SCRS/2022/062 Collect. Vol. Sci. Pap. ICCAT, 79(5): 80-151 (2022)

PRE-WORKSHOP ANALYSIS IN PREPARATION FOR THE 2022 ICCAT ECOREGION WORKSHOP "IDENTIFICATION OF REGIONS IN THE ICCAT CONVENTION AREA FOR SUPPORTING THE IMPLEMENTATION OF ECOSYSTEM BASED FISHERIES MANAGEMENT"

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SUMMARY

The overall aim of the workshop is to advance in the identification of ecologically meaningful regions (ecoregions) that can serve as a basis to produce more integrated ecosystem-based advice, and thereby support the operationalization of ecosystem-based fisheries management (EBFM) in the International Commission for the Conservation of Atlantic Tunas (ICCAT). Ideally, the candidate ecoregions should have boundaries that make ecological sense but should also be practical for facilitating the provision of integrated advice at the regional level. This report summarizes a pre-workshop analysis following the Terms of References agreed upon by the SC-ECO which will be presented at the workshop to inform group discussions. The expected outputs of this workshop are: 1) a better understanding of the role and purpose of ecoregions as a tool to support EBFM implementation in ICCAT; 2) decision criteria including the major thematic factors to guide the development of draft ecoregions; 3) an understanding of the data layers and analytical methods proposed for deriving the ecoregions with their strengths and weaknesses; and 4) a proposal of candidate draft ecoregions within the ICCAT convention area.

RÉSUMÉ

L'objectif général de l'atelier est de progresser dans l'identification de régions écologiquement significatives (« écorégions ») qui peuvent servir de base pour produire un avis écosystémique plus intégré, et ainsi soutenir la mise en marche de la gestion des pêcheries basée sur les écosystèmes (EBFM) à la Commission internationale pour la conservation des thonidés de l'Atlantique (ICCAT). Idéalement, les écorégions potentielles devraient avoir des limites qui ont un sens écologique, mais aussi être pratiques pour faciliter la formulation d'avis intégrés au niveau régional. Le présent rapport résume une analyse préalable à l'atelier, conformément aux termes de référence convenus par le Sous-comité des écosystèmes, qui sera présentée lors de l'atelier afin d'alimenter les discussions de groupe. Les résultats attendus de cet atelier sont: 1) une meilleure compréhension du rôle et de l'objectif des écorégions en tant qu'outil pour soutenir la mise en œuvre de l'EBFM au sein de l'ICCAT ; 2) des critères de décision, y compris les principaux facteurs thématiques, pour guider le développement des projets d'écorégions ; 3) une compréhension des couches de données et des méthodes analytiques proposées pour dériver les écorégions avec leurs forces et leurs faiblesses ; et 4) une proposition de projets d'écorégions potentielles dans la zone de la Convention de l'ICCAT.

RESUMEN

El objetivo general de las jornadas es avanzar en la identificación de regiones ecológicamente significativas (ecorregiones) que puedan servir como base para generar asesoramiento más integrado basado en el ecosistema y respaldar así la operacionalización de la ordenación pesquera basada en el ecosistema (EBFM) en la Comisión Internacional para la Conservación del Atún Atlántico (ICCAT). Lo ideal sería que las ecorregiones candidatas tuvieran unos límites

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con sentido desde el punto de vista ecológico, pero que también fueran prácticos para facilitar la prestación de asesoramiento integrado a nivel regional. Este informe resume un análisis previo a las jornadas según los términos de referencia acordados por el Subcomité de ecosistemas, que se presentará en las jornadas para aportar información a los debates del grupo. Los resultados esperados de estas jornadas son: 1) un mayor entendimiento del papel y el propósito de las ecorregiones como herramienta de apoyo a la implementación de la EBFM en ICCAT; 2) criterios de decisión, lo que incluye los principales factores temáticos para guiar el desarrollo de los proyectos de ecorregiones; 3) una comprensión de las capas de datos y los métodos analíticos propuestos para elaborar las ecorregiones con sus puntos fuertes y puntos débiles; y 4) una propuesta de proyecto de ecorregiones candidatas dentro de la zona del Convenio de ICCAT.

KEYWORDS

Ecoregions, spatial framework, regional advice, integrated advice

1. Background

National and international fisheries management organizations are increasingly adopting more holistic approaches to research, assess, monitor and manage fisheries. One of these approaches is the operationalization of Ecosystem-Based Fisheries Management (EBFM)[4]. EBFM 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 (FAO 2003). It attempts to account for the connectivity between species, their habitats and the physical environment, and their connection with humans (Rice *et al.* 2011). Since the EBFM is a place-based approach rather than a species-based approach, it creates the need to think, plan and act in terms of ecosystems, requiring a spatial context within which ecosystems can be described, monitored and reported on (Trenkel 2018, Fogarty 2014, Pierre *et al.* 2010). Therefore, one of the starting points and fundamental requirements to effectively implement EBFM is the delineation of spatial units or ecologically meaningful regions, i.e. ecoregions (Staples *et al.* 2014, Fletcher *et al.* 2010). Ecoregions are generally geographically defined areas exhibiting relative homogeneous ecosystems, and are designed to be units of analysis to support ecosystem planning, incentivized ecosystem research and integrated ecosystem assessments, and decision-making for the integrated management of natural resources (Ormernik and Bailey 1997, Ormernik 2004).

ICCAT has committed to operationalize EBFM in accordance with internationally agreed standards. Regionalization of the ICCAT convention area into areas that are ecologically meaningful, yet large enough to be practical, could provide a foundation for developing a wide range of integrated scientific and advice products. These may include the production of integrated ecosystem assessments, ecosystem risk assessments, and large-scale ecological modeling, among others, to assist in the production of more integrated ecosystem-based advice to the Commission (Zador *et al.* 2016; Koen-Alonso *et al.* 2019, Rice *et al.* 2011b). Yet, it is not clear at what spatial and regional scales integrated research and advice products would be potentially useful to guide EBFM operationalization in the context of ICCAT species and fisheries.

In 2017, an EU funded project conducted some initial work towards a broad-scale delineation of the Atlantic and Indian Oceans into ecologically meaningful regions. These ecological regions aimed to be large enough to be practical to provide ecosystem-based advice to inform fisheries management in the context of tuna and billfish fisheries (Juan-Jordá *et al.* 2019). This project developed and tested an evaluation criterion to identify regions, mainly based on: (1) the existing knowledge of biogeographic classifications of the pelagic environment, (2) the spatial distributions of major tuna and billfish species, and (3) the spatial dynamics of the main fishing fleets targeting these species. Based on these criteria, seven preliminary candidate ecoregions were proposed within the ICCAT convention area (Todorovic *et al.* 2019), and two preliminary candidate ecoregions were proposed in the IOTC convention area (Juan-Jordá *et al.* 2019) (**Figure 1**).

In 2018, this initial work was presented at the ICCAT Subcommittee on Ecosystems (SC-ECO) and the IOTC Working Party on Ecosystems and Bycatch (WPEB), as a conceptual scientific exercise to discuss its potential

[4] The term Ecosystem Approach to Fisheries Management (EAFM) and Ecosystem-based Fisheries Management (EBFM) is used interchangeably in this document. The SubCommittee on Ecosystems used the term EBFM while the ICCAT ammended Commission mandate uses the term EAFM.

utility and to explore avenues for future work. In IOTC, the WPEB recommended convening a workshop 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-WPEB14). This IOTC workshop took place in September 2019 with the participation of CPC national scientists and external experts. The most important output of this workshop was the constructive and technical discussions that took place in framing the general process of ecoregion delineation, from defining a checklist evaluation criteria to guide the classification, to evaluating data inputs and methods to derive the classification, and examining and refining candidate ecoregions based on expert knowledge within the Indian Ocean. This process resulted in a draft proposal of seven ecoregions within the IOTC convention area (Nieblas *et al*. 2019, Juan-Jorda *et al* 2019b). In 2019, the WPEB recommended a second IOTC Ecoregion workshop to refine the entire process based on the expert advice and feedback received in the first IOTC ecoregion workshop (IOTC-WPEB15). The second IOTC Ecoregion Workshop took place in January 2022 (19th-21st) resulting in a refined process for guiding the delineation of ecoregions and a refined proposal of ecoregions for the IOTC convention area (workshop report in preparation).

In 2020, the process used to delineate candidate ecoregions in the IOTC convention area was presented to the SC-ECO. From this experience, the SC-ECO recommended convening a workshop in 2021 to advance in the identification of draft ecoregions and foster discussions on their potential use to facilitate the implementation and operationalization of EBFM within ICCAT.

2. Main objective, tasks addressed and expected outputs of workshops

The current work has been performed in preparation for the first ICCAT ecoregions workshop, "Identification of regions in the ICCAT convention area for supporting the implementation of the ecosystem based fisheries management", to be held online from March 15 to 17th, 2022.

The overall aim of this workshop is to advance in the identification of ecologically meaningful regions that can serve as a basis to produce more integrated ecosystem-based advice, and thereby support the implementation and operationalization of EBFM in ICCAT.

This work specifically addresses the Terms of References agreed on during the 2021 SC-ECO meeting (Juan-Jordá *et al*. 2021) which included the following tasks:

Task 1. Review several world case studies (e.g. NAFO, ICES, CCAMLR, USA, Australia) in order to understand how pelagic regionalizations have supported the implementation of EBFM in other organizations and countries.

Task 2. Review the current reporting structure of ICCAT data and stock boundaries and discuss potential constraints on using ecoregions to structure ecosystem-based advice.

Task 3. Discuss and develop a checklist of evaluation criteria which identifies the factors to be considered when defining ecoregions in the ICCAT convention area.

Task 4. Review existing biogeographic classifications in the Atlantic Ocean, which are often used to inform the delineation of ecoregion boundaries, and discuss their relevance in the context of ICCAT species and its fisheries.

Task 5. Review existing data sets in terms of availability, quality and completeness to guide the choice of key data inputs for deriving the draft ecoregions. The data sets revised will include (i) existing biogeographic classifications, (ii) spatial distribution and catches of ICCAT species (e.g., oceanic tunas, billfishes, sharks, neritic species, other bycatch species), (iii) spatial distributions of ICCAT fisheries (e.g., baitboats, longlines, gillnets, purse seines) and (iv) other potentially relevant data layers.

Task 6. Develop a baseline ecoregion proposal analyzing selected datasets using spatial analysis that will be adjusted with expert knowledge. The spatial analysis will include examining the spatial patterns of species compositions and fishing fleets dynamics across multiple biogeographic provinces, and clustering analyses to group biogeographic provinces according to their similarity in terms of species composition and fisheries composition. The use of quantitative approaches that link different data layers describing the ecosystems including fisheries, coupled with expert advice are often used to ecoregion delineation.

Task 7. Test and validate the usefulness of the candidate ecoregions with respect to monitoring large scale changes in the ecosystem.

The current work has also been planned and performed to support the expected outputs of this workshop:

- A better understanding of the role and purpose of ecoregions as tools to support EBFM implementation
- A set of criteria including the major factors to be considered to guide the development of draft ecoregions.
- An understanding of the data layers and methods used for deriving the ecoregions with their strengths and weaknesses.
- A proposal for candidate draft ecoregions.

3. Report structure

This report is structured following the main Tasks included in the TORs of this workshop. For each Task, we briefly describe the actions taken in preparation for this workshop, which will be presented to the Group during the 3 days workshop for open discussion and feedback with the objective of refining the process of ecoregion delineation in ICCAT.

