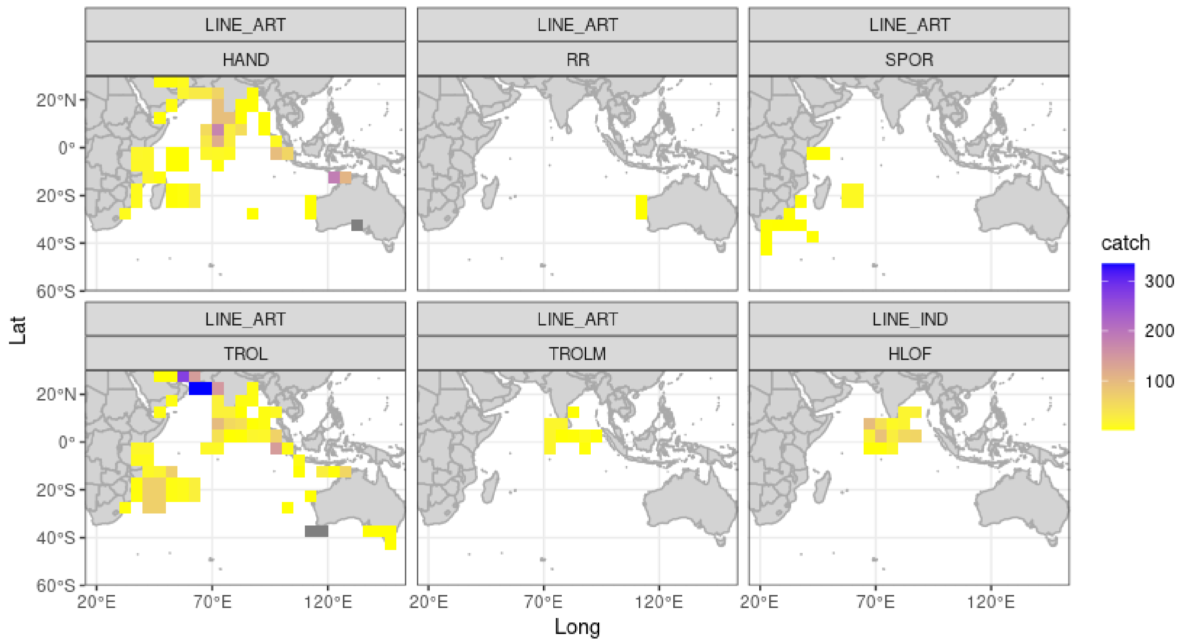


Figure 18. Spatial distribution of the median annual raised catches (MT) over 2005-2019 for the artisanal line fisheries ("LINE_ART", i.e., HAND, RR, SPOR, TROL and TRLM; see Table 3) and industrial line fisheries ("LINE_IND", i.e.,HLOF). The median of the total annual raised catch per grid cell over 2005-2019 includes catches of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes).

Industrial gillnets (GILL_IND) are important fisheries both offshore (GIOF) and coastally (GILL) (Figure 19). The GIOF are mostly in the gulf regions and northern basin, and GILL operates around the entire basin. Artisanal gillnets (GILL_ART) are gillnets operating with longlines (GL), and similar to LG, operate around Sri Lankan waters.

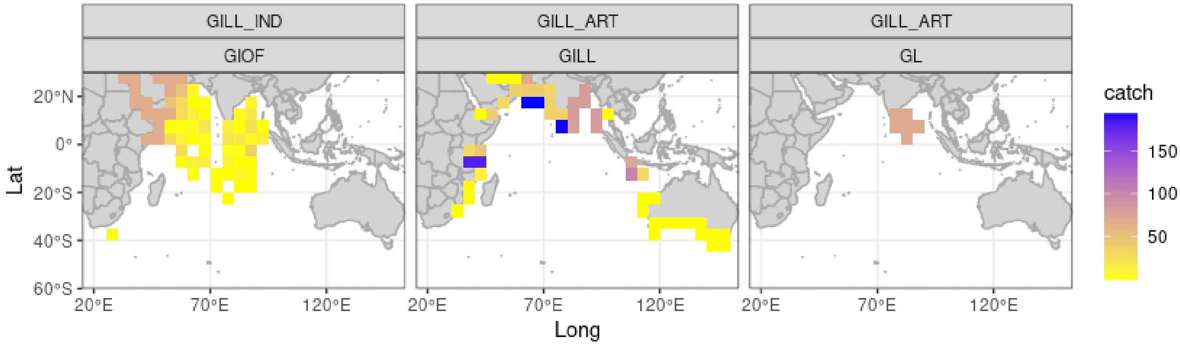


Figure 19. Spatial distribution of the median annual raised catches (MT) over 2005-2019 for the industrial gillnet fisheries ("GILL_IND", i.e., GIOF) and artisanal gillnet fisheries ("GILL_ART", i.e., GILL and GL; see Table 3). The median of the total annual raised catch per grid cell over 2005-2019 includes catches of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes)

The artisanal danish seine fishery (DSEI_ART, i.e. DSEI) reports high catch around Indonesia, but there is little to no spatial information available. For this reason, the IOTC Secretariat's raising process attributes spatial catches evenly across those grid cells that are considered to be the most common fishing grounds for a given fishery (Figure 20), using the total annual catch for the gear reported by the concerned member country.

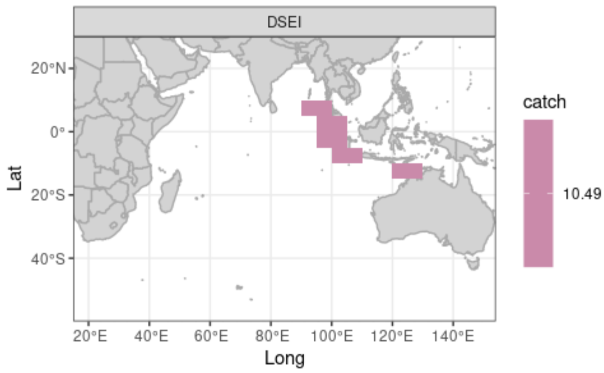


Figure 20. Spatial distribution of the median annual raised catches (MT) over 2005-2019 for the artisanal danish seine DSEI ("DSEI_ART", i.e., DSEI) fishery (see Table 3). The median of the total annual raised catch per grid cell over 2005-2019 includes catches of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes).

The artisanal baitboats (BB_ART, i.e. BB), are also an important fishery, but their distribution and that of industrial baitboats (BB_IND, i.e. BBOF) are limited mostly to the waters south of the Indian peninsula (Figure 21).

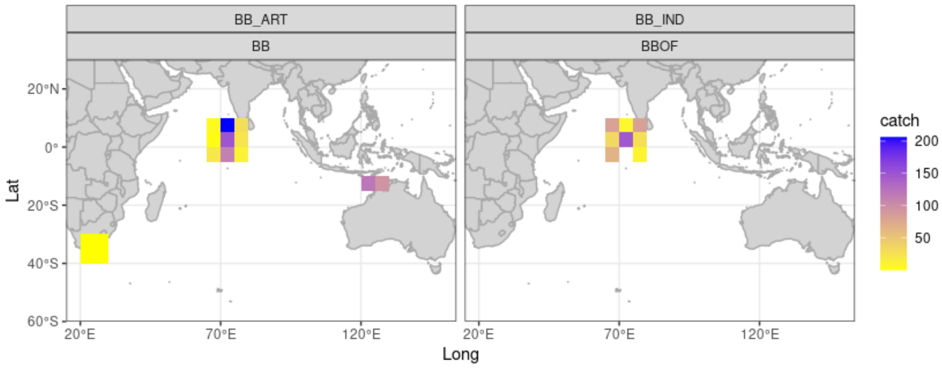


Figure 21. Spatial distribution of the median annual raised catches (MT) over 2005-2019 for the artisanal baitboat (“BB_ART”, i.e., BB) and industrial baitboat (“BB_IND”, i.e., BBOF) fisheries (see Table 3). The median of the total annual raised catch per grid cell over 2005-2019 includes the catches of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes).

The remaining fisheries (OT_ART) include a wide variety of artisanal fisheries (Table 3), which are variably distributed around the IOTC coastal area, but are mostly found in the north (Figure 22).

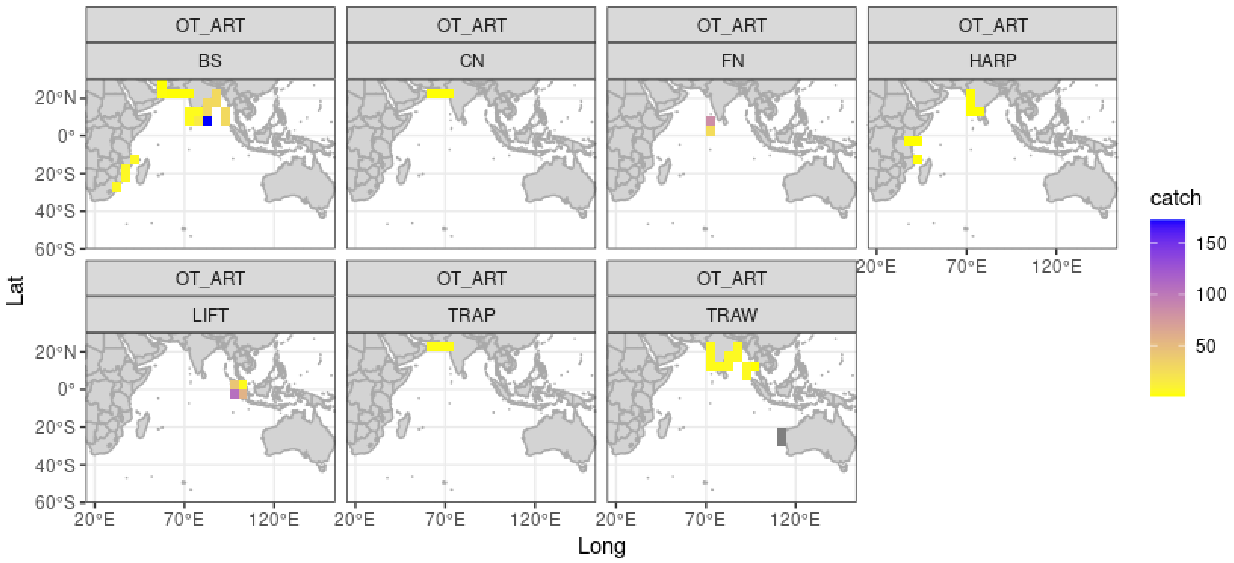


Figure 22. Spatial distribution of the median annual raised catches (MT) over 2005-2019 for the other artisanal fisheries “OT_ART” (BS, CN, FN, HARP, LIFT, TRAP, TRAW) (see Table 3). The median of the total annual raised catch per grid cell over 2005-2019 includes catches of ALB, YFT, BET, SKJ, and SWO (see Table 1 for species codes).

As in 2019, we find the updated raised catch data to be “good” in terms availability, quality and completeness (Table 5), and they **will be retained to represent a proxy for the spatial distribution of the main IOTC fisheries.**

A summary of data layers included in the spatial analysis based on criteria

We provide a summary of the updated and revised data layers that have been evaluated for use in the spatial analysis to inform the delineation of ecoregions based on the established criteria (Table 5). We note that not all the data layers reviewed here could be included in the spatial analyses due to deficiencies in availability, quality and completeness (Table 5). We expect that expert contributions at the workshop will compensate for the missing or inadequate data layers.

Table 5. Data layers explored and updated during the course of this study. Data that were considered 'good' in terms of quality, completeness and availability were retained as inputs in the final statistical spatial analysis (green rows).

Data layers	Data type	Data quality and completeness	Time range of dataset	Included in statistical spatial analysis	Data source	Reference
			Oceanography/biogeography of the Indian Ocean			
Combined MEOW-PPOW biogeographic classification	Shapefile	Good		Yes	http://data.unep-wcmc.org/datasets/38	Spalding et al. 2007 Spalding et al. 2012
			Spatial distribution of IOTC species			
IOTC oceanic tuna and billfish species (SKJ, YFT, BET, SWO and ALB)	Raised catch	Good	1952-2019; used in analysis : 2005-2019	Yes	Official IOTC data request	IOTC Secretariat
IOTC neritic species (COM, FRZ, KAW, LOT)	Catch	Low overall	1952-2019; used in analysis: 2005-2019	No	https://www.iotc.org/WPB/17/Data/07-CEAll	IOTC Secretariat
shark species (BHS, FAL, MSK)	Catch	Medium	1952-2019	No	https://www.iotc.org/WPB/17/Data/07-CEAll	IOTC Secretariat
			Spatial distribution of IOTC fisheries			
IOTC fisheries (gears)	Raised catch data	Good	1952-2019; used in analysis : 2005-2019	Yes	Official IOTC data request	IOTC Secretariat

Step 4 - Analytical model

Actions taken during first workshop and Group advice

During the first IOTC ecoregion workshop, several quantitative spatial analyses were performed to derive baseline ecoregions to be considered by the Group. Guided by the best practices reviewed and outlined in the 2019 analysis, we decided on a statistical hierarchical spatial approach that was divided into three major steps: 1) a basic spatial overlapping analysis with the purpose of selecting a final biogeographic classification to base all subsequent spatial analysis, 2) a specificity and fidelity indicator analysis that measures the dominance (i.e specificity) and spatial prevalence (i.e. fidelity) of individual species and fisheries with the selected biogeographic classification, and 3) a hierarchical clustering analysis to cluster biogeographic provinces according to their degree of similarity based on the specificity and fidelity indicators. Each of these spatial analyses were based on those data layers which were classified as "good" quality, i.e. oceanography (via biogeographical classifications), species distributions of the five main IOTC species (via raised georeferenced catch), and fisheries distributions (also via raised georeferenced catch).

The basic spatial overlapping analysis followed the methods of the EU project and investigated the qualitative degree of overlap between existing biogeographic classifications (i.e. Longhurst biogeographic classification, PPOW classification, and combined MEOW-PPOW classifications with MEOW provinces given preference over the PPOW provinces) and the spatial distribution of major IOTC species (ALB, YFT, BET, SKJ, and SWO) and the main fisheries targeting them. The distribution of neritic species was implicitly represented by the inclusion of biogeographic classifications of the coastal zone. The overlap analyses concluded that the combined MEOW-PPOW classification allowed for the variability of catch distributions and composition by species and fisheries to be presented, especially around islands and coastal zones (see also Criteria 1 above).

We then used the selected biogeographic classification and calculated an indicator that characterizes the dominance and spatial prevalence of each species and type of fishery to each biogeographic province, following Dufrene and Legendre (1998) and Reygondeau et al. (2012). This indicator is the product of two indices: specificity and fidelity, and we hereafter refer to it as the SF Indicator. The specificity, $A_{i,j}$ of a species or fishery i to a province j is the ratio of the abundance (N_{ij}, here estimated using catch in MT) to the sum of the abundance of the species in all the provinces (N_i). Specificity is thus a measure of how much a species associates with a province, or a representation of its "preference and dominance" of or in one province over others. The fidelity $B_{i,j}$ of a species or fishery i for a province j is the ratio of the number of geographical grid cells where the species is present in province j to the total number of cells of the province S_j. Thus, fidelity is a measure of the spatial prevalence of a species within a province, or a representation of how broadly a species is found (caught) within a province. The product of the specificity and fidelity indicator scaled to 100 provides the SF indicator value of species i with respect to province j in terms of percentage (SF indicator=$A_{i,j}$ x $B_{i,j}$ x 100%). The SF indicator gives an indication of the community composition of a province in terms of its species or fishery, highlighting those species and fisheries most dominant and prevalent in a province (Dufrene and Legendre 1998; Reygondeau et al. 2012)

Finally, we performed a hierarchical clustering algorithm on the SF Indicators for each province based on 1) their species composition, 2) fisheries composition and 3) species and fisheries composition combined. Clustering was performed first on each data layer separately to identify any major drivers of spatial patterns, and then on the combination of data layers for an integrative analysis. The Group advised further spatial analyses for a next proposal, with their specific feedback including :

1. An improvement of the visualization of the specificity-fidelity indicators to increase their interpretability; for example, the Group suggested (1) rescaling and fixing the y axis from 0 to the maximum value of the indicators across all the panels, (2) grouping tropical vs subtropical and temperate species and grouping gear types by major gear types to improve visualization and interpretability of results.
2. For the fidelity indicator, the Group suggested the following refinements and considerations:
    a. There were some opinions that the fidelity indicator as it is calculated now (based on presence/absence approach) is not very informative as grid cells with a small number of catches would be given the same weight as grid cells with a larger number of catches.The Group suggested examining the potential of using thresholds to evaluate the inclusion or exclusion of grid cells into the calculation of the fidelity indicator. It was suggested to explore a threshold (1) based on the relative catches in each grid cell to exclude those grid cells with very small catches or (2) based on the total number of years a species is found to occur in each grid cell or the number of years a particular grid cell is fished with a particular gear to exclude those grid cells where species or fisheries are rarely found.
    b. The Group also suggested that there might potentially be a high correlation between the fidelity value of a province and the province size (number of grid cells of the province), and that this could add a bias whereby small provinces have a higher fidelity value. The Group suggested checking the relationship between the size of the province and their fidelity values to identify any bias in the calculation of this indicator.
3. For the clustering analysis, the Group members suggested exploring both the specificity and fidelity indicators (with the modifications suggested by the Group) to characterize both the composition of species and fisheries by province, and looking at their different combinations and their effects on the clustering of provinces (similar to a sensitivity analysis). In addition,

some Group members suggested using only the specificity indicator to describe the species composition, and only the fidelity indicator to describe the fishery composition of each province (with the modifications suggested by the Group), and combine them for subsequent clustering analysis.

Action taken in preparation for second workshop, findings and proposed solutions

To address these suggestions, we first worked to refine and update the calculations of the specificity and fidelity indicators, paying careful attention to improve the visualizations of the results for enhanced interpretability.

Specificity indicator

The specificity indicator for species and fisheries was calculated with the updated data (Figure 23).

If we consider that specificity is a measure of a species association to a province, or a representation of its “preference and dominance” of one province over others, we find that tropical tuna species (SKJ, YFT and BET) are mostly dominant in the northern provinces, and are more associated with the Indian Ocean Monsoon Gyre, i.e. the oceanic northern basin, as well as the Western Indian Ocean, i.e. the area and islands around Madagascar, including Seychelles. ALB, the temperate tuna species is mostly dominant in the southern provinces, with a preference for the Indian Ocean Gyre, i.e. in the southern oceanic basin, and also has a substantial preference for the Western Indian Ocean. Tropical tuna species are mostly distributed in the north of the Western Indian Ocean, and ALB is found mostly in the south of the area in more temperate waters (Figure 7). SWO are subtropical species that are found throughout the IOTC area, but appear to be more dominant with the Indian Ocean Monsoon Gyre most (Figure 23 right) and are found there mostly offshore of the Bay of Bengal (Figure 7). Next, SWO also appears to dominate in the Indian Ocean Gyre (Figure 23 right), which encompasses the latitudinal band of ocean where the longline fishery targeting swordfish (LL_IND_SWO) operates consistently (Figure 15).

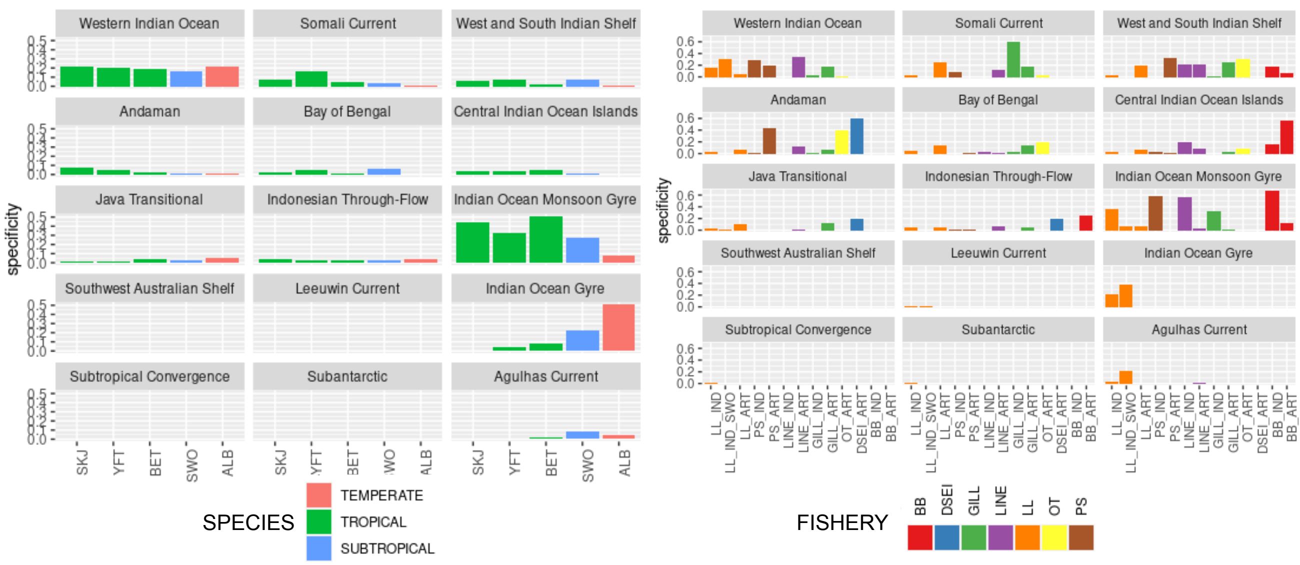


Figure 23. The specificity of species (left) and fisheries (right) for a province. No thresholds are applied to the specificity values. Colored bars relate to the habitat of each species (left) and to the main fishery groupings (right). The subplots are arranged starting from the top left plot in a clockwise fashion for the provinces around the Indian Ocean starting with the Western Indian Ocean, with the northern provinces displayed on the top half of the figure, and the southern provinces on the bottom half. See Figure 5 for the location of the different provinces. See Table 3 for the codes of the different fisheries and their groupings.