The delineation of ecoregions requires the implementation of multiple steps, each of them supported by multiple activities and decisions along the way (Loveland and Merchant 2004, Mackey *et al*. 2008). These range from defining the purpose of ecoregions *a priori*, to choosing what criteria, data and analytical methods will be used to derive a sensible proposal of ecoregions fit for purpose, and validating the ecoregions, among others. Therefore, we think it is important to have a clear and well-structured framework to guide the process of ecoregion delineation to increase understanding and replicability of the process and make this process iterative. Below, we present the framework used to guide the delineation of ecoregions in this work, which can be summarized in six main steps, with the objective of increasing clarity, transparency, and ultimately to make the process iterative and replicable (**Figure 2**).

This framework can be summarized in six major steps and it follows a stepwise process, with several feedback loops aiming to incorporate lessons learned and new knowledge gained along the way and learning-by-doing. Each step is briefly summarized below, and we also relate each of the Tasks addressed in this report to this framework throughout the document to increase clarity.

1. Purpose and uses of ecoregions

- It is imperative that the main purpose and potential uses of the ecoregions are discussed and defined *a priori*, since ecoregions should be designed to **serve specific purposes** and satisfy specific user requirements. Many of the decisions in the process depend on the ultimate use of ecoregions (Loveland and Merchant 2004, Mackey *et al*. 2008). Furthemore, the intended use and applicability of the ecoregions must guide the identification of their expected qualities and the approach taken to delineate them.
- It is also important to revise the existing spatial frameworks already used for different purposes (e.g. data collection and reporting, stock boundaries to inform single species assessments, ecosystem boundaries to inform ecosystem modeling, etc..) to identify any potential constraints on using ecoregions to structure ecosystem-based advice.

2) Criteria to guide regionalization

- In any regionalization exercise, a **set of criteria** also needs to be discussed and established *a priori* to define the **main thematic factors** (e.g. oceanography, biogeography, taxonomy, fisheries, socio-economics, etc..) guiding and informing the analysis for the delineation of ecoregions (ICES 2021).

3) Data compilation and its quality evaluation

- The **data compilation and data requirements** to address and characterize each thematic factor established in the criteria (step 2) also need to 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 datasets used to inform the delineation of ecoregion boundaries also need to be carefully evaluated for their **quality, completeness, and availability**.

4) Analytical model

- There is a **wide range of quantitative and qualitative approaches** to carry out classification analysis to inform ecoregion delineations. 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 (Loveland and Merchant 2004, Mackey *et al.* 2008).
- 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** are also commonly performed to determine the influence of different data layers and parameters informing the ecoregion delineation (Mackey *et al.* 2008).

5) Interpreting results and deriving proposal of ecoregions

- The different classification analyses provide preliminary candidate ecoregions (referred here as baseline ecoregions), which need to be carefully revised. Revision may include the evaluation of the strength and weaknesses of the datasets used to drive the classification analysis, and the strengths and weaknesses of the analytical methods used.
- It is also a common practice to analyze the resulting candidate ecoregions to determine the **heterogeneity between** and the **homogeneity within** the resulting classification groups, so their regional structure can be objectively evaluated (Bailey 1983).
- If a hybrid approach is chosen for the classification exercise, the candidate ecoregions derived from the quantitative analysis need to be mapped, refined and adjusted with expert knowledge, in order to produce a revised **proposal of ecoregions.**
- **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

- The ecoregions derived from the steps above should be considered as **working hypotheses to be tested and validated** (Bailey 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). Therefore, 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).

We mapped each of the Tasks addressed in this report on the framework used to guide the process of ecoregion delineations to increase clarity and encourage a participatory and iterative process (**Figure 2**).

4. Task 1. Potential role of ecoregions in ICCAT and experiences from other fisheries organizations using ecoregions to structure ecosystem-based advice

An increasing number of national (e.g. EU, Canada, USA, Australia) and international fisheries organizations (e.g. ICES, NAFO, CCAMLR) are implementing the EAFM in their convention areas. Many of these organizations have successfully derived and are using spatially-explicit units (ecoregions) to guide ecosystem planning, research and assessments, ultimately to structure their ecosystem-based advice to inform fisheries management decisions (Zador *et al*. 2016, Koen-Alonso *et al*. 2019, Pierre *et al*. 2013, ICES, 2021b).

This task has two objectives: (1) bringing experts from other fisheries organizations to share with us their experiences developing and using ecoregions as an additional tool to provide more integrated and ecosystem based-advice to their respective end-users, and (2) discuss the potential role and uses of ecoregions as tools to guide EAFM implementation in ICCAT.

We have invited several experts (Dr. Stephani Zador, Dr. Pierre Pepin and Dr. Mark Dickey-Collas) to share with us their experiences in how ecoregions have been derived and are currently used as an complementary tool to inform and support EBFM implementation in the North Atlantic Fisheries Management Organization (NAFO), the International Council for the Exploration of the Sea (ICES) and the North Pacific Fisheries Management Council in Alaska, USA.

Below we also provide **a list of potential uses of ecoregions as tools** to guide EAFM implementation (Rice *et al* 2011) to be discussed at the workshop in the context of ICCAT species and fisheries. These are:

- **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, additional data collection (e.g. stomach contents for trophic analyses) 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 advice) 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.

5. Task 2. Review the current reporting structure of ICCAT data and stock boundaries and potential constraints of using ecoregions to structure ecosystem-based advice

The use of ecoregions as tools to facilitate the development of the knowledge base, information and advice products to produce more integrated advice **seeks to complement the current activities and advice** produced by the SCRS to the Commission. Yet, it is worth examining if this additional tool for facilitating integrated research and advice would impact (and how) the current activities of Contracting Parties and Cooperating non-Contracting Parties regarding the collection and submission of fisheries data statistics, and the activities and advice produced by the SCRS to the Commission. Therefore, this task has the objective of reviewing the current reporting structure of ICCAT data and stock boundaries, and examine any potential constraints and impacts derived from using ecoregions as tools to facilitate the development of integrated products and advise.

Below, we show the ICCAT Sampling Areas and Stock/Statistical areas used for the submission of fisheries statistics (**Figure 3**) and also show the organogram of ICCAT (**Figure 4a**) illustrating the Commission structure. We have also prepared a simple illustration showing how research and advice for single species/stocks and bycatch and ecosystems impacts is currently prepared and presented by the SCRS to the Commission, and how we envision ecoregions might facilitate the production of more integrated research and advise products (**Figure 4b**). In our view, the use of ecoregions to steer more integrated advice at a more regional scale does not change the way fishery statistics are being collected and reported by Member States and it does not change the current practices and activities of the SCRS in providing single species/stock advice to the Commission. Instead, we view the ecoregions as an additional and complementary tool seeking to strengthen the provision of integrated scientific advice of the SC-ECO and SCRS to the Commission. At the workshop we plan to have a group discussion on how ecoregions might impact current practices in ICCAT and/or how they may strengthen them.

6. Task 3. Preliminary criteria to guide ecoregion delineation and expected qualities of ecoregions

In practice the derivation of pelagic ecoregions requires the classification or regionalization of the pelagic ocean into a number of regions to reduce complexity to a manageable and understandable number of units. Therefore, any regionalization exercise requires discussion to set *a priori* the **main criteria** for guiding and informing the analysis for the delineation of ecoregions, as well as the **expected qualities** of the ecoregions derived (ICES 2021, UNESCO, 2009). It is also important to set *a priori* the **main properties** of ecoregions (e.g. whether their boundaries will be static or not, whether a hierarchical classification would be allowed, etc..) which also drive the decisions in the process (UNESCO, 2009). Therefore, this task has two main objectives: first, we present a preliminary criteria, where we define the main thematic factors that are used to guide the delineation of ecoregions presented in this report together with their expected qualities, and second we list the main properties of ecoregions which we took into account to guide all the steps in the delineation process.

In **Table 1**, we present the main criteria which includes the three main thematic factors used for guiding the ecoregion classification presented in this report, and we also establish the expected qualities of the ecoregions based on the chosen criteria. The first thematic factor seeking to inform the delineation of ecoregions is the oceanography and biogeography of the pelagic waters in the Atlantic Ocean. Oceanographic processes and environmental conditions are often used to inform ecologically relevant boundaries as they regulate ocean productivity and are critical to understanding species distributions, community composition and ultimately ecosystem dynamics (Longhurst 2007, Spalding *et al* 2021). The second thematic factor seeks to use the spatial patterns in the distribution of ICCAT species (oceanic tuna and billfish species, neritic species) and the ecological communities they form to contribute to the delineations of ecoregions. While tuna and billfishes are widely distributed over the global ocean, there are a number of studies that have consistently revealed differences in the spatial distribution of these highly migratory species over large environmental gradients at the basin scale (Fonteneau, 1998, Worm *et al* 2005, Reygondeau *et al* 2012). Note the distribution of bycatch species and vulnerable species (e.g. sea turtles, seabirds, some sharks) were intentionally not used to inform and guide the delineation of ecoregions. Bycatch species are seen 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 integrated assessments of bycatch (see potential uses of ecoregions under Task 1). The last thematic factor seeks to use the spatial patterns of the main ICCAT fisheries and their fishing grounds to also contribute to the delineation of ecoregions. Having an understanding of the spatial patterns of fisheries/fleets (who is fishing, what is being caught and where, and the fishing methods being used) is important to link research, assessment and monitoring of fishing impacts to effectively provide integrated advice (e.g. mixed fisheries scenarios, cumulative impacts of fisheries) and support the integrated management of fisheries (Uriarte *et al* 2014). Linking major oceanographic and biogeographic patterns, together with the patterns of ecological communities of tunas and billfishes and the main fisheries targeting them can offer insight into the ordering of complex ecosystems and their dynamics, which are relevant to both natural resource management and conservation.

We recognize spatial heterogeneity in marine systems. Therefore, we anticipate that deriving ecoregions with the set of expectations established under each thematic factor will need some level of compromise since no one ecoregion will be able to me*et al*l the expectations in Table 1 (Loveland and Merchant 2004). After all, 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.

Based on the outlined criteria (**Table 1**), for the purposes of this study, we define an ecoregion as an ecologically and geographically defined area (spatial unit) characterized by distinct oceanographic/environmental conditions, biological communities of tuna and tuna-like species, and fisheries/fleets targeting them. We expect the ecoregion to capture general spatial patterns of relatively homogeneous ecosystems at specific scales (Bryce *et al*. 1999).

Furthermore, the intended use and applicability of the ecoregions (summarized in Task 1) are a guide to 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. Below we summarize a list of **properties of ecoregions** which are taken into account to guide all the steps in the delineation of ecoregions. These are:

- Ecoregion boundaries should be considered **static** for use as a practical tool for resource assessment and management. However, it is 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 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 should be relatively **few in number** to make them a practical tool to inform EBFM 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 should be **geographically distinct** to guide EBFM implementation. Ecoregions with similar characteristics, but in geographically diverse areas should be treated separately.

7. Task 4. A review of existing biogeographic classifications in the Atlantic Ocean and their relevance in the context of ICCAT species and its fisheries.

According to the Criteria, the ecoregions should be characterized by distinct environmental and oceanographic conditions and their boundaries should appropriately demarcate areas with a clear oceanographic and biogeographic justification. Furthermore, biogeographic classifications are increasingly gaining importance in the fisheries policy sector since, commonly, the first step of any policy implementation requires setting appropriate spatial scales and identifying representative areas for management (Rice *et al.* 2011). Biogeographic classifications can guide and facilitate the identification of meaningful ecoregions. Therefore, this task has the objective of reviewing existing marine pelagic biogeographic classifications relevant for the Atlantic Ocean and examining their relevance in the context of ICCAT species and fisheries. Based on this review, we will select those biogeographic classifications that we deem most relevant to use as the oceanography and biogeography data layer (thematic factor 1) for subsequent spatial analysis towards deriving candidate ecoregions under Task 6.

We reviewed eight biogeographic classifications including, Large Marine Ecosystems (LMEs), Longhurst Biogeochemical Provinces (Longhurst), Dynamic Longhurst Biogeochemical Provinces (Dynamic Longhurst), Marine Ecosystems of the World (MEOW), Pelagic Provinces of the World (PPOW), Biogeography of Tuna and Billfish Communities (BTBC), Global Open-Ocean Biomes (GOOB), and Near Surface Global Marine Ecosystems (NSGME) (**Table 2**). We briefly describe each of them and highlight the criteria and methodology used for their delineation, type of data considered, main characteristics (coastal vs oceanic, type of marine environment classified, static vs dynamic boundaries) and resulting classification system.

Task 4.1 Large Marine Ecosystems (LMEs)

The Large Marine Ecosystem Classification (**Figure 5**) was proposed as an ecosystem oriented management regime (Sherman 1986, 1991). It aimed to delineate all the coastal areas into regions of appropriate scale to be practical for policy development, management, and monitoring of fishery resources due to growing anthropogenic pressures in the marine realm. The LME regions are based on a set of oceanographic features including bathymetry and hydrography, and a set of community features including productivity and trophic relationships, as well as ecosystem health indices, which are then revised through extensive expert consultations (Sherman, 1994). They also have a strong socioeconomic component and a strong management context to facilitate transboundary and ecosystem-based management which makes it helpful for stakeholders. The LMEs are based on extensive research and analyses, which resulted in the classification of 66 regions (**Figure 5**). The LME delineation is a continuously evolving process, which has tried to combine oceanographic and biological analysis with geopolitical features. Within the boundaries of LMEs 90% of the world's fisheries productivity occurs, as well as the majority of ocean pollution, exploitation, and habitat alteration (Watson *et al* 2003). Therefore, LMEs are viewed as appropriate EAFM management units for many marine activities and fisheries; however some authors note that they are neither large enough nor pelagic enough to be useful for highly migratory fish stocks (Sibert 2005).

There are ~21 LMEs within the ICCAT convention area (**Figure 5**).

Task 4.2 Longhurst Biogeochemical Provinces

The Longhurst's classification system into biogeochemical provinces provides ecologists with a thorough manual on regional oceanography to facilitate study of ocean ecosystems on a quantitative level (Longhurst, 2007). This classification uses available physical and biological oceanographic datasets in order to make it more measurable and replicable. The physical oceanographic data used reflect the discontinuities in physical processes in the ocean, like nutricline depth, mixing, fronts, which delineated the main biomes in the classification - Polar, Westerlies, Trades and Coastal biomes (**Figure 6**). The biological datasets analyzed include phytoplankton distribution and concentration, and primary productivity which were used to further partition the biomes into 57 provinces, out of which 22 are coastal (**Figure 6**). Other parameters such as mixed-layer depth and photic depth, were also used to further partition the biomes. Longhurst 2007 noted that the boundaries of the biomes and provinces vary seasonally and inter- annually, and that shifting boundaries are impractical for management, therefore, the boundaries were deliberately fixed in space. While Longhurst provinces extend to the coastal regions, some authors note that the provinces have not been sufficiently subdivided near the coast (Watson *et al* 2003).

There are four biomes and ~26 Longhurst provinces within the ICCAT convention area (**Figure 6**).

Task 4.3 Dynamic Longhurst biogeochemical provinces

Reygondeau *et al* (2013) explored the seasonal and interannual variability of Longhurst biogeochemical provinces (**Figure 7**). Employing a non-parametric probabilistic ecological niche model, they reclassified the global ocean with updated data (based on four environmental variables) and dynamic borders. They found that while static classifications schemes should take into account seasonal and interannual variability, this is often not the case, and large shifts of the boundaries occur. They found seasonally poleward displacements of up to 18° for subtropical provinces, and longitudinal shifts of up to 27°.

Task 4.4 Marine Ecosystems of the World (MEOW)

The marine ecoregions of the world (MEOW) were created with the main purpose of reconciling the differences between the existing coastal classifications and in order to provide a more global, comprehensive classification of the coastal areas (Spalding *et al.* 2007). It aims to provide a system that is appropriate for management of resources, conservation planning and other actions, allowing multiscale analyses, while respecting the natural boundaries. This classification is largely based on reviews and synthesis of existing biogeographic boundaries based on various taxonomic and oceanographic data inputs, which were chosen in the first data-gathering phase, then finally selected based on data availability. A large expert group also provided further insights and exchanged opinions to inform the final biogeographic boundaries. This classification is therefore not simply the result of modeling different relevant physical and biological datasets, but of a more comprehensive process that uses expert knowledge to finalize the classification (Spalding *et al.* 2007). The resulting classification is nested hierarchically, consisting of 12 realms, 58 provinces and 232 ecoregions (**Figure 8**). The outer boundary for the system was set at the 200m isobath. MEOW ecoregions are the smallest scale of the classification scheme and include relatively homogeneous compositions of both benthic and neritic species and distinct oceanographic and topographic features.

The ICCAT convention area includes six MEOW realms and ~21 coastal provinces (**Figure 8**).

Task 4.5 Pelagic Provinces of the World (PPOW)

Spalding and colleagues developed a classification covering the pelagic regions of the open ocean (up to 200m depth) that builds up on MEOW in 2012 (Spalding *et al.* 2012). Similar to MEOW, PPOW is a hierarchical classification scheme based on existing biogeographical information and expert knowledge of pelagic biota. In hierarchical order, this scheme includes 37 pelagic provinces which are broadly grouped into 4 realms (Northern Coldwater, Indo-Pacific Warm water, Atlantic Warm water and Southern Coldwater) or into 7 major biomes (polar, gyre, eastern boundary currents, western boundary currents, equatorial, transitional and semi-enclosed seas) (**Figure 9**). Spalding *et al* (2012) note that species distribution data, especially in the global pelagic zone is patchy and biased, and a quantitative approach would lead to false confidence in the resulting recommendations. Therefore, for the PPOW classification they followed a qualitative approach, employing expert knowledge to inform the delineation of boundaries. PPOW provinces, the smallest scale of the PPOW scheme, are large areas of epipelagic ocean that are based on large-scale, spatio-temporally-stable (i.e. seasonally recurrent) oceanographic processes. PPOW provinces comprise relatively homogeneous compositions of pelagic species and large-scale oceanographic features, such as ocean gyres, equatorial upwelling, basin-edge upwelling, semi-enclosed pelagic zones, and large- scale transition zones.

The ICCAT convention area contains three PPOW realms, seven biomes, and 16 provinces (**Figure 9**).

Task 4.6 Tuna Biogeographical Provinces

Reygondeau *et al*. 2012 divided the oceanic biosphere into nine global provinces of tuna biogeography (TBP) based on tuna and billfish spatial patterns of catch per unit effort of major fishing fleets (the Japanese and Korean longline fleets) (**Figure 10**). These provinces were delineated using a quantitative statistical model that incorporated the distribution of the major species. Furthermore, it described the physical environment for each province, and compared the identified provinces with Longhurst provinces. It demonstrated that despite the highly migratory nature of tuna and billfish species, these species have a clear spatial partitioning into well-defined communities (Reygondeau *et al* 2012). The provinces were characterized by either single or multiple species dominance, or diversified communities where there were no dominant species.

The ICCAT convention area includes 13 provinces with distinct tuna and billfish communities (**Figure 10**).

While this study used the CPUE of major commercial species caught by Japanese and Korean longline fleets as a proxy to infer fish abundances and inform the global provinces of tuna biogeography, it should be noted that the CPUE of longlines excludes some commercial species important in the ICCAT convention area, such as skipjack, which are not captured by longline due to low catchability, and neritic species, which are not targeted by industrial longlines. Restricting the analysis to CPUEs of a few selective gears may lead to a poor representation of tuna and billfish communities.

Task 4.7 Global open-ocean biomes

Fay and McKinley *et al* 2014 iIdentified regions with common biogeochemical functions at the largest possible scale in order to support oceanic biogeochemical studies (**Figure 11**). This study defined 17 open-ocean biomes classified from four observational data sets: sea surface temperature (SST), spring/summer chlorophyll a concentrations (Chl-a), ice fraction, and maximum mixed layer depth (maxMLD). Dynamic ocean biome boundaries were mapped by considering the interannual variability of each data layer between 1998 and 2010. A core biome map was also mapped which only included the grid cells that remained stable across the 13 years analyzed.

The ICCAT convention area includes 9 open ocean biomes (**Figure 11**).

Task 4.8 Near surface global marine ecosystems

Zhao *et al* 2019 classified the pelagic waters of the world's ocean into relatively enduring regions demarcated by environmental characteristics to assist conservation planning, research and management. This study defined seven-clusters of marine epipelagic ecosystems based on a statistical classification and mapping of 20 ocean physical and biological variables (**Figure 12**). The seven marine ecosystems are characterized by enduring environmental characteristics.

The ICCAT convention area includes ~10 cluster-regions including oceanic and coastal areas, although the entire inshore areas are considered one unit cluster (**Figure 12**).

Task 4.9 Relevance in the context of ICCAT species and its fisheries

Some of the biogeographic classification revised are only coastal (LME, MEOW), others oceanic covering some coastal regions (PPOW and GOOB), others cover both coastal and oceanic pelagic waters (Longhurst, Dynamic Lonhurst, BTBC, NSGME) (**Table 2**). The LMEs and MEOW classifications are coastal classifications, and therefore, they have limited direct application by themselves in identifying potential ecoregions for ICCAT species and fisheries, which are widely distributed in coastal and oceanic areas. The Longhurst classifies both the coastal and oceanic environment making it relevant for ICCAT species, both oceanic tunas and billfishes as well as the coastal species, and ICCAT fisheries (industrial and artisanal). The PPOW also classifies the oceanic environment and some parts of the coastal environment leaving out some coastal shelf areas (which are classified under the MEOW classification developed by the same author). The Longhurst and the PPOW classifications are qualitative classifications, and both have a strong basis on the regional oceanography, which is an important factor in determining species distributions as well as informing the delineation of ecosystem-resembling regions with distinct biophysical characteristics. One of the drawbacks of the Longhurst classification system is that it is focused mainly on a set of abiotic properties of the water columns, and it is not based on species and community-based data, except from phytoplankton concentration. The PPOW classification is based on both oceanographic attributes and the patterns of species distributions, which makes it more comprehensive. The PPOW is also based on a detailed review of existing biogeographic classifications for the open ocean, including the Longhurst classification, and it uses expert knowledge to reconcile the differences between existing politically and ecologically oriented regional classifications, such as those from some Regional Fisheries Management Organizations and the UNEP Regional Seas. This also makes the PPOW classification more comprehensive. The Longhurst and the PPOW classifications derived and mapped static boundaries acknowledging the seasonal and inter- annual variability of the boundaries (**Table 2**).

The most recent biogeographic classification of Zhao *et al* 2019 is based on the most comprehensive quantitative analysis of 20 environmental variables covering both the biological and physical characteristics of the pelagic environment. While this NSGME classification resulted in seven distinct marine ecosystems globally, these are spatially disaggregated into multiple large and small disjointed regions within the Atlantic Ocean, resulting in impractical management units. Yet, it shows large oceanic homogenous areas with relatively enduring environmental characteristics which agree to a large extent with the PPOW and Longhurst classifications and therefore, this classification can also be used for informing and guiding decisions when delineating ecoregions in ICCAT.

There are also two classifications that explore the seasonal and interannual variability of the pelagic environment when identifying and mapping pelagic regions (Dynamic Lonhurst and GOOB) (**Table 2**). While all the biogeographic classifications acknowledge the dynamic nature of the marine environment and the importance of understanding the extent of the spatial and temporal variability of the boundaries, they also note the practical application of dynamic boundaries for natural resource management is complicated. Yet, these dynamic classifications are very useful to understand the extent of the core (more stable) and periphery (more dynamic) of the ecoregions, and therefore they can also be used for informing and guiding decisions when delineating ecoregions in ICCAT

The tuna and billfish biogeography based on the global distributions of tuna and billfish species was reviewed in part because it demonstrates that tuna and billfish species have a clear spatial partitioning into well-defined communities despite their wide distributions and highly migratory behavior (Reygondeau *et al* 2012). Yet compared to all the other classification reviewed, it is not a biogeographic classification of the pelagic environment based on the biological and physical characteristics of the water column which ultimately drive the patterns in species distributions.