The specificity of fisheries for provinces indicates that there is a large diversity of dominant fisheries in the northern coastal provinces relative to the southern provinces where it appears that only industrial longline fisheries (LL_IND, LL_IND_SWO) are dominant (Figure 23 right). The fisheries that dominate in the Western Indian Ocean province are line, longline, purse seine, and gillnet fisheries. The fisheries that dominate in the northern oceanic Indian Ocean Monsoon Gyre province are the industrial baitboat (BB_IND), purse seine (PS_IND), line (LINE_IND), longline (LL_IND) and gillnet (GILL_IND) fisheries. Industrial gillnets (GILL_IND) dominate in the Somali Current, and the Danish seine (DSEI) fishery dominates in the Andaman province most. The artisanal baiboat fishery (BB_ART) is mostly dominant in the Central Indian Ocean Island province, which encompasses the Maldives (Figure 5). Finally, other artisanal fisheries (OT_ART) such as cast net, fish net or traps (Table 3) are mostly dominant in the northern coastal provinces.

Fidelity indicator

The fidelity indicator required further analysis. Following the Group's advice, we first investigated the relationship between the size of the provinces (i.e., number of grid cells), and the value of the fidelity indicator of species and fisheries for the province to determine whether province size introduced a significant bias to the analysis (Figure 24). The newly regrouped provinces range in size between 4-60 grid cells (Figure 24 left). We found no relationship between the total number of grid cells in a province and its value of fidelity (r^2<0.05; Figure 24 right panels).

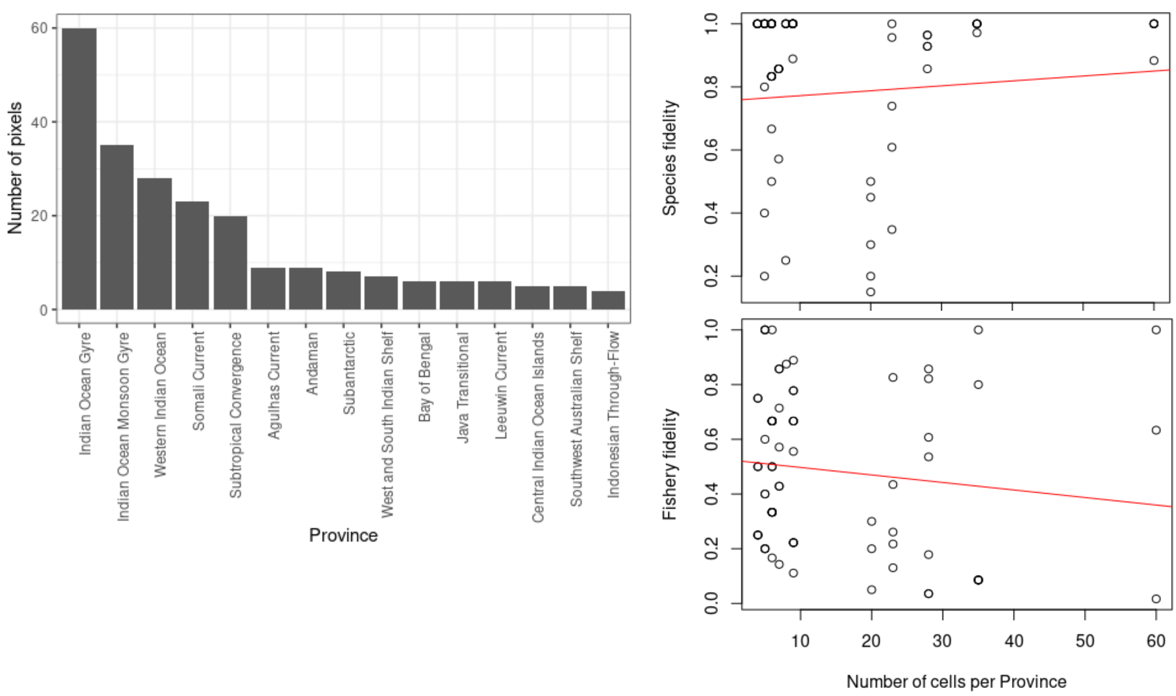


Figure 24. The number of grid cells per province (left), and the number of grid cells per province regressed against the fidelity indicator for species (top right) and fisheries (bottom right). The red line represents the linear model.

Fidelity thresholds

We explored and applied two types of thresholds on the inputs for calculating the fidelity indicator. The thresholds were developed to filter the fidelity of species or a fishery to a province based on 1) the number of years a species or a fishery is present in a grid cell, hereafter referred to as the persistence threshold, and 2) the amount of catch in each grid cell, hereafter referred to as the catch threshold. We investigated increasingly strict persistence threshold values from 3 to up to 14 years, e.g. a 3-year persistence threshold indicates that the species or fishery is in the grid cell for at least 3 years between 2005 and 2019. There are 15 years of data analyzed in this study (2005-2019), thus 3 years represents a very low threshold, and 14 years represents a very strict threshold.

The catch threshold was based on the frequency of catch within each grid cell. We calculated the catch in each grid cell and plotted the frequency of grid cells with different levels of catch (MT) (e.g., Figure 25). We then defined increasingly strict catch thresholds based on the percentile of different catch levels in the grid cells from the 1st to 25th percentiles, e.g. at the 0.25 catch threshold the species or fishery catch in that grid cell represents the 25th percentile or more of all the grid cells' catch. The actual value of the catch threshold differs by species or fishery as it is based on the percentile of the catch of that species or fishery.

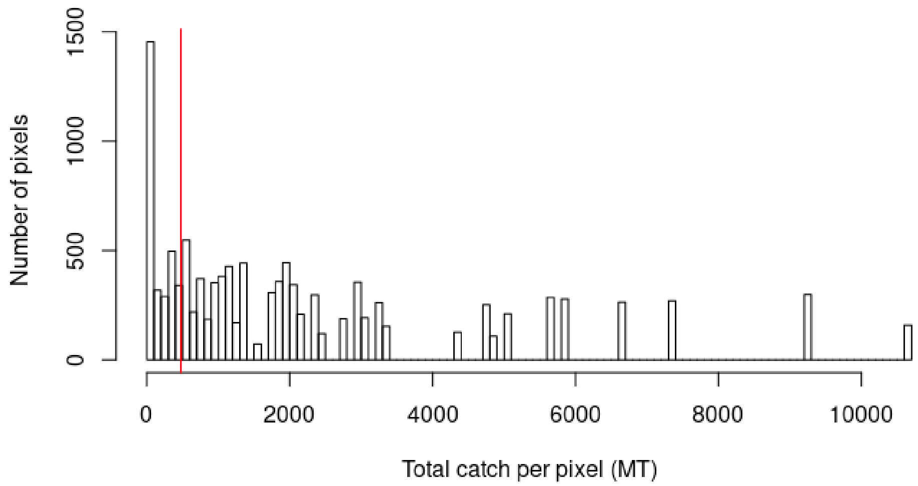


Figure 25. The calculation of the catch threshold using the LL_IND_SWO fishery as an example. The plot shows the frequency of the total catch per grid cell for the LL_IND_SWO fishery throughout the Indian Ocean, and the catch_threshold of 0.25 percentile as indicated by the red vertical line. This 25th percentile for the LL_IND_SWO fishery is 472 MT. Only grid cells with catch > 472 MT are included when estimating the fidelity indicator.

The final threshold values that are presented in this report and applied to the fidelity indicator are based on a "low" and a "high" scenario (Table 6). The objective of the thresholds was to remove the rare or unrepresentative grid cells from the fidelity indicator. The "high" level threshold values were purposefully strict to remove highly unrepresentative grid cells (e.g. grid cells with species with very small catches and caught rarely, or grid cells with fisheries with very small catches and found then rarely). The "low" level threshold values were those that we found to be the highest threshold values that could be applied before we began to lose all the grid cells from a province and therefore lose the ability to calculate the fidelity indicator for that province. For example, when examining species patterns of fidelity, a persistence threshold >5 years and a catch threshold >0.15 percentile, removed all grid cells for the Subantarctic, Subtropical Convergence, and the Southwest Australian Shelf provinces, and therefore the possibility to calculate the fidelity indicator in these provinces. Therefore, we defined the "low" threshold level for calculating the fidelity of species to be 5 years for the persistence threshold, and the 0.15 percentile for the catch threshold.

We note the "low" persistence thresholds levels applied to fisheries allowed for a much higher persistence threshold (10 years) than when applied to species (5 years). While the "low" catch threshold level applied to fisheries allowed for a much lower catch threshold level (0.01 percentile) than when applied to species (0.15 percentile). We interpret this to mean that some fisheries can be representative of a province while having few catches, but being consistently present in a province, e.g., artisanal coastal fisheries. For species, we interpret the "low" threshold levels to reflect the probability that species can be still caught in relatively high quantities (below the 0.15 percentile) in areas where they may not always be present (i.e. periphery of their distributions).

Table 6. The “low” and “high” threshold levels for (1) the persistence threshold in years, and (2) the catch threshold in percentiles that were applied to calculate the fidelity indicator for both species and fishery. The associated scenarios of parameter inputs for the clustering algorithm are also included. In the Input data column, the Combined category indicates that the input data are based on both species and fisheries data. The column Optimal k 0.1 gives the optimal number of clusters, k found for each scenario at the 10% sum of squares threshold level obtained by bootstrapping 1000 times the k-means analysis on k between 2 and 10 (see text for details).

Clustering scenario	**Threshold Level**	**Input data**	**Persistence threshold (years)**	**Catch threshold (percentile)**	**Optimal k 0.1**
HiS	High	Species	13	0.25	4
LowS	Low	Species	5	0.15	3
HiF	High	Fishery	13	0.05	6
LowF	Low	Fishery	10	0.01	5
HiC	High	Combined	Species: 13 Fishery: 13	Species: 0.25 Fishery: 0.05	4
LowC	Low	Combined	Species: 5 Fishery: 10	Species: 0.15 Fishery: 0.01	4

For illustrative purposes, we present the fidelity indicators for both species (Figure 26 left) and fisheries (Figure 26 right) for a province without any thresholds applied (Figure 26 top panel), with low thresholds applied (Figure 26 middle panel) and high thresholds applied (Figure 26 bottom panel). We note a strong effect of the persistence and catch thresholds on the fidelity indicator. For species, we note that the biggest changes are evident for the temperate ALB species in that their signal disappears from the northern provinces when thresholds are applied, indicating that their spatial prevalence in these warmer tropical regions (i.e. around the coastal northern provinces, and Central Indian Ocean Islands) is lower and more irregular within these provinces, i.e.possibly reflecting the outer boundaries of their distributions (Figure 26 left middle and bottom). The persistence and catch thresholds also dramatically affect the fidelity values for the three tropical tuna species (SKJ, YFT and BET), and to a lesser extent to BET, in the very southern provinces (i.e. Southwest Australian Shelf, Subtropical Convergence, and the Subantarctic). These species showed higher fidelity values for these colder temperate southern provinces before the thresholds were applied, and had lower (Figure 26 left middle) to no fidelity values (Figure 26 left bottom) afterward thresholds were applied, reflecting their low spatial prevalence in these provinces and reflecting the outer boundaries in their distributions.