After examining all the biogeographical classifications, we believe both coastal classification and oceanic classification are crucial to represent the full range of oceanographic conditions of species under the ICCAT convention (including neritic and oceanic species). Though the LME and MEOW biogeographic classification incorporate coastal features important to neritic species distribution, we decided not to further investigate them as 1) they do not include pelagic oceanic provinces important to the major ICCAT species, and 2) in the case of the LMEs these do not sufficiently represent the important oceanic islands (e.g., the Azores, Canary Islands). We think the Longhurst BGCP and PPOW could be the most useful to guide the development of ecoregions in ICCAT since they are static and cover both oceanic and coastal areas (the PPOW includes oceanic areas up to the continental shelf in some regions). Yet we acknowledge all classifications reviewed provide background knowledge for understanding major oceanographic processes in the Atlantic Ocean and for understanding also the extent of the spatial and temporal variability of these processes and boundaries.

8. Task 5. A review of existing data sets to guide the choice of key data inputs for deriving the draft ecoregions.

This task has the objective of reviewing existing datasets and choosing those key data layers best characterizing each of the main thematic factors included in the criteria (**Table 1**) for guiding the delineation of ecoregions.

Here we present an overview of the different data layers explored. We reviewed (i) existing biogeographic classifications to capture the regional oceanography of the Atlantic Ocean, (ii) the spatial distribution of catches for ICCAT species to identify the core distributions and co-occurrence of species assemblages, and (iii) the spatial distribution of catches to identify the core fishing grounds of major ICCAT fisheries. All data layers were evaluated for their inclusion into the spatial analysis (Task 6) based on their availability, quality and completeness (**Table 3**). We note that not all data reviewed here passed the evaluation and we expect missing or inadequate data layers to be further informed by expert contributions at the workshop.

Task 5.1 Thematic factor - Regional oceanography and biogeography of the Atlantic Ocean

To infer the major oceanographic patterns and environmental drivers experienced by the species under the ICCAT convention, we took advantage of existing knowledge and reviewed the existing biogeographic classifications of the Atlantic Ocean to see if any could be used as the basis for informing the spatial analysis as the oceanographic data layer in Task 6 of this report. Thus, we reviewed eight biogeographic classifications of the Atlantic Ocean in the previous Task 4 of this report and their relevance for ICCAT species and fisheries. We find that the Longhurst BGCP (**Figure 6**) and PPOW (**Figure 9**) classifications are the most useful to guide the development of ecoregions in ICCAT since they are static and cover both oceanic and coastal areas (the PPOW includes oceanic areas up to the continental shelf in some regions), and capture well the regional oceanography in the Atlantic Ocean. Therefore, we retained both for further analysis in Task 6.

Task 5.2 Thematic factor - Spatial distribution of ICCAT species

This thematic factor uses the spatial distribution of catches to identify the core distributions of ICCAT species and co-occurrence of species assemblages to inform the delineation of ecoregions (see Criteria **Table 1**). To infer the spatial distribution of the major ICCAT species (**Table 4**), we used the median annual catch of the public ICCAT Task 2 5°x5° georeferenced raised catch data (CATDIS(all)) over the last 15 years (2006-2020), regridded to the 5°x5° CWP grid (https://www.fao.org/fishery/geonetwork/srv/eng/catalog.search#/metadata/cwp-grid-map-5deg_x_5deg) (Table 3). This dataset includes the most important species in terms of catches and economic value covered by the convention, i.e. albacore tuna *Thunnus alalunga* (ALB), bigeye tuna *Thunnus obesus (BET),* white marlin *Tetrapturus albidus* (WHM), Atlantic bluefin tuna *Thunnus thynnus (BFT),* blue marlin *Makaira nigricans* (BUM), skipjack tuna *Katsuwonus pelamis* (SKJ), Atlantic sailfish *Istiophorus albicans (SAI),* swordfish *Xiphias gladius* (SWO), and yellowfin tuna *Thunnus albacares* (YFT) (**Table 4**).

The CATDIS raised catch dataset does not cover neritic tunas, Spanish mackerels, or bonitos, among other species (see complete list in **Table 4**), which are species also covered in the ICCAT mandate and may support important coastal fisheries throughout their distribution. Therefore, to infer the distribution of neritic tunas, bonitos and Spanish mackerel species, we used Task 2 catch and effort data (T2CE; https://www.iccat.int/Data/t2ce_20220131.7z) (**Table 3**). We also used the T2CE dataset to infer the spatial distributions of targeted sharks (e.g. blue shark). On the database README, ICCAT notes several issues with this dataset, which should be used with caution and guided by experts. For example, the species catch coverage ranges from 5% to 100% of the nominal catch, the time and area stratification are heterogeneous; and there are issues with misreporting of catch species composition. To account for issues of heterogeneity in time/area stratification, we use the median annual catch over the last 15 years (2006-2020) regridded to the 5°x5° CWP grid. In the T2CE database, there are a large number of species with low quantities of catch reported. These are grouped as: − "oSmt": other small tuna; − "oTun": other tuna; − "oSks": other sharks and are not included in this analysis.

To address potentially erroneous reporting in both datasets, all catches of tropical tuna (SKJ, YFT, BET) captured below 45°S and above 60°N were removed.

Southern bluefin tuna *Thunnus maccoyii* (SBT) was not included in the analysis as this species is managed by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). The CCSBT has no geographically definitive convention area, and its management applies wherever SBT are found. The distribution of SBT highly overlaps with the southern edge of the ICCAT convention area (**Figure 13**). We note that the overlap of this convention area with the ICCAT convention area indicates interactions between the SBT fishery and other ICCAT species and fisheries.

Catch data were used instead of catch per unit effort to infer species distributions as this analysis aims to include as many species as possible caught from diverse ICCAT fisheries and 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. We note that these data are fisheries dependent, and thus may not be the ideal for inferring species distributions (Reygondeau *et al* 2012). However, as fisheries-independent data are few, we believe that catch data can be useful in inferring patterns of species distributions and co-occurrence of species to inform ecoregion delineation.

5.2.1 Oceanic species of tunas and billfishes

The majority of the raised catch of the major ICCAT oceanic species are in the central Atlantic Ocean basin (**Figure 14A**). Other regions of high catch include the Mediterranean Sea and the coastal areas off Brazil (**Figure 14A**). We find that in general, the tropical species YFT, BET and SKJ are primarily caught in a latitudinal band around the equator extending from the west coast of Africa to the Caribbean Sea (**Figure 14B**). Swordfish catches predominate transitional zones in the north and south Atlantic and in the Mediterranean Sea, and ALB is primarily caught in the north and south temperate bands and also the Mediterranean Sea. BFT is caught in the northern Atlantic and the Mediterranean (**Figure 14B**). The SAI, BUM and WHM are widely distributed in the tropical and subtropical regions and are primarily caught in coastal areas off western Africa and northeast of South America.

Examining the spatial distribution of the catches of each major oceanic species individually and by gear (**Figure 15A-I**), we find that ALB are caught mostly by longlines in the southern and western Atlantic and the Mediterranean, by baitboat in the northeastern Atlantic and in the Benguela Current system, by trolling in the northwestern Atlantic, and to some degree by purse seine in the equatorial Atlantic (**Figure 15A**). We find that BET are mostly caught in the equatorial Atlantic by longlines and purse seines. BET is also caught in relatively large quantities by baitboat off Morocco (**Figure 15B**). BFT is caught across the northern Atlantic basin and in the Mediterranean. In the Atlantic, they are caught by a variety of gears, though mostly longline. Traps are used at the mouth of the Mediterranean, and they are caught almost exclusively by purse seine in the Mediterranean (**Figure 15C**). BUM are bycatch of longlines caught throughout the tropical and subtropical ICCAT convention area, though most catches are in the equatorial region, and it is also caught and targeted in the eastern and western tropical coastal areas by more coastal gears (gillnets, rod and reel) (**Figure 15D**). Similarly, SAI in the greater Atlantic are mostly bycatch of the longline fishery; however, they are targeted in coastal regions, especially along the west African coast by the gillnet fishery (**Figure 15E**). SKJ are caught in large quantities in the equatorial Atlantic by the purse seine fishery. They are also caught off southern Brazil and Uruguay and northern Morocco by baitboats. Some catches of SKJ outside these zones are reported by the longline fishery (**Figure 15F**). SWO are subtropical species caught widely throughout the ICCAT convention area, particularly by the longline fishery. SWO is caught in especially high amounts in the Mediterranean Sea (**Figure 15G**). WHM is a subtropical marlin species bycaught in small quantities throughout the Atlantic mostly by the longline fishery (**Figure 15H**). YFT have high catches relative to other ICCAT species, and are primarily caught in the eastern equatorial Atlantic by the purse seine fishery. They also have relatively high catches in the western part of this region by the longline fishery, which is also responsible for most of the rest of the catch throughout the ICCAT convention area. YFT are also caught in coastal areas off southern Brazil, Uruguay, Morocco and Venezuela and South Africa by baitboats (**Figure 15I**).

We find the georeferenced raised catch data for the nine oceanic tuna and billfish species “good” in terms availability, quality and completeness (**Table 3**), and they **will be retained to represent the spatial distributions and abundance of this species in later analysis.**

5.2.2 Neritic species of tunas, bonitos and Spanish mackerels

Small tuna are mostly reported in the Mediterranean Sea and the tropical latitudinal band of the ICCAT convention area from the Caribbean to West Africa, and rarely reported in the higher latitudes of the Atlantic Ocean (**Figure 16A**). The most widely reported species include FRI, followed by DOL, WAH, BON and BLF. The majority of FRI is reported by the industrial purse seine fishery in the equatorial Atlantic (Figure 17H). The majority of the DOL and WAH is reported by longline fisheries and other coastal fisheries (e.g. baitboat) in the western tropical Atlantic (Figure 17G and M). BLF is reported mostly by the handline fishery off Brazil, with some reports by longlines and purse seines in the Caribbean Sea (**Figure 17A**). BLT are reported off Senegal and the Iberian Peninsula, mostly by the trawl fishery (**Figure 17B**). BON are reported in coastal zones on both sides of the Atlantic mostly by the trawl, gillnet and purse seine fisheries (**Figure 17C**). BOP are reported at only a few locations in northwestern Africa by the gillnet and purse seine fisheries (**Figure 17D**). BRS are reported off Venezuela with unknown gears (**Figure 17E**) and CER are reported only in one grid cell in the Caribbean by the handline fishery (**Figure 17F**). KGM are reported with unknown gears off Venezuela (**Figure 17I**). LTA are relatively widely reported throughout their distribution on both sides of the Atlantic by a variety of fisheries, though reports from southern Brazil by the purse seine and baitboat fisheries are beyond their supposed distribution (**Figure 17J**). The catch reported for MAW (mostly by trawl and gillnet) are relatively few, but correspond well to the supposed distribution of this species (**Figure 17K**). Finally, the SSM are reported in only one point in the Gulf of Guinea, though their supposed distribution is in the central and northwestern Atlantic (**Figure 17L**).

The quantity and quality of knowledge of the biology and fisheries of small tunas is very fragmented and varies between species (ICCAT 2019), which is also supported by **Figure 17A-M**. Some species appear to have relatively good spatial reporting in their supposed distributions (e.g. BLF, FRI, WAH), while others’ catches cover a small area of their supposed distributions and can be even well outside their supposed distribution area (e.g. SSM, BLF, LTA). There are many catches reported with unknown gears (Figures 17A-M, UN gear code). ICCAT (2019) notes that this is largely due to difficulties in data collection as these species are most often caught by artisanal fisheries, or are discarded at sea by industrial fisheries as bycatch because they are considered to have low economic value. Catch qualities are rarely reported in logbooks, though observer programs are improving the estimates of the catches. There are also issues with misidentification, which can lead to statistical problems.

Thus, overall, we find the catch data for neritic species of tunas, bonitos and Spanish mackerels, while easily available, are still incomplete and of low quality, and **they will not be retained for further analyses** in Task 6**.**

5.2.3 Oceanic Sharks

Shark species caught by ICCAT fisheries (either targeted or caught as bycatch) are caught throughout the Atlantic basin and primarily along the northwestern Atlantic Ocean off Portugal, the Gulf of Guinea, the southern African coast and the southern Brazilian coast and off Uruguay (**Figure 18A**). This catch is primarily made up of blue shark (BSH), which is a wide-ranging species found from tropical to temperate zones (**Table 4**), with some catch of the temperate porbeagle (POR) and subtropical shortfin mako (SMA) (**Figure 18B**).

As noted, BSH catches are reported throughout the Atlantic, particularly in the east and south of the Atlantic basin primarily by the longline fishery. Many catches are also reported by unknown fisheries in the middle northern basin around the Azores (**Figure 19A**). POR has few catch reports, which are mostly off the northeastern United States and Canada by the longline, gillnet, and trawl fisheries there (**Figure 19B**). SMA catches are also relatively widely reported in the eastern and southern basin of the Atlantic, particularly in the Benguela region off southern Africa (**Figure 19C**). This species is mostly reported by the longline fishery, with many reports coming from unknown gears in the northern Atlantic basin.

Actions taken on previous ICCAT recommendations have led to improved data reporting of shark catches in the convention area, with data considered to be sufficient for quantitative analyses on BSH, POR and SMA (ICCAT 2019B); however, the quality of the georeferenced catches in the T2CE dataset remains poor. Noting this, we consider that the data available via the T2CE dataset for sharks still require expert guidance prior to use in the spatial analysis under Task 6. Among the sharks reviewed here, only BSH is considered a target species in ICCAT fisheries and therefore, it has the potential to be added as a layer of information in the spatial analysis in future analysis.

Thus, overall, we find the catch data for some sharks are easily available; however its completeness and quality are not sufficient, and **they will not be retained for further analyses.**

5.3 Thematic factor - Fishing grounds of the major ICCAT fisheries

This thematic factor uses the spatial distribution of catches to identify the core distributions and co-occurrence of fisheries assemblages as a proxy to determine the main fishing grounds of each fishery to inform the delineation of ecoregions (see Criteria **Table 1**). To infer the recent spatial distribution of the major ICCAT fisheries (**Table 5**), we again used the median annual catch of the public ICCAT Task 2 5°x5° georeferenced raised catch data (CATDIS(all)) over the last 15 years (2006-2020), regridded to the 5°x5° CWP grid.

The raised dataset was used in preference to the T2CE as it has been reviewed by the ICCAT secretariat and experts and corresponds to the fisheries targeting the main oceanic ICCAT species (Section 5.2.1), which is the primary data source informing species distributions for the spatial analysis (**Table 3**). This dataset includes the main gear types operating within the convention area (**Table 5**), but it does not distinguish catch at the minor gear types (e.g. artisanal coastal longliners vs industrial longliners); thus limiting our ability to distinguish between industrial and artisanal activities.

We use the gear groups that are listed in the raised catch data (CATDIS) to represent the different fisheries, which includes, purse seine (PS), longline (LL), baitboat (BB), trolling (TR), gillnet (GN), trap (TP), trawl (TW), rod-and-reel (RR), handline (HL) and harpoon (HP). Only gear group codes are included in the raised catch CATDIS dataset, whereas the T2CE dataset includes all the gear codes (**Table 5**). Noting this, we retained only those gear groups that contributed at least 0.5% of the overall catch (**Figure 20**); thus excluding rod-and-reel (RR), handline (HL), and harpoon (HP) fisheries from the spatial analysis under Task 6.

We note that the largest catches are attributed to PS (**Figure 20**), which are primarily localized in the equatorial Atlantic targeting tropical species (SKJ, YFT, and BET), with some important catches in the Mediterranean targeting BFT (**Figure 21**, **Figure 22A**). LL is the second major fishery (**Figure 20**), operating throughout the convention area (**Figure 21**, **Figure 22B**). LL catches reflect the spatial distribution of oceanic species to a large degree (see **Figure 14**), with longline catches of SWO and ALB in the higher latitudes, and catches of tropical species in the lower latitudes (**Figure 22B**). LL targets mostly BET in the equatorial east and YFT in the equatorial west (**Figure 22B**). BB are the third most important fishery by catch (**Figure 20**), but these catches are far more localized off the southern coast of Brazil and northwestern Africa targeting SKJ (**Figure 21**, **Figure 22C**). Some BB operate in the northeastern Atlantic with catches mostly consisting of ALB and BFT (**Figure 22C**). The TR fishery catches mostly ALB in the northern hemisphere, with a large majority of the catch in the near-coastal zones of the western Atlantic. SAI are caught by TR in the equatorial zone and lower latitudes of the southern hemisphere (**Figure 22D**). The GN fishery is the fifth most important fishery by catch (**Figure 20E**), with the majority of its catches closer to the coast. Catches consist of mostly ALB in the northwestern Atlantic, SWO in the southern Mediterranean, and billfish in the equatorial region (SAI, BUM, and SWO) (**Figure 22E**). The TP fishery operates in and at the mouth of the Mediterranean, targeting BFT (**Figure 22F**). The TW fishery operates mostly in the northeast Atlantic, with small catches in the west in the northern hemisphere (**Figure 22G**). In the CATDIS database, only ALB are reported for this fishery. RR is a near-coastal fishery operating mostly in the west and the Mediterranean (**Figure 22H**). The RR fishery also reports captures of BFT in the northwestern and eastern Atlantic, SAI in the coastal equatorial west, and BUM in the southern hemisphere off the Brazilian coast (**Figure 22H**). The HL fishery is also near-coastal with catches of BFT in the northwestern Atlantic and SAI in the south western Atlantic (**Figure 22I**). The least important fishery by catch in the CATDIS database is HP, which operates in the coastal northwest and Mediterranean and reports only catches of SWO (**Figure 22J**).

Upon examination of the spatial distributions of the fisheries in the raised catch CATDIS database, we find the top seven fisheries by catch (PS, LL, BB, TR, GN, TP, TW) to be "good" in terms availability, quality and completeness (**Table 3**), and they **will be retained to represent a proxy for the spatial distribution of fishing grounds of the main ICCAT fisheries.**

9. Task 6. Analytical methods for deriving a baseline ecoregion proposal

This task has the objective of (1) conducting a classification analysis based on the criteria outlined in Task 3 and the selected datasets outlined in Task 5 for developing a baseline ecoregion proposal, and (2) adjusting the baseline ecoregion proposal using expert knowledge. This covers step 4 and 5 of the framework used for guiding the delineation of ecoregions (**Figure 2**).

Guided by the criteria and expected qualities outlined in Task 3, we decided on a statistical hierarchical spatial approach for the classification analysis that was divided into three major steps: 1) a basic spatial overlapping analysis with the purpose of examining the chosen biogeographic classifications (Longhurst and PPOW) to be used as the oceanographic data layer upon which 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 within the provinces of the selected biogeographic classification, and 3) a hierarchical clustering analysis to cluster biogeographic provinces according to their degree of similarity in terms of species and fisheries composition based on the specificity and fidelity indicators. Each of these spatial analyses were based on those data layers which were classified as "good" quality (**Table 3**), i.e. oceanography (via biogeographical classifications), species distributions of the ICCAT oceanic species (via raised georeferenced catch), and fisheries distributions (also via raised georeferenced catch).

Task 6.1 Overlaps of species and fisheries on top of selected biogeographical classifications

We investigated the qualitative degree of overlap between selected biogeographic classifications (i.e. Longhurst and PPOW classifications; Section 5.1) and the spatial distribution of major oceanic ICCAT species (Section 5.2.1) and the main fisheries targeting them (Section 5.3). This spatial analysis allows us to investigate how well the biogeographic classification represents the spatial distribution of the species and fisheries data layers.

6.1.1 Longurst

To overlap the 5°x5° catch data to the Longhurst provinces we assigned single-data point provinces to the nearest neighboring province, and joined non-contiguous provinces. This resulted in 23 Longhurst provinces in the ICCAT convention area. The Longhurst biogeographic classification was retained for further investigation because this scheme is hierarchical, representative of the regional oceanography of the Atlantic Ocean and it incorporates coastal and oceanic zones, though the classification near the coast has been noted to be "fuzzy" (Watson *et al* 2003). The data points nearest to the coast are forced to take the value of their nearest biogeographical province.

We find that the Longhurst provinces have a relatively good overlap with the major spatial patterns of species distributions in that the equatorial provinces (WTRA, ETRA, GUIN) overlap reasonably well with the tropical species (SKJ, YFT, BET) though some tropical tuna catches spill over into the North Atlantic Tropical Gyre (NATR), the Canary Coastal (CNRY) and the South Atlantic Gyral (SATG); the boundaries of the more temperate provinces (NADR, ARCT, SARC in the north Atlantic, and SATG, BENG and SSTC in the south Atlantic) align with the distribution of temperate species (ALB and BFT [only found in the north Atlantic]); and the transitional province boundaries align reasonably well with subtropical billfishes (**Figure 23**). However, we find the Longhurst provinces lacking in terms of explaining species distributions around important island chains (e.g. Azores in the central north Atlantic, the Canary Islands and Cabo Verde off northwest Africa).

In terms of fisheries, we find that the Longhurst equatorial provinces (ETRA, WTRA) appear to correspond reasonably well with the extent of the tropical PS fishery, though PS catches spill over into the North Atlantic Tropical Gyre (NATR), the Canary Coastal (EACB) and the South Atlantic Gyral (SATG) (**Figure 24**). LL is the most widespread gear occurring in most provinces. The coastal regions capture some of the more coastal gears, particularly RR in the northwestern Atlantic and TP at the mouth of the Mediterranean; but other near-coastal gears (especially BB) have catches that extend into the oceanic provinces. We again find that the fisheries around important island chains are not well represented by the Longhurst provinces (i.e. Azores and the Canary Islands).

We find that the Longhurst provinces represent well enough the spatial distribution of the major tuna and billfish species and fisheries in the ICCAT convention area to warrant further investigation and inclusion in subsequent spatial analyses (Section 6.2).

6.1.2 PPOW

To overlap the 5°x5° catch data to the PPOW provinces, we assigned single-data point provinces to the nearest neighboring province, and joined non-contiguous provinces. This resulted in 16 PPOW provinces within the ICCAT convention area (**Figure 25**). PPOW provinces are oceanic and defined up to the continental shelf (**Figure 25**). Similar to what was done with the Longhurst provinces, catches over the continental shelf are assigned to the nearest PPOW province.

We find that PPOWs have a good correspondence to latitudinal patterns in species distributions, especially in the equatorial Atlantic where the Equatorial Atlantic and Canary Current provinces overlap well with the catches of the tropical species (SKJ, YFT and BET) (**Figure 25**). The Equatorial Atlantic province also matches the southern extent of the tropical species distribution (**Figure 25**) with more precision than equatorial Longhurst provinces (ETRA, WTRA) (**Figure 23**). The North Central Atlantic Gyre and South Central Atlantic Gyre provinces appear to capture well subtropical billfish species distributions in the transitional zones (with some albacore catches), and the temperature species (ALB, BFT) distributions are captured well in the provinces in the higher latitudes (North Atlantic Transitional and Gulf Stream provinces in the North Atlantic, and Subtropical Convergence and Subantarctic provinces in the South Atlantic). While the PPOWs are not defined at the continental shelf, there are several boundary current provinces that match some of the important species assemblages nearer to the coast and around the Canary Islands and Cabo Verde (**Figure 25**).