The impacts of the persistence and catch thresholds are also obvious when applied to the fisheries fidelity indicators. For example, we note that fidelity scores for the industrial longline fishery targeting swordfish (LL_IND_SWO) are filtered out in the northern provinces reflecting their low spatial prevalence in this region; the Danish seine fishery (DSEI) also disappears in each province that it is present, and the presence of gillnet fisheries (GILL) in some of the southern provinces is also filtered out. We also note the values of the fidelity indicators tend to decrease for most fisheries and provinces when the thresholds are applied, indicating that there is some spatial heterogeneity for fisheries (in terms of their spatial prevalence) within a province. Like the fidelity indicator for species, the application of high catch and persistence threshold levels on the fishery data results in the exclusion of some fisheries in some of the provinces (Figure 26 right bottom). In conclusion, we find that the high catch and persistence threshold levels appear to remove the species and fisheries from

Figure 26. The fidelity of species (left) and fisheries (right) for a province with no thresholds (top), low thresholds (middle), and high thresholds (bottom) of persistence and catch applied. Low and high threshold values as in Table 6. The colored bars for species plots indicate the habitat of each species, and for fisheries plots indicate the major fishery for each gear type. The subplots are arranged starting from the top left plot in a clockwise fashion for the provinces around the Indian Ocean starting with the Western Indian Ocean (see Figure 5). Some province subplots are missing in the high-threshold plots as the threshold has filtered out all species and fishery information from some provinces.

Figure 27. The SF Indicator of species (left) and fisheries (right) for a province with no thresholds (top), low thresholds (middle), and high thresholds (bottom) of persistence and catch applied. Low and high threshold values as in Table 6. The colored bars for species plots indicate the habitat of each species, and for fisheries plots indicate the major fishery for each gear type. The subplots are arranged starting from the top left plot in a clockwise fashion for the provinces around the Indian Ocean starting with the Western Indian Ocean. No province subplots are missing even where no data exist.

the provinces where they have the least spatial prevalence. Furthermore, a better understanding of the most representative and spatially prevalent species and fisheries for each province emerges when the high threshold levels are applied.

If we consider that the fidelity indicator is a measure of how broadly present and spatially prevalent a species or fishery is within a province, we find that tropical species are spatially prevalent in the northern provinces (warmer and more tropical provinces) as expected (Figure 26 left). SKJ appears most spatially prevalent in the coastal northern provinces; BET is spatially prevalent in the northern oceanic Indian Ocean Monsoon Gyre, and YFT is spatially prevalent in all northern provinces. SWO is spatially prevalent around the Indian peninsula, in the northern oceanic Indian Ocean Monsoon Gyre, and surprisingly less so in the southern oceanic Indian Ocean Gyre, where ALB is more spatially prevalent. ALB, a temperate species, appears to be found throughout, except in the northern coastal provinces (Figure 26 left middle and bottom).

As noted above, the fisheries fidelity indicator shows a relatively high spatial prevalence for a wide range of fisheries in the northern provinces, while in the southern provinces only the industrial longline fisheries (LL_IND, LL_IND_SWO) have a high spatial prevalence (Figure 26 right). Longline fisheries have a high spatial prevalence throughout the IOTC area except the Somali Current province. Line and gillnet fisheries have a higher spatial prevalence in the coastal provinces and around islands. The industrial purse seine fishery (PS_IND) has the highest spatial prevalence in the Western Indian Ocean and Indian Ocean Monsoon Gyre in the north, while artisanal purse fishery (PS_ART) has the highest spatial prevalence throughout the northern coastal provinces (West and South Indian Shelf and Andaman provinces). Other artisanal fisheries (OT_ART) are also prevalent in the coastal provinces including the West and South Indian Shelf, Andaman, Bay of Bengal and Central Indian Ocean Island provinces.

Specificity-Fidelity (SF) Indicator

Finally, we calculated theSF indicator of species and fisheries for a province as a product of their specificity*fidelity*100 with the catch and persistence thresholds applied to the fidelity for both species (Figure 27 left) and fishery (Figure 27 right).

The SF indicator of species and fisheries reinforces some of the patterns already discussed when the specificity and fidelity indicators were analyzed independently (Figure 23 and Figure 26). The SF indicator of species for a province clearly shows that tropical tuna species (SKJ, YFT and BET) are mostly dominant (their total catches are mostly concentrated within the province, i.e. high specificity) and spatially prevalent (spreads broadly within the province, i.e. high fidelity) in the northern oceanic Indian Ocean Monsoon Gyre province, followed by the Western Indian Ocean province. ALB, the temperate tuna species, is mostly dominant and spatially prevalent in the Indian Ocean Gyre province, followed by the Western Indian Ocean province. SWO is a subtropical species that is found throughout the IOTC area. It does not show a high SF value for any of the provinces, yet it appears to be more dominant and spatially prevalent with the oceanic provinces (the Indian Ocean Monsoon Gyre and Indian Ocean Gyre), the Western Indian Ocean, and to a lesser extent with the coastal northern and southern provinces. Overall, we find that species tend to be more important (dominate and be prevalent) in some provinces more than others,and as such, some provinces end up with low values of the SF indicator for species. We interpret these low-values as the outer boundary distributions of the species. We note that the southern provinces (i.e. Southwest Australian Shelf, Leeuwin Current, Subtropical Convergence, Subantarctic, Agulhas Current) have little to no information (very low SF indicator values) when the high threshold levels are applied (Figure 27 bottom left), but we also observe very little information in these provinces even when no thresholds are applied (Figure 27 top left).

The SF indicator of fisheries for a province shows that there is a large diversity of fisheries (mostly artisanal) that are important in the northern coastal provinces relative to the southern provinces and the oceanic provinces (Figure 27 right). Southern and oceanic provinces are mostly dominated by industrial fisheries. The industrial purse fishery (PS_IND) is mostly dominant and spatially prevalent in the Indian Ocean Monsoon Gyre, followed by the Western Indian Ocean, while the presence of the artisanal purse fishery (PS_ART) is only important in the coastal West and South Indian Shelf and Andaman provinces. The industrial longline fisheries (LL_IND) are mostly dominant and spatially prevalent in the oceanic provinces (Indian Ocean Monsoon Gyre and the Indian Ocean Gyre) and the Western Indian Ocean, while the longline targeting swordfish (LL_IND_SWO) is more dominant and spatially prevalent in the Western Indian Ocean, Agulhas Current and Indian Ocean Gyre provinces. Artisanal longline fisheries (LL_ART) are important in the northern coastal provinces (e.g., Bay of Bengal, Andaman). Artisanal line fisheries (LINE_ART) are more dominant and spatially prevalent in the northern coastal provinces (Western Indian Ocean, West and South Indian Shelf, Andaman and Central Indian Ocean Islands). Gillnet fisheries are more dominant and spatially prevalent in the northern coastal areas, particularly industrial gillnet fishery in the Somali Current province, and artisanal gillnet fisheries in the Indian peninsula (West and South Indian Shelf, and Bay of Bengal provinces). Artisanal baitboat fisheries (BB_ART) are more dominant and spatially prevalent in the Maldives (the Central Indian Ocean Islands) and the Indonesian Throughflow province. Again we note that the southern provinces (i.e. Southwest Australian Shelf, Leeuwin Current, Subtropical Convergence, Subantarctic, Agulhas Current) have little to no information when the high threshold levels are applied (Figure 27 bottom right), but we also observe very little information in these provinces even when no thresholds are applied (Figure 27 top right).

Based on our analysis (Figure 23, 24, 25 and 26), we consider that the relevance of a species to a province cannot only be described with the specificity indicator alone (which represents its dominance in the province relative to other provinces) since the fidelity indicator of the species also incorporates information on the spatial prevalence of the species within the province. Similarly, we consider that the relevance of a fishery to a province cannot only be described with its fidelity (its spatial prevalece) to a province since the specificity of a fishery also describes its dominance for a province relative to other provinces in terms of total catchces and their prevalence over time. **Therefore, we recommend that the combined SF indicator, which includes both the specificity and fidelity of a species and fishery for a province, is the most representative method for spatially representing community composition in terms of species and fisheries, and we use this combined SF Indicator as the input for the clustering algorithm**.

Clustering analysis

We then performed a clustering analysis on the SF Indicators for each province to group provinces based on their similarity in terms of species and fishery composition. The clustering analysis was done in a stepwise fashion in order to elucidate the spatial patterns driving the analysis. First clustering was performed on each data layer separately (based on species composition alone, or fishery composition alone) to identify any major drivers of spatial patterns, and then on the combination of data layers for an integrative analysis.

To perform the clustering analysis, we first scaled data by removing the mean and dividing by the standard deviation of the combined SF indicators for species and fisheries. Principal Components Analysis (PCA) was then applied to the scaled data to investigate the contributions of and correlations between the different components of the SF indicator. We used a combination of kmeans (*kmeans*, stats package, http://cran.r-project.org/; Hartigan and Wong 1979) and hierarchical clustering (*hclust*, fastcluster stats package, http://cran.r-project.org/; Müllner 2013) to objectively classify biogeochemical subprovinces.

Optimal clusters

The kmeans partitioning method was used to help guide the determination of the optimal number of clusters, k. kmeans, using Euclidean distances, assigns data points to *k* clusters and minimizes the sum of squares between the data points to the cluster center. With this algorithm, *k* must be defined *a priori*. In order to define *k*, we bootstrap (1000 times) *k* between 2 and 10. The between-clusters sum of squares is then divided by the total sum of squares to find the explained sum of squares. An arbitrary 10% threshold was defined, which we used to identify the optimal *k* for the clustering algorithm (Table 7), whereby the explained sum of squares for each additional *k* increases by less than 10%.