The PPOWs also match relatively well the spatial distributions of fisheries (**Figure 26**). The Equatorial Atlantic province and Canary Current province correspond well with the extent of the tropical PS fishery. LL is the most widespread gear occurring in most provinces. The more coastal boundary current provinces (Canary Current, Benguela Current, and Gulf Stream) encompass more coastal fisheries (BB, RR). A fishery that is not well matched by the PPOWs includes the BB fishery off the southern coast of Brazil and Uruguay (**Figure 26**).

We find that the PPOW provinces represent well enough the spatial distribution of the major species and fisheries in the ICCAT convention area to warrant further investigation and inclusion in subsequent spatial analyses (Section 6.2).

Task 6.2 Indicator analysis

After a qualitative examination and verification of the representativeness of the selected biogeographic classifications for major ICCAT species and fisheries, we used the provinces of the selected biogeographic classification schemes as areas within which to calculate an indicator to characterize the dominance and spatial prevalence of each species and type of fishery to the different geographical areas, following Dufrene and Legendre (1998) and Reygondeau *et al*. (2012). This indicator is actually the product of two indices: specificity and fidelity, and we hereafter refer to it as the SF Indicator.

6.2.1 Calculation of the specificity indicator

The specificity, *Ai,j* of a species or fishery *i* to a province *j* is calculated as the ratio of the abundance (*Nij*, here estimated using catch in MT) to the sum of the abundance of the species in all the provinces (*Ni*) (**Figure 28** left). Specificity is thus a measure of how much a species (or fishery) associates with a province, or a representation of its "preference and dominance" of or in one province over others. **Figure 28** (right) is an example of the specificity indicator calculated for species based on the spatial distributions of their catches. The sum of the specificity indicator for a species or fishery across all provinces equals 1. The specificity values per province can range from 0 to 1; 0 meaning a species (or fishery) is never found in a province, and 1 meaning that a species (or fishery) is only found in that one province.

6.2.2 Calculation of the fidelity indicator

The fidelity *Bi,j* of a species or fishery *i* for a province *j* is calculated as 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 *Sj* (**Figure 29** left). 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) or a fishery operates within a province (see **Figure 29** (right) for an example). The fidelity values for a species or fishery range from 0 to 1 within a province, 0 meaning that a species (or fishery) is found nowhere in the province and 1 meaning that a species (or fishery) is found in all grid cells of a province.

We investigated the relationship between the size of the provinces (i.e., number of grid cells per province), 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 30**). The Longhurst provinces range in size between 3-67 grid cells (**Figure 30** top left) and the PPOWs range between 6-59 grid cells per province (**Figure 30** bottom left). We found no significant relationship between the total number of grid cells in a province (neither Longhurst nor PPOW) and its value of fidelity (r^2<0.06 for all regression analyses for species and fisheries; **Figure 30** right panels).

The fidelity indicator as described and commonly used (Dufrene and Legendre 1998 and Reygondeau *et al*. 2012) is based on a presence/absence approach that is not very informative as grid cells with a small number of catches are given the same weight as grid cells with a larger number of catches. Therefore, we explored the application of thresholds to evaluate the inclusion or exclusion of grid cells into the calculation of the fidelity indicator, with the objective to remove the rare or unrepresentative grid cells from 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 31**). 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.

The final threshold values that are presented in this report and applied to the fidelity indicator are based on a "high" threshold scenario (**Table 6**). The threshold levels were purposefully strict to remove 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). In some cases, the thresholds led to the loss of all grid cells within a province. We found this result acceptable as these were the provinces with very low catches and were not considered to be representative to ICCAT species and fisheries.

We note the persistence thresholds levels applied to species indicated a much higher persistence (13 years) than when applied to fisheries (5 years). While the catch threshold level applied to fisheries allowed for a much lower catch threshold level (10th percentile) than when applied to species (25th percentile). We interpret this to mean that fisheries are more spatially dynamic and variable, and spatially fragmented than the spatial distribution of species in the ICCAT convention area.

For illustrative purposes, we present the fidelity indicators for both species (**Figure 32** top) and fisheries (**Figure 32** bottom) for the PPOWs without any thresholds applied (**Figure 32** left panels) and high thresholds applied (**Figure 32** right panels). We note a strong effect of the persistence and catch thresholds on the fidelity indicators for both species and fisheries. We see that tropical species are less likely to have high values in the higher latitudes, and temperate species are less likely to have high values in the lower latitudes when the thresholds are applied (**Figure 32** top panels). For fisheries, we note again that the provinces in the higher latitudes have lower fidelity values when the thresholds are applied, and that fidelity values of some fisheries are lowered or removed from provinces where they do not have large or consistent catches (e.g. PS outside of the tropical provinces) (**Figure 32** bottom panels). We find a better understanding of the most representative and spatially prevalent species and fisheries for each province emerges when the high threshold levels are applied.

6.2.3 Calculation of the Specificity-Fidelity (SF) indicator

The product of the specificity and fidelity indicator scaled to 100 provides the SF indicator value of species *i* (or fishery *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 fisheries, highlighting those species and fisheries most dominant and prevalent in a province (Dufrene and Legendre 1998; Reygondeau *et al*. 2012).

Next, we present the SF indicator using specificity and fidelity with the high catch and persistence thresholds applied for both the Longhurst and PPOW classification schemes, for species and for fisheries.

6.2.4 SF indicator for species

The SF indicator of species and fisheries reinforces some of the patterns already discussed when the spatial distribution of species and fisheries were analyzed independently **(Figure 14** and **Figure 15**). 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 equatorial Atlantic, particularly the ETRA, WTRA, GUIN, and CNRY Longhurst provinces (**Figure 33** top panel); or the Equatorial Atlantic, Guinea Current and Canary Current PPOW provinces (**Figure 33** bottom panel). We find that the Longhurst and PPOW provinces in the higher latitudes have lower overall indicator values that are dominated by temperate species (ALB and BFT in the north, ALB in the south). BFT has particularly high values in the Mediterranean, where the majority of the catch is. In the north Atlantic, ALB dominates the NADR, NASE and NATR Longhurst provinces, and North Atlantic Transitional and the North Central Atlantic PPOWs. In the South Atlantic, ALB dominates the SATL and BENG Longurst provinces, and the South Central Atlantic Gyre and Benguela Current PPOWs.

SWO is a subtropical species that is found throughout the ICCAT area (**Figure 15G**). It has a relatively low SF value for most provinces because its catches are spread over a large number of provinces to the exclusion of the provinces in the highest latitudes. Though the values are low, there are several provinces where SWO is the dominant species. It appears to be more dominant and spatially prevalent within the Mediterranean (Mediterranean stock), as well as in the North Atlantic transitional zone in NASE and NASW Longhurst provinces or North Central Atlantic Gyre PPOW (North Atlantic stock), and in the South Atlantic transitional zone in SATL Longhurst and South Central Atlantic Gyre PPOW. The other billfishes (SAI, WHM, BUM) appear to be relatively dominant and prevalent in the equatorial provinces (ETRA and WTRA Longhurst provinces, and Equatorial Atlantic and Guinea Current PPOW provinces), yet the WHM is not found in the ETRA and Guinea Current.

Overall, we find that some provinces have low or no values of the SF indicator for species. We interpret these lower-values as the outer boundary or outside the distribution of the species. We note that the southern provinces (i.e. SSTC, SANT, ANTA Longhurst provinces, and the Subantarctic, Antarctic Polar Front, and Antarctic PPOW provinces) 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, due to low catches in these zones. These southern areas correspond to the southern bluefin tuna distribution, a species not included in this study.

6.2.5 SF indicator for fisheries

Similar to the species SF indicator, we find the highest fisheries SF values in the equatorial Atlantic where this is the most catch reported. The equatorial Longhurst provinces (ETRA, GUIN and WTRA) and PPOW provinces (Equatorial Atlantic and Guinea Current) are dominated by the PS fishery and to a lesser degree either LL and/or BB (**Figure 34**). Outside of the equatorial zone, PS is found in the Mediterranean province. LL is found in almost all provinces to varying degrees, with a strong presence in the South Central Atlantic Gyre, Equatorial Atlantic, North Central Atlantic Gyre, and the Mediterranean PPOW provinces, and with a similar extent with the SATL, ETRA, WTRA, NATR and MEDI Longurst provinces. BB has its highest SF values in the equatorial Atlantic, particularly in the Canary Current provinces (CNRY Longhurst province), but also in the coastal southern Atlantic off southern Brazil and Uruguay (BRZL Longhurst province and Malvinas Current PPOW province). TR is quite specific to the northern eastern Atlantic, with some SF values dominating the provinces around Europe (NASE and NADR Longhurst provinces, North Atlantic Transitional PPOW). TP is found only in the provinces at the mouth of the Mediterranean (NASE Longhurst province and the Canary Current PPOW)). TW appears quite specific with high fidelity in the transitional zones in the northeastern Atlantic (NADR Longhurst province, and the North Atlantic Transitional PPOW). The highest SF values for GN are in the Mediterranean and in the equatorial provinces (ETRA Longhurst and Guinea Curreny PPOW). Again we note that the provinces in the higher latitudes have little to no information when the high catch and persistence threshold levels are applied, but we also observe very little information in these provinces even when no thresholds are applied (not shown).

Based on our SF indicator analysis (**Figures 33, 34**), and relative to the criteria identified in **Table 1**, we consider that the community assemblage of a province is best represented by both the species and the fisheries that occupy and operate in that province. We find that the high catch and persistence thresholds help to identify the most spatially prevalent species and fisheries in each province (spread broadly within the province with relatively high catches that persist over time), and they help to filter out from the spatial analysis those provinces with little or no information, allowing clearer spatial patterns to be resolved. Therefore, we consider that the combined SF indicator, which includes both the specificity and fidelity of a species and fishery for a province filtered by high catch and persistence threshold levels, 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**.

6.3 Clustering approach

We performed a hierarchical clustering algorithm on the SF Indicators for each province 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 (species and fisheries) for an integrative analysis.

To perform the clustering analysis, 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.

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 2% threshold was defined, which we used to identify the optimal *k* for the clustering algorithm, whereby the explained sum of squares for each additional *k* increases by less than 2%.

As one of the expected properties of the 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 Canberra distances. Canberra distance examines the sum of series of fraction differences between coordinates of a pair of objects. This distance is very sensitive to a small change when both coordinates are nearest to zero. The Canberra distance method is very sensitive to the weighting of values in each cluster enabling us to determine differences when values are small (Faisal *et al*. 2020).

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.

We run the hierarchical clustering algorithm on the SF indicator values, including the specificity and the fidelity indicator with the high catch and persistence thresholds applied for species, fisheries and both species and fisheries combined for both the Longhurst and PPOW biogeographical classifications.

6.3.1 Species-based SF indicator

Clustering on the species-based SF indicator for both the Longhurst and PPOW biogeographic classifications yielded similar results. In both scenarios, we find that the higher latitude provinces cluster by themselves (SSTC and ARCT Longhurst provinces, and Subantarctic and Subarctic Atlantic PPOW provinces) (**Figure 35, 36**). These provinces have very low SF values, which are given entirely by ALB for the southern provinces and BFT for the northern provinces (**Figure 36** indicator panel). The equatorial Atlantic provinces also clustered together in both biogeographical classifications due to high SF values of tropical tuna and billfish, though the PPOW equatorial cluster extends to the Inter American Seas (cluster 4; purple; **Figure 36**). The two classifications also cluster the transitional gyres on either side of the equator together (NATR and SATL Longhurst provinces and North Central Atlantic Gyre and South Central Atlantic Gyre PPOW provinces) as these are made up of relatively low SF values from a diversity of temperate species (ALB, SWO) and to a lesser extent subtropical billfishes (SAI) and tunas (BET). Longhurst differs from PPOW; however in splitting the northern Atlantic into two latitudinal bands, the northern band clustered with the Mediterranean whereas the PPOW clusters the Mediterranean by itself. The northern Longhurst cluster (cluster 3; pink; **Figure 35**) groups provinces with very low SF values for temperate species (ALB and BFT) and SWO. The Longhurst clusters further differ from PPOW by clustering the coastal currents together, whereas the PPOW boundary current provinces are clustered with their neighboring offshore provinces. Longhurst has more, smaller provinces with more distinct SF assemblages, which likely accounts for the differences in the cluster results.

6.3.2 Fishery-based SF indicator

Clustering on the fishery-based SF indicator for both the Longhurst and PPOW biogeographic classifications (**Figure 37, 38**) yielded broadly similar patterns, but the similarities were less strong than for clustering on the species-based indicator (**Figure 35, 36**). This may again be due to the fact that Longhurst has more, smaller provinces than PPOW, but also is likely due to the more diverse assemblages of fisheries than species within each province.

In both scenarios, we find that the higher latitude provinces cluster together (SSTC and ARCT Longhurst provinces, and Subantarctic and Subarctic Atlantic PPOW provinces) as these provinces are characterized by low SF values of LL (**Figure 37, 38**). The equatorial Atlantic provinces for Longhurst are split into north (NATR and CARB) and south clusters (WTRA, ETRA) which clusters with MEDI. The northern cluster (cluster 6, blue, **Figure 37**) is characterized by low values of mostly LL and a variety of other fisheries. The southern cluster (cluster 5, turquoise, **Figure 37**) is characterized by LL and PS. For the PPOWs the Equatorial Atlantic is clustered with the Caribbean, which both have relatively high SF values for LL, and at least some PS (Equatorial Atlantic has high values for SF). As noted the Longhurst MEDI clusters with ETRA and WTRA (the three provinces have LL and PS fisheries), but for PPOW, the Mediterranean clusters with the Canary and Guinea Currents likely due to the composition of LL, PS, and also other more coastal fisheries (BB). The southern Atlantic (SATL) clusters with the Benguela Current (BENG) for Longhurst (cluster 8, red, **Figure 37**), and similarly, in the PPOW, the South Atlantic Gyre clusters with the Benguela Current and the Malvinas in the south Atlantic (cluster 4, purple, **Figure 38**). In the PPOW, North Atlantic Gyre also clusters with cluster 4, which is characterized by LL and to a lesser extent BB. The Longhurst clustering further splits the northern Atlantic into western and eastern clusters, with the west characterized by low values of LL (cluster 1, gold, **Figure 37**), and the east further split into a northern cluster (cluster e, pink, **Figure 37**) characterized by TR and TW and a southern cluster (cluster 4, purple, **Figure 37**) by a large variety of different gears, including BB.

6.3.3 Combined (species- and fishery-based) SF indicator

Finally, clustering on both the species- and fishery-based SF indicator for both the Longhurst (**Figure 39**) and PPOW (**Figure 40**) biogeographic classifications also yielded broadly similar patterns. We find that the higher latitude provinces cluster separately (SSTC and ARCT Longhurst provinces, and Subantarctic and Subarctic Atlantic PPOW provinces), characterized by low SF values of LL and temperate species (BFT and ALB) in the north and by LL and ALB in the south. The Mediterranean clusters by itself with the combined indicator for both Longhurst and PPOW. The equatorial Atlantic provinces for Longhurst cluster are split into west (NATR, CARB, WTRA) and cluster with the South Atlantic Gyre (SATL; cluster 6, blue, **Figure 39**), and east (ETRA, GUIN, CNRY; cluster 7, green, **Figure 39**). These are likely split due to the higher dominance of LL with YFT and WHM in the western tropical Atlantic, and PS and BB with SKJ (and no presence of WHM) in the eastern tropical Atlantic. In contrast, PPOW combines all equatorial provinces into one cluster (Inter American Seas, Equatorial Atlantic, Canary Current and Guinea Current) (cluster 5, turquoise, **Figure 40**). The north Atlantic is split into three clusters in the Longhurst due mostly to the specific fisheries in these areas (clusters 1, 3, 4; **Figure 39**). The PPOW clusters the provinces on either side of the equatorial zone together characterized by diverse species assemblages dominated by ALB, SWO and SAI with mostly LL fishing and some BB. PPOW also splits the north Atlantic into two, including an additional cluster (cluster 1, gold, **Figure 40**) characterized by temperate species (ALB) and a variety of fisheries (TR and TW).

6.4 Proposal of candidate baseline ecoregions and their refinement based on expert knowledge

This section aims to present a **baseline ecoregion proposal** derived from a data-driven approach. This baseline proposal will be used as a starting point for discussions and **adjustments based on expert knowledge**.

6.4.1 Baseline ecoregion proposal

In general, we find that both the Longhurst and the PPOW provinces yield reasonable results. However, we note that the PPOW results in fewer clusters that follow simple latitudinal bands symmetric around the equator (**Figure 40**). Thus, in our view, the cluster analysis scenario that (1) best represents groups with distinct species and fisheries composition, (2) adheres to the criteria outlined in **Table 1** and the main properties of ecoregions, and (3) it is most useful to start discussions and potential refinements with expert knowledge, is the scenario based on the combined SF indicator using PPOW provinces (**Figure 40**).

One of the main properties of the ecoregions is that each ecoregion should be geographically contiguous. Adhering to this guideline, we have refined the 7 clusters of the combined PPOW analysis into 8 geographically contiguous clusters (**Figure 41**). 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 9 different ecoregions (**Figure 41**).

6.4.2 Expert knowledge

The data-driven spatial clustering approach has produced a final **baseline ecoregion proposal** which comprises nine different ecoregions (**Figure 41**). 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. distribution of neritic tunas and targeted sharks). Expert knowledge is also expected to refine the boundaries of the baseline ecoregions to ensure that the final candidate ecoregions comply with the expected qualities of the ecoregions based on Criteria (**Table 1**). We expect that the Group will develop a proposal of refined candidate draft ecoregions.

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

- The appropriateness of the three thematic factors included in the criteria for guiding the delineation of ecoregions and whether each thematic factor should have different weights for informing the classification (e.g. give more weight to the species layer than fisheries layer);
- The use of biogeographical provinces (Longhurst v PPOW) to capture regional oceanography;
- The inclusion of neritic species and targeted sharks as a data layer for informing the classification;
- The thresholds for refining the fidelity indicator (i.e. exploring the impacts of other levels on cluster analysis);

- 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 be put forward;
- The geographical delineation of final cluster analysis: The current baseline proposal was further delineated into 9 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.

10. Task 7. Validating and testing ecoregions

The quantitative proposal of baseline ecoregions produced under Task 6 and adjusted by expert knowledge in the course of the workshop may appear to be definitive. Yet candidate ecoregions should be considered a working hypothesis to be tested and validated before they are used for resource planning, research and management (Bailey 1983, Loveland and Merchant 2004). Task 7 has for its objective the validation and testing of the draft ecoregions for their intended use. This task is the last step in the framework for guiding the ecoregion delineation (**Figure 2**).

The candidate ecoregions derived in Task 6 are based on a criteria governed by three thematic factors (regional oceanography-biogeography, spatial distribution of ICCAT species and species assemblages, and spatial patterns of fishing grounds of major ICCAT fisheries) that are believed to be important for informing ecoregion boundaries. Therefore, one way the candidate ecoregion could be validated is by **statistically evaluating the hypothesis underlying the regionalization and the expected qualities** of the resultant ecoregions (see **Table 1**), so that the core areas and boundaries of the ecoregions can be objectively evaluated. In addition, it is also a common practice to **develop pilot products to test the general applicability and intended uses of the ecoregions**. The ultimate test of the utility of ecoregions as tools for resource planning, research, assessment and provision of advice may be the extent to which they meet the end user needs (Bailey 1983, Loveland and Merchant 2004). A pilot study to validate and test the draft ecoregions could have multiple objectives including (1) testing the concept of ecoregions and their utility, (2) testing the usefulness of an ecoregion framework as "units of analysis" for regional assessments (e.g. impact and risk assessments), and (3) identifying the advantages, disadvantages, challenges and benefits of using ecoregions as "units of analysis".

At this stage of the delineation process, we expect to have a group discussion at the workshop to define some potential activities for validating the candidate ecoregions derived in the workshop. Yet, here, we propose a potential validation exercise as an example to inform discussions. As discussed in Task 1, ecoregions can be used to steer planning, research, assessments and production of more integrated advice**.** More specifically, the ecoregion units could provide a regional framework for assessing status, trends and threats and for addressing multi-fishery and multi-taxa interactions and emergent trade-offs at the ecoregion level. This may include monitoring and reporting the state and trends of bycatch and vulnerable species of the most relevant fisheries within an ecoregion, monitoring responses to mitigation measures, and then summarizing this information in regional bycatch assessments conducted at the ecoregion level (sometimes referred as "fisheries and ecosystem overviews"). Along these lines, a pilot study could seek to elucidate and highlight regional challenges and priorities in the management of bycatch at the ecoregion level. Using a multi-taxa and multi-fishery approach, a regional approach would 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.

There may also be opportunities to validate the ecoregions with the existing large and comprehensive datasets. The seabird distribution data derived from the seabird tracking dataset of BirdLife International (**Figure 42**) represents a potential source of data for validating the core areas and boundaries of the candidate ecoregions and their potential for conducting a regional integrated assessment of bycatch. Thirty four species of seabirds interact and are caught as bycatch in ICCAT fisheries throughout the Atlantic Ocean including the Caribbean and the Mediterranean Seas, impacting their demography and their conservation status (Pardo *et al*. 2017, Gianuca *et al*. 2019). The species and fisheries involved in these interactions, and the extent of these interactions, differ geographically through the ICCAT convention area (e.g. one relevant area is the southern Atlantic where many species of albatross and petrels interact with fisheries operating in this region (mostly longline) (BirdLife International 2019, Jimenez *et al*. 2020). The availability of the seabird distribution data, together with seabird richness, density and mortality, offers an opportunity to validate the core areas and boundaries of the candidate ecoregions and test the utility of ecoregions for developing regional integrated bycatch assessments.

11. Conclusion and future steps

This report summarizes the preparatory work performed prior to the ICCAT ecoregion workshop. This work will be presented and discussed at the upcoming workshop where expert advice will be solicited. We expect that the workshop participants will review all the steps of the framework leading to the proposal of baseline ecoregions (**Figure 2**). It is also expected that during the workshop the baseline ecoregions will also be adjusted using expert knowledge while being assessed against the proposed criteria in **Table 1** to derive a proposal of ecoregions in the ICCAT convention area.

The expected outputs of this workshop include:

- A better understanding of the role and purpose of ecoregions as tools to support EBFM implementation
- A set of criteria including the major factors to be considered to guide the development of draft ecoregions.
- An understanding of the data layers and methods used for deriving the ecoregions with their strengths and weaknesses.
- A proposal for candidate draft ecoregions.
- A workshop report with an executive summary with the main outcomes to be presented at the SC-ECO meeting in 2022

12. Acknowledgements

MJJJ and AEN were supported by "*la Caixa"* Foundation Postdoctoral Junior Leader Fellowship under agreement No 847648.

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Table 1. Criteria for evaluating and guiding the delineation of ecoregions. This table includes the main thematic factors informing the classification analysis and also the expected qualities of the resulting ecoregions. Ultimately, the aim of the ecoregions is to use them as spatial units to support integrated ecosystem planning, research, assessments and advice for EBFM implementation.