Hierarchical clustering

As one of the expected properties of the IOTC ecoregions is a hierarchical regionalisation, we performed hierarchical clustering, using the *hclust* function (Müllner 2013). Hierarchical clustering produces a dendrogram based on a set of Lance-Williams dissimilarities calculated from the distance matrices. The distance matrices are calculated on the SF indicators for the *n* objects being clustered (here *n* = 15 provinces) using Euclidean distances. We use the complete linkage method to calculate the dissimilarities from which the dendrogram is based, which aims to find similar clusters of values. The dendrogram displays the “tightest” cluster, i.e. the cluster with the least internal variability, on the left of the dendrogram, with single observation clusters being the tightest clusters possible. The hierarchical clustering does not produce a prescribed number of clusters, but the dendrogram enables an understanding of dis/similarities between observations at multiple scales. To enable an objective output, we use the optimal *k* found in the kmeans analysis of the above step to cut the resulting dendrogram into *k* clusters.

Clustering based on several threshold scenarios

We tried multiple scenarios for the clustering analysis using different fidelity threshold levels incorporated into the calculation of the SF indicator for species, fisheries and both species and fisheries combined (Table 7; Figures 28-30).

Table 7. A number of cluster analyses were performed based on several catch and persistence threshold scenarios applied to the fidelity indicator when calculating the SF indicator for species, fisheries and both combined species and fishery information. This table also displays the optimal *k* clusters found at the 10% sum of squares threshold for each scenario as well as the percent of variance explained in the first two PCA dimensions for each scenario (see text for details).

Scenario	Level	Type	Persistence threshold (years)	Catch threshold (percentile)	Optimal k 0.1	PCA1	PCA2
LowS	Low	Species	5	0.15	3	75.1%	22.0%
HiS	High	Species	13	0.25	4	72.7%	23.4%
LowF	Low	Fishery	10	0.01	5	33.5%	19.3%
HiF	High	Fishery	13	0.05	6	29.6%	18.1%
LowC	Low	Combined	Species: 5 Fishery: 10	Species: 0.15 Fishery: 0.01	4	39.1%	21.3%
HiC	High	Combined	Species: 13 Fishery: 13	Species: 0.25 Fishery: 0.05	4	38.7%	17.7%

Clustering on the species-based SF indicator resulted in three clusters in the low-level threshold scenario and four clusters in the high-level threshold scenario. We find a high degree of variability is explained in the first PCA dimension for both scenarios (72-75%), with the total explained variability in two dimensions of between 96-97% (Table 7, Figure 28). In both threshold scenarios, we find that the northern oceanic Indian Ocean Monsoon Gyre forms the tightest cluster. The PCA indicates that the tropical tuna species (SKJ, YFT and BET) are highly associated with this province (Figure 28 top left). The low threshold scenario further groups the Western Indian Ocean with the southern oceanic Indian Ocean Gyre (Figure 28 top right), but these are separate clusters in the high threshold scenario (Figure 28 bottom right). In both scenarios, the Western Indian Ocean seems to be highly explained by SWO and the Indian Ocean Gyre by ALB (Figure 28 left). The high-threshold scenario, which is stricter in terms of the catch thresholds and number of years included in the persistence thresholds,

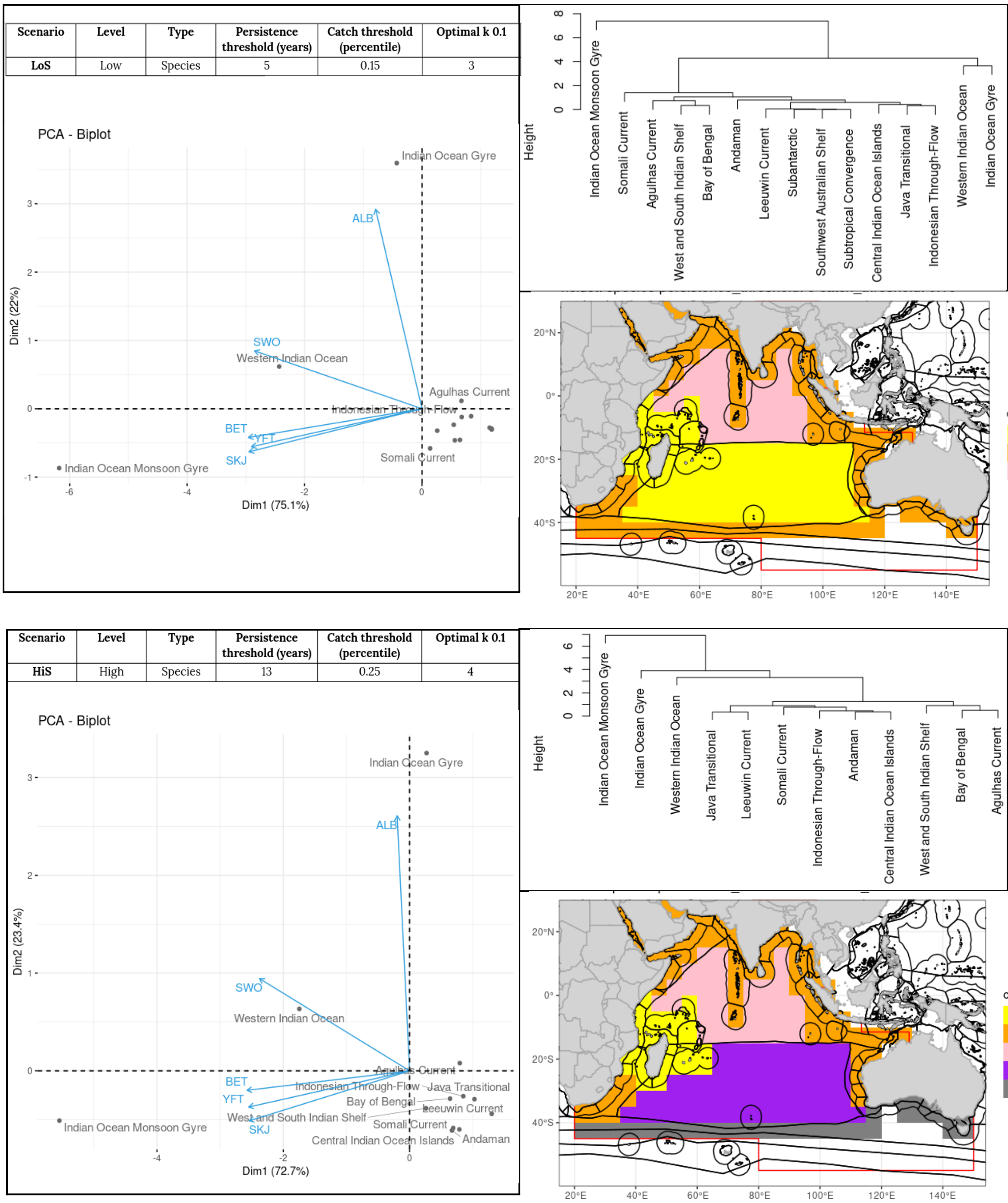


Figure 28. The cluster analysis results for the low threshold scenario (top three panels) and the high threshold scenario (bottom three panels) for the species-based SF indicator. Table 7 presents the six different scenarios that the clustering analyses were based on.

excludes the southernmost provinces (Southwest Australian Shelf, Subantarctic, and Subtropical Convergence) from the clustering analysis due to lack of data (none of the species are representative of these provinces), but the low-threshold scenario clusters them with the coastal provinces. The coastal and southern provinces appear to group together because they are not highly associated with any one species (Figure 28 top).

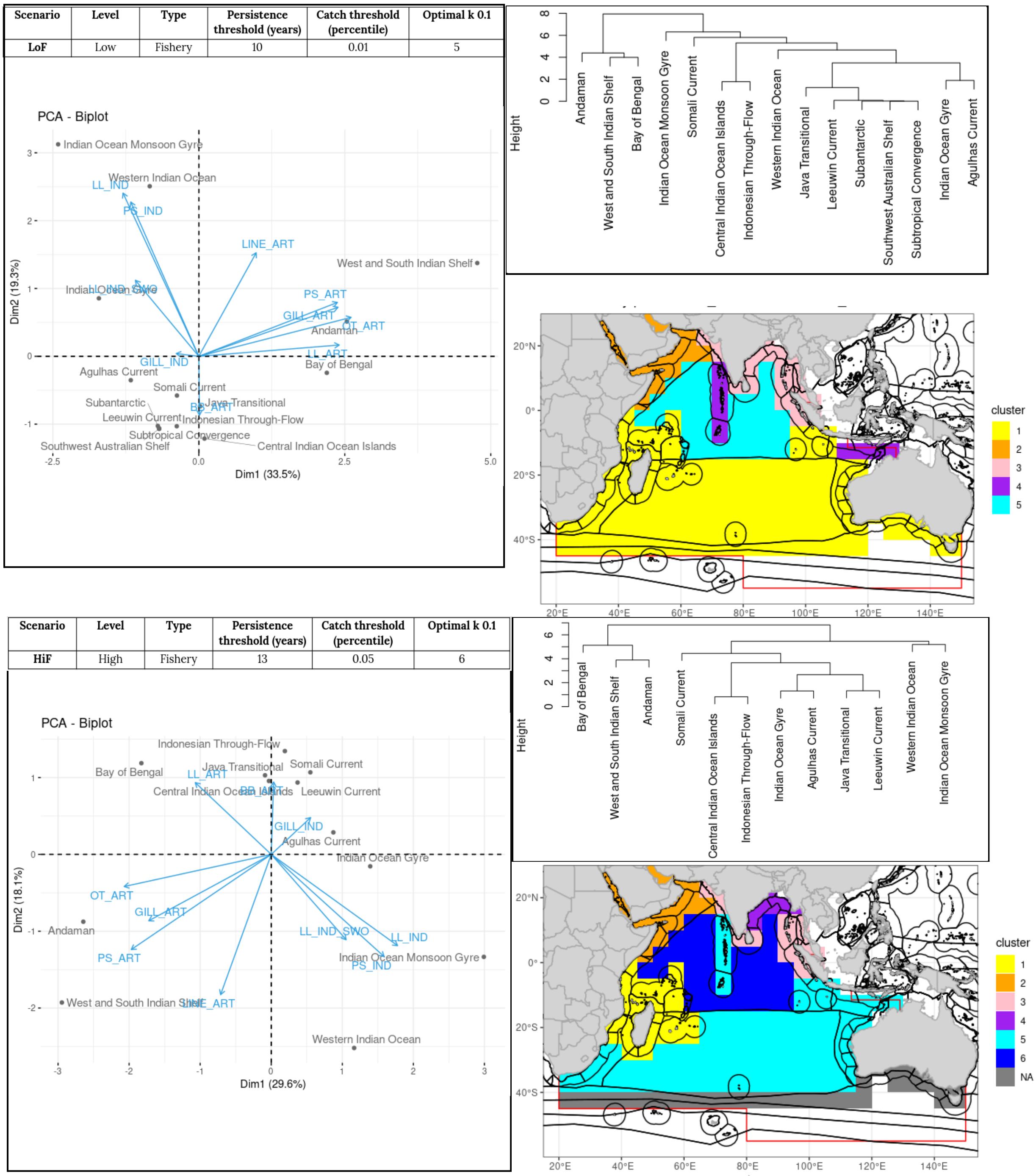
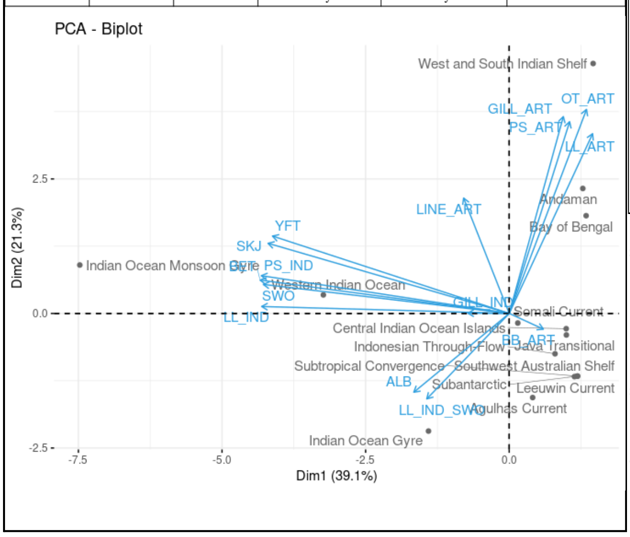
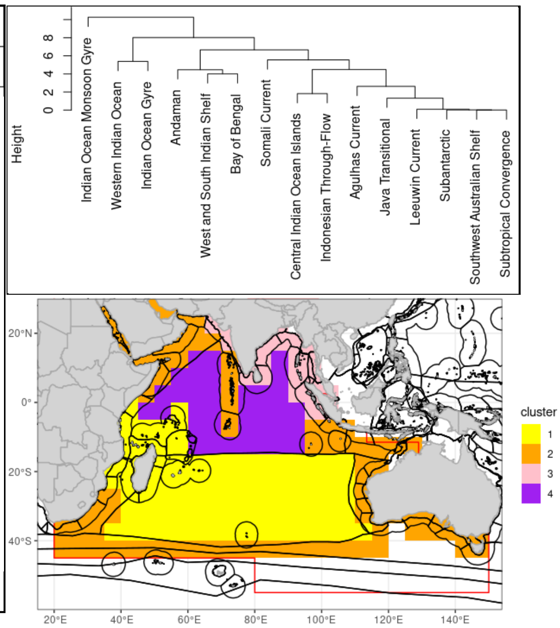


Figure 29. The cluster analysis results for the low threshold scenario (top three panels) and the high threshold scenarios (bottom three panels) for the fishery-based SF indicator. Table 7 presents the six different scenarios that the clustering analyses were based on.

Clustering on the fishery-based SF indicator resulted in give clusters in the low-threshold scenario and six clusters in the high-threshold scenario (Table 7, Figure 29). Relative to the species-based scenarios above, we found much lower variability explained in the first two dimensions of the PCA for both low and high fishery-based scenarios (48% and 53% respectively). We also note that the fishery-based clusters are much less tight than the species-based clusters; however some general patterns can be detected. For example, the industrial longline and purse seine fisheries tend to explain the northern oceanic Indian Ocean Monsoon Gyre, the Western Indian Ocean and to some extent the southern Indian Ocean Gyre where the industrial longline fishery targeting swordfish is also associated (Figure 29 left). Artisanal fisheries appear to be associated with the north-eastern coastal provinces, and the industrial gillnet fishery (GILL_IND) appears to be associated with the Somali Current. Artisanal baitboat fisheries (BB_ART) appear to associate with the Indonesian Throughflow and the Central Indian Ocean Islands to a degree (Figure 29 left). The low-threshold scenario for fisheries groups the Western Indian Ocean with the southern oceanic Indian Ocean Gyre, as well as the southernmost provinces.

Scenario	Level	Type	Persistence threshold (years)	Catch threshold (percentile)	Optimal k 0.1
LoC	Low	Combined	Species: 5 Fishery: 10	Species: 0.15 Fishery: 0.01	4





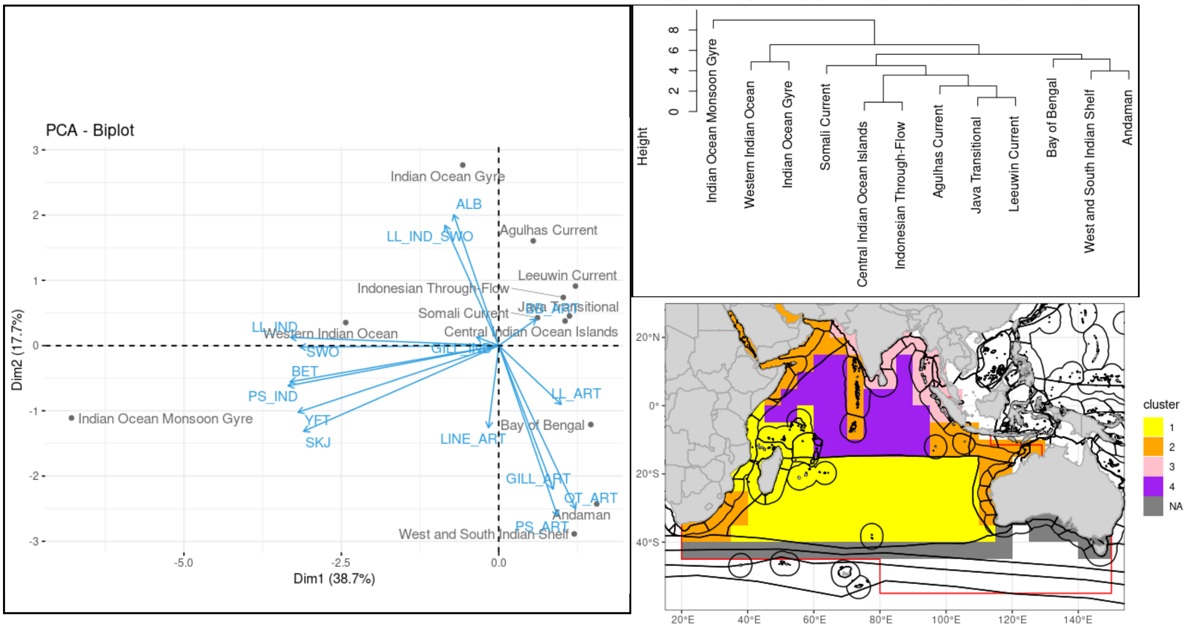


Figure 30. The cluster analysis results for the low threshold scenario (top three panels) and the high threshold scenarios (bottom three panels) for the species-and fishery-based (combined) SF indicator. Table 7 presents the six different scenarios that the clustering analyses were based on.

While the high-threshold scenario separates the Western Indian Ocean from the southern oceanic Indian Ocean Gyre and excludes from the clustering analysis the southernmost provinces entirely. However, the high threshold scenario clusters the Central Indian Ocean Islands and the Indonesian Throughflow with the southern oceanic Indian Ocean Gyre, while the low-threshold considers these two provinces a separate cluster (Figure 29 top right). Furthermore, the high-threshold scenario considers the Bay of Bengal its own separate cluster, while the low-threshold scenario groups this province with the other northeastern coastal provinces (the Andaman and the West and South Indian Ocean Shelf) (Figure 29 right).

Finally, clustering the provinces based on the SF indicator that includes both information on the species and fisheries, we find that both the low- and high-threshold scenarios result in four clusters as the optimal number. These clustering scenarios explain 56-60% of the variability in the first two dimensions of the PCA (Figure 30 left). We note that the cluster results are very similar between the low and high scenarios for the combined SF indicator, with the difference that the analysis in which the low thresholds were applied clusters the southernmost provinces (Southwest Australian Shelf, Subtropical Convergence and Subantarctic) with the coastal provinces, and the analysis in which the high thresholds were applied excludes them entirely from the analysis. (Figure 30 right). The northern oceanic Indian Ocean Monsoon Gyre is again the tightest cluster between both scenarios, and is explained to a large degree by tropical species (SKJ, YFT, and BET), and the industrial purse seine and longlines (Figure 30 left). In the combined SF indicator-based clustering, the Western Indian Ocean is clustered with the southern oceanic Indian Ocean Gyre, apparently due to the influence of ALB, SWO and the industrial longlines, particularly for swordfish (LL_IND_SWO) operating in this province. The northeastern basin (Andaman, West and South Indian Shelf provinces) appears to be clustered due to their association with several artisanal fisheries (PS_ART, OT_ART, GILL_ART, LL_ART, LINE_ART), and the remaining provinces are grouped together into a cluster that is geographically spread over different regions (1) the Agulhas Current, (2) the Somali Current, (3) the Central Indian Ocean Islands, and (4) the Indonesian Through-Flow together with the Java Transitional and Leeuwin Current) (Figure 30 right).

Step 5 - Interpretation of results, derivation and refinement of the baseline ecoregion proposal

Actions taken during first workshop and Group advice

In 2019, the clusters resulting from the cluster analyses on the SF indicator for species, fishery, and both species and fishery combined were presented to the Group. Some questions remained on how to interpret the clusters resulting from the hierarchical cluster analysis, which were discussed with the group. These included discussions on how to treat the clusters spread across wide geographic distances, or how to interpret the clusters for species or fisheries with low fishing activity and catches (e.g. neritics and sharks).

The clusters resulting from the clustering analysis were then used as a starting point for discussions and adjustments based on expert knowledge. Expert knowledge was required to refine the cluster groupings and address any potential misclassifications and errors based on poor or incomplete data inputs (e.g. there are significant coastal catches that are not officially reported to the IOTC). Expert knowledge was also required to refine the boundaries of the baseline ecoregions to ensure that the final candidate ecoregions comply with the evaluation criteria. Through the discussions within the Group, expert knowledge was used to refine the groupings and develop a proposal of draft ecoregions (Figure 2), which were finally presented to the WPEB15 (Juan-Jorda 2019).

In the course of the 2019 workshop discussions, the Group further recommended assessing the spatial and temporal heterogeneity between clusters and homogeneity within clusters of the resultant baseline ecoregions proposed to the Group. This type of analysis can improve the interpretation and understanding of the patterns of species and fisheries distributions. For example, changes in the spatial distribution of species informing clusters might be due to reporting or fleet operations and not species presence/absence. Furthermore, this type of analysis can provide information on the strength and confidence of the clustering results (i.e. the more homogenous a cluster, the more confident we are that it represents a unique grouping).

Action taken in preparation for second workshop, findings and proposed solutions

Based on the refined purposes and uses of ecoregions (step 1), the refined criteria (step 2), the updated datasets (step 3) and the refined analytical analyses (step 4) above, we have updated the baseline ecoregions proposal, including an examination of the heterogeneity and homogeneity within and between the proposed ecoregions (presented below). This is presented below for discussion at the second IOTC ecoregion workshop. We expect that this proposal of candidate baseline ecoregions (also presented below) will be discussed, adjusted and refined using the expert knowledge of the participants.

Baseline ecoregion proposal

To our view, the cluster analysis scenario that best represents groups with distinct species and fisheries composition and is most useful to start discussions and potential refinements with expert knowledge is the scenario based on the SF indicator including both species and fishery information and using the high catch and persistence thresholds when calculating the fidelity indicator ("HiC" scenario (Table 7); Figure 30 bottom panel). The high catch and persistence thresholds were chosen as they help to identify the most spatially prevalent species and fisheries (spread broadly within the province with relatively high catches that persist over time) in each province, and they help to filter out from the clustering analysis those provinces with little or no information, allowing clearer spatial patterns to be resolved.

One of the expected properties of the ecoregions is that each ecoregion should be geographically contiguous, a quality which was accepted by the Group in the first workshop, and helped shape the final draft ecoregions proposed to the WPEB15. Following this precedent, we have refined the four clusters from the HiC scenario into 7 geographically contiguous clusters (Figure 31). For this, we split the coastal cluster 2 (orange, Figure 30 bottom left) into four different ecoregions (Figure 31). We considered that the Somali Current and the Central Indian Ocean Islands are geographically separate. We note that the high threshold scenario excludes the southernmost provinces due to lack of data, and we suggest that these provinces be treated as a single ecoregion as well. Thus, the final baseline ecoregion proposal comprises eight different ecoregions (Figure 31).

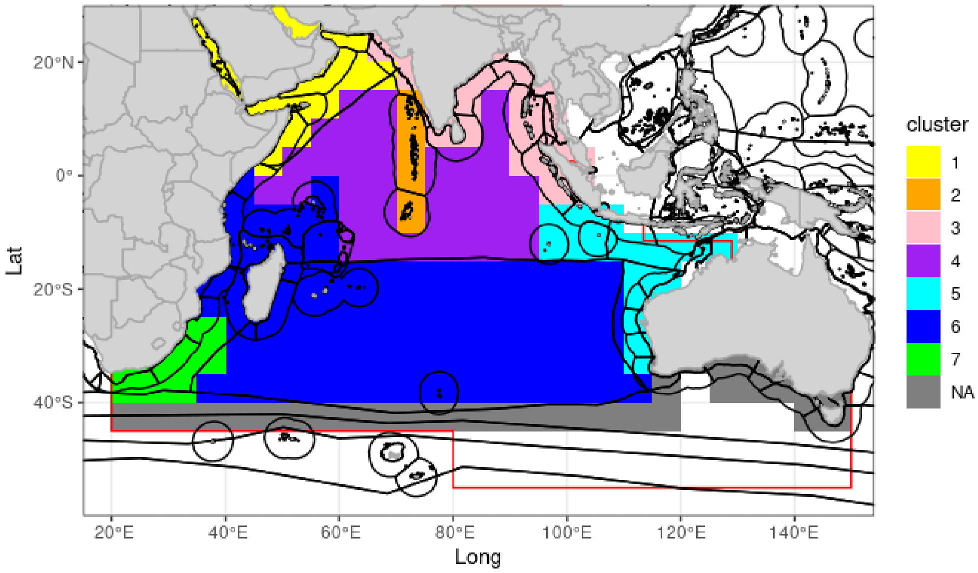


Figure 31. The baseline ecoregion proposal was derived from the "HiC" cluster scenario (Figure 30 bottom left; Table 7), which was selected as the most representative clustering result that represents groups with distinct species and fisheries composition. The HiC coastal cluster 2 (Figure 30 bottom left) was split into four geographically distinct ecoregions, and the southern NA cluster is proposed as an additional ecoregion as well. The final baseline ecoregion proposal comprises eight different ecoregions. Ecoregion 1: Coastal northwest; Ecoregion 2: Coastal central islands; Ecoregion 3: Coastal northeast; Ecoregion 4: Oceanic tropical; Ecoregion 5: Coastal southeast; Ecoregion 6: Oceanic subtropical; Ecoregion 7: Coastal southwest; Ecoregion 8: Oceanic temperate.

Baseline ecoregion variability

We investigated the variability of the specificity, fidelity and SF indicators of species and fisheries, within and between the final eight baseline ecoregions proposed here (Figure 32). The boxplots show the main characteristics of each ecoregion based on the specificity, fidelity and SF indicators of species and fisheries. The boxplots in Figure 32 also assist to further elucidate patterns and verify clustering statistics. The range of the box is the interquartile range (IQR) of the data, where the colored box represents the range of values between the 25th and 75th percentile. The whiskers at the lower and upper ends of the box indicate the largest and smallest value no further than 1.5 times the IQR. Outliers are beyond 1.5 times the IQR and are plotted as separate points.

From the boxplots, we can see relatively high between-ecoregion heterogeneity for species specificity in that the Oceanic tropical ecoregion (the Indian Ocean Monsoon Gyre) and Oceanic subtropical ecoregion (the Western Indian Ocean and Indian Ocean Gyre) are significantly higher than the other ecoregions, which seem to have similarly low levels (Figure 32 left). However, noting this, there appears to be also high within-ecoregion variability in Oceanic tropical ecoregion, indicating low within ecoregion homogeneity. We interpret this as the Oceanic tropical ecoregion and the Oceanic subtropical ecoregion as the ecoregions where these species have the highest preference. There is higher variability within the ecoregions for fishery specificity, especially for Coastal northeast ecoregion and the Oceanic tropical ecoregion, but the boxplot supports the clustering analysis that Coastal northeast, Oceanic tropical, and Oceanic subtropical ecoregions are substantially different from the remaining ecoregions. The NA cluster, or the Oceanic temperate ecoregion (which integrates those provinces excluded from the clustering analysis) also seems to be significantly different from the others, though data are few.

We note high variability for the fidelity indicator for both species and fishery, indicating low within-cluster homogeneity for these indicators (large IQR; Figure 32 middle panels). We also note that most of the box plots overlap (with the exception of the Coastal northwest ecoregion in species fidelity (Figure 32 middle-left panel), indicating low heterogeneity between ecoregions for the fidelity indicator. We note relatively high within-ecoregion homogeneity for Coastal northwest ecoregion and Coastal southwest ecoregion for both the fidelity indicator of species and fisheries (narrow IQR).

Finally, we note that the SF indicator, which incorporates the patterns of the specificity and fidelity of both species and fisheries, indicates important heterogeneity between the Oceanic tropical the Oceanic subtropical, and the Coastal northeast ecoregion with the remaining ecoregions similarly valued, aligning with the clustering analyses (Figure 32 right). We note the high internal heterogeneity for Oceanic tropical ecoregion, which encompasses a wide diversity of species and fisheries. The Coastal northeast ecoregion is also relatively heterogeneous, reflecting to a large part the diversity of fisheries in this ecoregion. Oceanic subtropical ecoregion is a region of high catch, and has high indicator values, but the diversity of the species and fisheries in this ecoregion is relatively low, as reflected by its narrow IQR.

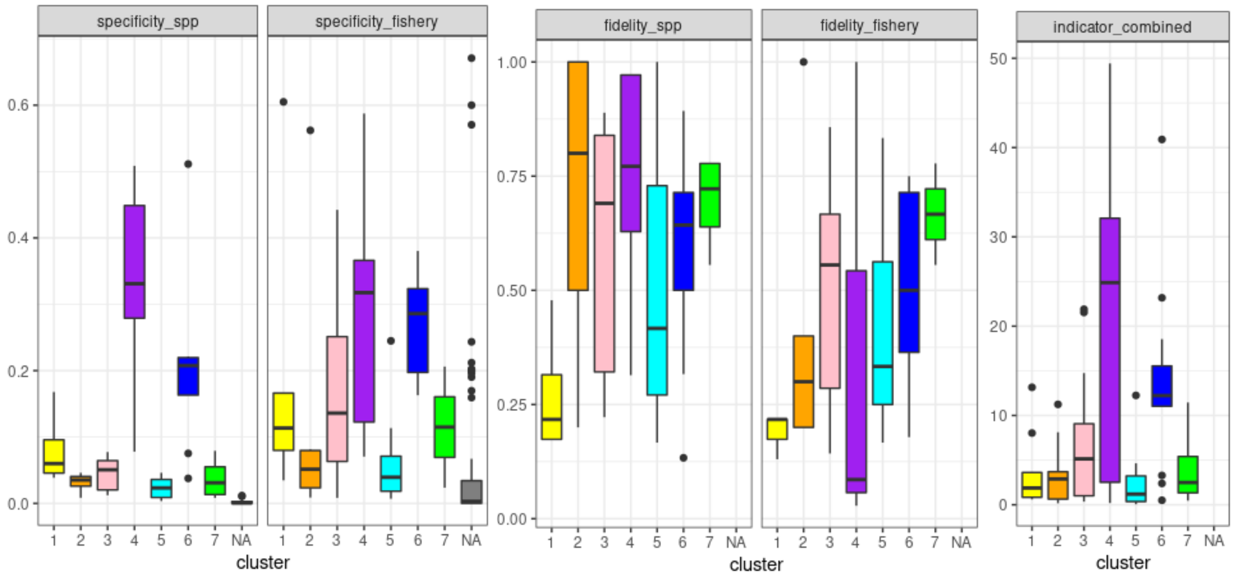


Figure 32. Boxplots of the specificity of species and fishery (left two panels), fidelity of species and fishery (middle panels), and the SF (specificity*fidelity) indicator of both species and fishery combined (right panel). The lower and upper ranges of the boxes correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the upper end of the box to the largest value no further than 1.5 * inter-quartile range (IQR) from the box edge. The IQR is the distance between the first and third quartiles. The lower whisker extends from the box edge to the smallest value at most 1.5 * IQR of the box edge. Data beyond the end of the whiskers are outliers and are plotted individually. Colors and cluster numbers correspond to those in Figure 31.

We investigated the temporal variability of the total annual raised catch by species (Figure 33) and by fishery (Figure 34) in order to identify whether there are major trends or variability in the time series of data for each ecoregion. We note that the variability of the total annual catch by species over time within ecoregions appears quite stable (Figure 33), and reinforces the pattern of high homogeneity in Coastal central islands, Coastal southeast, Coastal southwest, and the Oceanic temperate ecoregion. Greater heterogeneity in the total annual catch by species over time is found in the Coastal northwest, Coastal northeast; Oceanic tropical; and Oceanic subtropical ecoregions. Patterns across ecoregions indicate that both Oceanic tropical and Oceanic subtropical ecoregions have the highest catches (Figure 33). We see again that the tropical species dominate the catches in the Oceanic tropical ecoregion, particularly YFT and BET, whereas there are few catches of ALB in this province. We note that early in the time series, catches of YFT and BET were much higher in the Oceanic tropical ecoregion than towards the end of the time series (Figure 33). Some reduction in YFT catch can be noted in Coastal northwest over then 15 years of the time series, and we see some variability in the catches of YFT, SWO and SKJ for the Coastal northeast;. The other ecoregions appear to have relatively little interannual variability. In Oceanic subtropical ecoregion, catches of all species are distributed more evenly, with little interannual variability.

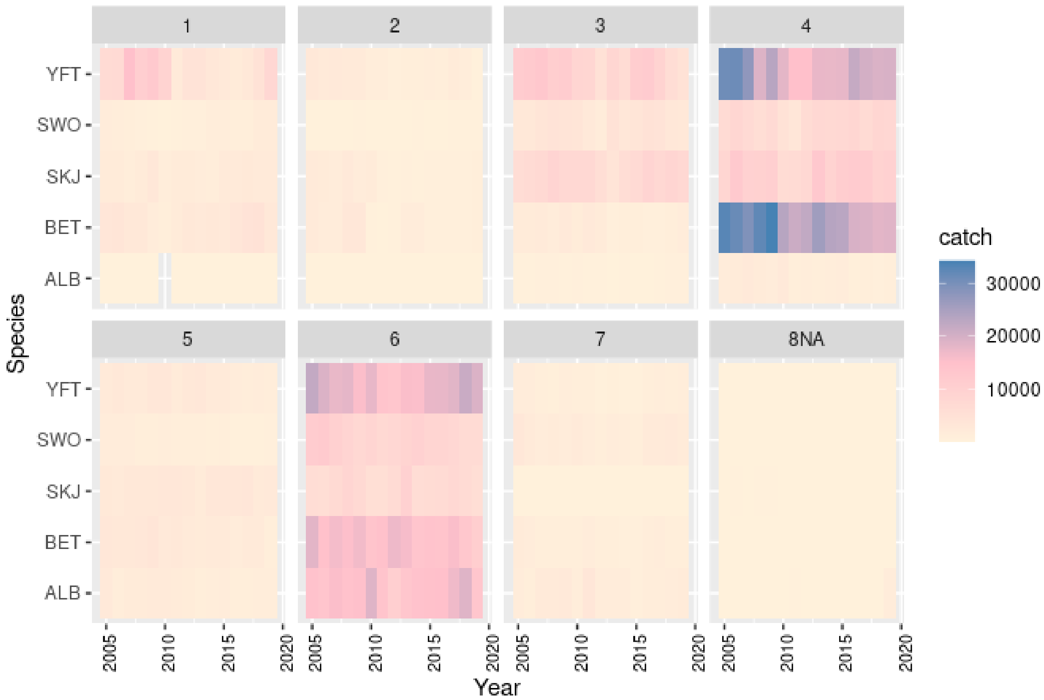


Figure 33. The total annual raised catch (MT) by species for each year between 2005 and 2009 in each cluster 1-8NA as in Figure 31. No threshold has been applied to these data.

In general, the catch of each fishery seems highly stable across years within each ecoregion. The fisheries present between ecoregions are very different, likely leading to the patterns of heterogeneity we see for the fisheries-based indicators in Figure 32. We find that there are many ecoregions where fisheries are only present for a year or two with very little catch, which supports our understanding of fisheries persistence and catch (see above). We find that the catch Oceanic tropical and Oceanic subtropical is dominated by the PS_IND and LL_IND fisheries (Figure 34). The LL_IND fisheries interannual variability appears to mirror the interannual variability of the YFT and/or BET fishery in Figure 33, which may indicate some change in the fishery for these early years. Some variability is notable in the LL_IND fishery in the Coastal northwest, the Coastal northeast, and the Coastal southeast ecoregions, and the GILL_IND fishery appears to have higher catch in the Coastal northwest ecoregion between 2007-2010 relative to the rest of the time series.

An important point to note is that for both species and fisheries, we see similar trends and patterns within and across ecoregions, indicating that the proposed baseline ecoregions are consistent with the data.

Figure 34. The sum of the catch (MT) by fishery for each year between 2005 and 2009 in each cluster 1-8NA as in Figure 31. No threshold has been applied to these data.

Expert knowledge

The data-driven spatial clustering approach has produced a final **baseline ecoregion proposal** which comprises eight different ecoregions (Figure 31). We expect that this baseline ecoregion proposal be used as a starting point for discussions and **adjustments based on expert knowledge**. Expert knowledge is expected to be used to refine the cluster groupings and address any potential misclassifications and errors based on poor or incomplete data inputs (e.g. there are significant coastal catches that are not officially reported to the IOTC). Expert knowledge is also expected to refine the boundaries of the baseline ecoregions to ensure that the final candidate ecoregions comply with the evaluation criteria (Table 2). We expect that the Group will develop a proposal of refined candidate draft ecoregions.

Here, we suggest some potential points that may require expert input:

- The choice of cluster scenario for the the baseline ecoregion proposal: Experts may wish to discuss the validity of the cluster scenario selected as the basis for the proposed baseline ecoregions, and may suggest that other scenarios (Table 7) be put forward;
- Geographical delineation of final cluster analysis: The current baseline proposal was further delineated into 8 total clusters based on the expectation that clusters be geographically contiguous, and this may be refined in discussions;
- Refinement of the delineations of the ecoregion boundaries based on expert knowledge of the main thematic factors included in the criteria.

Step 6 - Ecoregion validation and testing

Actions taken during first workshop and Group advice

During the first IOTC ecoregion workshop, the Group agreed on the importance to test their general applicability, as well as getting the Commission involved early in the process to build an inclusive and iterative process.

Action taken in preparation for second workshop, findings and proposed solutions

Based on the Group feedback, we added an additional step in the main framework for guiding the ecoregion delineation (Figure 3), which consists in formally **validating and testing the draft ecoregions for its intended use** by experts or any interested party**.** While it may appear that the ecoregions derived under step 5, after adjusting the quantitative proposal of baseline ecoregions with expert judgment, are definitive; in fact, they should be considered a working hypotheses to be tested and validated before they are used for resource planning, research and management (Bailey 1983, Loveland and Merchant 2004).

The ecoregions that are delineated in this workshop are working hypotheses that have arisen from knowledge of the thematic factors (oceanography/biogeography of the region, species distribution, and fisheries distributions) that are believed to be important for the intended use of the ecoregion. Therefore, their expected qualities (see Table 2) could be evaluated statistically, so the ecoregion boundaries can be objectively evaluated. In addition, it is also a common practice to develop pilot products to test its general applicability, potential usefulness, benefits and challenges of the draft ecoregions. The ultimate test of the utility of ecoregions as tools for resource planning, research and management may be the extent to which they meet the end user needs (Loveland and Merchant 2004).

There is an ongoing activity to develop a pilot study to validate and test the draft ecoregions (based on the ecoregion proposal derived in the first IOTC ecoregion workshop in Figure 2) with the objectives of (1) testing the concept of ecoregion and utility, (2) test the usefulness of having ecoregions as “reporting units” for regional assessments and (3) identify the advantages, disadvantages, challenges and benefits of using ecoregion as “reporting units”.

This ongoing pilot study consists of conducting a regional bycatch assessment based on a study presented to the WPEB17 meeting (Martin and Shahid 2021). This original study examined to what extent the Conservation and Management Measures (CMMs) supporting the conservation and management of vulnerable species interacting with IOTC fisheries as bycatch adopted in IOTC (the entire convention area) have been effective in terms: (1) of reducing the mortality on bycatch species, (2) of improving the data quality in the fisheries statistics collected for bycatch species, and (3) improving and steering relevant research for their successful implementation. While the original study focused on developing the bycatch assessment in IOTC fisheries at the spatial scale of the IOTC convention area and structured the results by major taxa groups (sharks, sea turtles, cetaceans), the on-going pilot study seeks to conduct a regional bycatch assessment for a selection of ecoregions (Somali Current, Indian Ocean Monsoon Gyre, and Indian Ocean Gyre ecoregions) focusing on the most relevant fisheries in the region and the most vulnerable species interacting with the core fisheries. The selected ecoregions are currently based on the 2019 draft ecoregions, and these will be updated based on the results of this workshop. Thus, the regional pilot study seeks to elucidate and highlight regional challenges and priorities in the management of bycatch. Using a multi-taxa and multi-fishery approach, this regional approach will allow us to qualitatively (and quantitatively, when possible) examine the relevant multi-taxa and multi-fishery interactions (and emerging trade-offs) relevant to the core fisheries in each ecoregion and the main vulnerable taxa interacting with the core fisheries of each ecoregion.

Specifically the following tasks are planned in the ongoing pilot study:

Task 1. Identify and summarize the core fisheries in each of the selected ecoregions

Task 2. With a focus on the core fisheries operating in the selected ecoregions, conduct a qualitative review to identify the most vulnerable taxa groups and species interacting with this core fisheries as bycatch.

Task 3. Identify relevant CMMs for the conservation and management of vulnerable species and quantify to what extent the existing CMMs are reducing the fishing mortality for the selected most vulnerable taxa groups and species in the ecoregions.

Task 4. Examine the state (quality and quantity) of the fishery catch statistics for selected vulnerable taxa groups (and species) to evaluate if the existing data collection and reporting are fit to support the effective implementation of relevant CMMs and identify priority areas for data improvements.

Task 5. Examine ongoing relevant research and to what extent is supporting the effective implementation of relevant CMMs, and recommend priority areas of research to address regional bycatch challenges.

The above tasks are still subject to discussion as the pilot study is still under development. Additionally, we are also in the process of finding funding to support the development of the above tasks.

Conclusions

This report summarizes the preparatory work performed prior to the second IOTC ecoregion workshop. This work will be presented and discussed at the upcoming IOTC second ecoregion workshop, where expert advice will be solicited. This report provides a refined analysis based on the feedback received in the first ecoregion workshop and provides the supporting documentation needed to inform the discussions to refine the process of ecoregion delineation. At the workshop, we expect that the workshop participants will review the analyses leading to the cluster groups (which form the basis of the baseline ecoregions). It is also expected that the baseline ecoregions will also be adjusted using expert knowledge, and be assessed against the proposed evaluation criteria in Table 3 to provide a refined proposal of ecoregions in the IOTC convention area to be presented at the next IOTC WPEB and Scientific Committee meetings for discussion and, if possible, endorsement.

The expected outputs of the second IOTC ecoregions workshop include:

- A list of potential uses of ecoregions as tools to guide EAFM implementation in IOTC
- A revised criteria including the main thematic factors and list of properties guiding the delineation of the ecoregions;
- A better understanding of the data layers and analytical methods used for deriving the ecoregions with its strengths and weaknesses;
- A refined proposal of baseline ecoregions (including sensitivity analysis) to be adjusted based on expert knowledge;
- Revised candidate draft ecoregions;

- The terms of reference for a pilot study to test the general applicability and use of the proposed ecoregions.
- A workshop report with an executive summary including the main outcomes of the second IOTC ecoregion workshop to be presented at the WPEB in 2022.

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