Criteria	
Thematic factors	**Expected qualities**
Oceanography and biogeography of the Atlantic Ocean	•The boundaries of proposed ecoregions appropriately demarcate areas with a clear oceanographic/biogeographic justification •The proposed ecoregions are characterized by distinct environmental/oceanographic conditions •It should be possible to link ecosystem research, assessment and monitoring of environmental/climate effects to effectively provide integrated advice and support integrated management
The distribution of the main ICCAT species and the spatial composition of the ecological communities they form (biogeography of tuna and billfish communities)	•The proposed ecoregions demarcate the core distribution of ICCAT tuna and billfish species (including both neritic and oceanic species) •The proposed ecoregions are characterized by distinct communities of tuna and billfish species
The spatial patterns of the fishing grounds of the main IOTC fisheries	•The proposed ecoregions demarcate the core distribution of major ICCAT fisheries (artisanal and industrial) operating in the convention area •The proposed ecoregions are characterized by distinct ICCAT fisheries •It should be possible to link ecosystem research, assessment and monitoring of fishing impacts to effectively provide integrated advice and support integrated management (e.g. mixed fisheries scenarios, cumulative impacts of fisheries)

Table 2. Comparing the selected marine biogeographic classifications.

Biogeographic classification	**Methodology used**	**Type of input data used**	**Characteristics**	**Resulting classification**
Large Marine Ecosystems (LMEs) Sherman and Alexander 1986 Sherman 1991, 1994	Qualitative analysis, expert knowledge	Informed by oceanographic processes and ocean productivity. Informed by hydrography, bathymetry, productivity, trophically dependent populations, fisheries and geopolitical considerations.	•Coastal (omits some coastal areas of islands) •Includes the benthic and pelagic environments •Static boundaries	66 regions
Longhurst biogeochemical Provinces (Longhurst) Longhurst 1995, 2007	Qualitative analysis, expert knowledge	Informed by satellite chlorophyll and physical variables associated with large-scale circulation patterns including sea surface temperature, ice fraction, and maximum mixed layer depth.	•Coastal and oceanic •Surface pelagic (0-200 m) •Static boundaries •Hierarchical classification	4 biomes, 57 BGCPs
Dynamic Longhurst Biogeochemical Provinces (Dynamic Longhurst) Reygondeau *et al* 2013	Quantitative analysis	Physical and biological properties of the water column (4 environmental parametres)	•Coastal and oceanic •Surface pelagic (0-200 m) •Dynamic boundaries	58 provinces
Marine Ecoregions of the World (MEOW) Spalding *et al.* 2007	Qualitative analysis, expert knowledge	Based on a critical review of existing classifications. Informed by biodiversity attributes (including taxonomy, patterns of dispersal and isolation of species, and their evolutionary history) and oceanographic processes.	•Coastal •Includes the benthic and pelagic environments •Static boundaries •Hierarchical classification	12 realms, 58 provinces and 232 ecoregions
Pelagic Provinces of the World (PPOW) Spalding *et al.* 2012	Qualitative analysis, expert knowledge	Based on a critical review of existing classifications. Informed by oceanographic processes, ocean productivity, and biodiversity patterns of species distributions and communities.	•Oceanic •Surface pelagic (0-200 m) •Static boundaries •Hierarchical classification	4 realms, 7 biomes, 37 provinces

Biogeography of tuna and billfish communities (BTBC) Reygondeau *et al* 2012	Quantitative analysis	Informed by tuna and billfish species distributions derived from fisheries statistical data (catch per unit effort of major longline fleets targeting tuna and billfish species)	•Coastal and oceanic •Surface pelagic (0-200 m) •Static boundaries	9 distinct tuna and billfish communities distributed globally
Global open-ocean biomes (GOOB) Fay and McKinley 2014	Quantitative analysis	Informed by satellite chlorophyll and physical variables associated with large-scale circulation patterns including sea surface temperature, ice fraction, and maximum mixed layer depth (4 environmental variables)	•Oceanic •Surface pelagic (0-200 m) •Dynamic boundaries	5 biomes globally distributed
Near surface global marine ecosystems (NSGME) Zhao *et al* 2019	Quantitative analysis	Physical and biological properties of water column (20 environmental variables)	•Coastal and oceanic •Surface pelagic (0-200 m) •Static	Seven-clusters of marine ecosystems

Table 3. Data layers explored 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) in Task 6.

Data layers	Data type	Data quality and completeness	Time range of dataset	Included in statistical analysis (Task 6)	Data source	Reference
Existing biogeographical classifications						
Large Marine Ecosystems	Shapefile	Good		no	http://lme.edc.uri.edu/	Sherman and Alexander 1986 Sherman 1991, 1994
Longhurst provinces	Shapefile	Good		yes	http://www.marineregions.org/download_file.php?name=longhurst_v4_2010.zip	Longhurst 1995, 2007
Dynamic Longhurst provinces		Good		no		Reygondeau *et al* 2013
Marine Ecosystems of the World	Shapefile	Good		no	http://www.worldwildlife.org/publications/marine-ecoregions-of-the-world-a-bioregionalization-of-coastal-and-shelf-areas	Spalding *et al.* 2007
Pelagic Provinces of the World (PPOW)	Shapefile	Good		yes	http://data.unep-wcmc.org/datasets/38	Spalding *et al.* 2012
Tuna Biogeographical Provinces		Good		no		Reygondeau *et al* 2012
Global open-ocean biomes		Good		no		Fay and McKinley 2014
Near surface global marine ecosystems		Good		no		Zhao *et al* 2019
Spatial distribution of species						
ICCAT main tuna and billfish species: open ocean	Catch data raised to total landings (ICCAT Task 2 CATDIS)	Good	1950-2020	yes 2006-2020	https://www.iccat.int/Data/Catdis/cdis5020_all.7z	ICCAT Secretariat
ICCAT neritic species (tunas, bonitos, spanish mackerel)	ICCAT Task 2 Catch and effort	Medium	1950-2020	no	https://www.iccat.int/Data/t2ce_20220131.7z	ICCAT Secretariat
ICCAT sharks (focus on targeted sharks)	ICCAT Task 2 Catch and effort	Medium	1950-2020	no	https://www.iccat.int/Data/t2ce_20220131.7z	ICCAT Secretariat
Spatial distribution of fisheries						

ICCAT fisheries (gears)	Catch data raised to total landings (ICCAT Task 2 CATDIS)	Good	1950-2010	Yes	https://www.iccat.int/Data/Catdis/cdis5020_all.7z	ICCAT Secretariat

Table 4. Species covered by the ICCAT convention and other species of importance, including links to the species manual and executive summary or detailed ICCAT stock assessment report where summaries are not available.

FAO English name	Scientific name	FAO Code	Habitat type	ICCAT executive summary
Species Directly Covered by the Convention				
Albacore tuna	*Thunnus alalunga*	ALB	Temperate oceanic	Summary
Bigeye tuna	*Thunnus obesus*	BET	Tropical oceanic	Summary
White Marlin	*Tetrapturus albidus*	WHM	Subtropical oceanic	Summary
Atlantic Bluefin tuna	*Thunnus thynnus*	BFT	Temperate oceanic	Summary
Blue Marlin	*Makaira nigricans*	BUM	Tropical oceanic	Summary
Skipjack	*Katsuwonus pelamis*	SKJ	Tropical oceanic	Summary
Atlantic sailfish	*Istiophorus albicans*	SAI	Tropical oceanic	Summary
Swordfish	*Xiphias gladius*	SWO	Subtropical oceanic	Summary
Yellowfin tuna	*Thunnus albacares*	YFT	Tropical oceanic	Summary
Southern bluefin tuna	*Thunnus maccoyii*	SBT	Temperate oceanic	Summary
Mediterranean spearfish	*Tetrapturus belone*	MSP	Subtropical oceanic	
Roundscale spearfish	*Tetrapterus georgii*	RSP	Subtropical oceanic	
Longbill searfish	*Tetrapterus pfluegeri*	SPF	Subtropical oceanic	
Butterfly kingfish	*Gasterochisma melampus*	BUK	Temperate oceanic	
Slender tuna	*Allothunnus fallai*	SLT	Temperate oceanic	
Neritic tunas, bonitos and Spanish mackerels				Summary
Wahoo	*Acanthocybium solandri*	WAH	Tropical neritic	
Bonito	*Sarda sarda*	BON	Subtropical neritic	
Plain bonito	*Orcynopsis unicolor*	BOP	Subtropical neritic	
Bullet tuna	*Auxis rochei*	BLT	Tropical neritic	
Frigate tuna	*Auxis thazard*	FRI	Tropical neritic	
King mackerel	*Scomberomorus cavalla*	KGM	Tropical neritic	
Atlantic black skipjack, Little tunny	*Euthynnus alletteratus*	LTA	Tropical neritic	
Blackfin tuna	*Thunnus atlanticus*	BLF	Tropical neritic	
Spanish Mackerel	*Scomberomorus maculatus*	SSM	Subtropical neritic	
West African Spanish mackerel	*Scomberomorus tritor*	MAW	Tropical neritic	
Serra Spanish mackerel	*Scomberomorus brasiliensis*	BRS	Tropical neritic	
Cero mackerel	*Scomberomorus regalis*	CER	Tropical neritic	
Common dolphinfish[5]	*Coryphaena hippurus*	DOL	Subtropical oceanic	

[5] Species not covered in the ICCAT Convention but it is considered an important species by the Small Tuna WG.

Other shark species of importance (targeted or caught as bycatch in ICCAT fisheries) not covered in the Convention[6]				
Sharks				Summary
Blue shark	*Prionace glauca*	BSH	Subtropical oceanic	Detailed
Shortfin mako	*Isurus oxyrinchus*	SMA	Subtropical oceanic	Detailed
Porbeagle	*Lamna nasus*	POR	Temperate oceanic	Detailed
Common thresher	*Alopias vulpinus*	ALV	Subtropical oceanic	
Bigeye thresher	*Alopias superciliosus*	BTH	Subtropical oceanic	
Silky shark	*Carcharhinus falciformis*	FAL	Subtropical oceanic	
Oceanic whitetip shark	*Carcharhinus longimanus*	OCS	Subtropical oceanic	
Scalloped hammerhead	*Sphyrna lewini*	SPL	Tropical oceanic	
Smooth hammerhead	*Sphyrna zygaena*	SPZ	Subtropical oceanic	
Great Hammerhead shark	*Sphyrna mokarran*	SPK	Subtropical oceanic	

[6] The new amendment to the ICATT Convention (not ratified yet) will include oceanic sharks.

Table 5. ICCAT fisheries by major gear group and a description of the gears included in each group.

Gear group code	Name	Description of gears included in the group	Included in the CATDIS
BB	baitboat	Baitboat; Baitboat: Ice-well; Baitboat: Freezer; Baitboat: Targeting ALB;	yes
GN	gillnet	Gillnet: Drift net; Gillnet: Drift nets - misto (used by Italy); Gillnet: Targeting ALB; Gillnet: Targeting SWO	yes
HL	handline	Handline	yes
HP	harpoon	Harpoon	yes
HS	haul seine	Haul seine	no
LL	longline	Longline; Longline: With mother boat; Longline: Foreign-based; Longline: Home-based; Longline: Bottom or Deep longliners; Longline: targeting ALB (Spain); Longline: japanese (Spain); Longline:"Stone-ball" (Spain); Longline: Targeting BFT (used by Italy); Longline: Targeting SWO (used by Italy); Longline: Derivante(used by Italy)	yes
PS	purse seine	Purse seine; Purse seine: Large scale (over 200 MT capacity); Purse seine: Small scale (less than 50 MT capacity); Purse seine: Double-boats; Purse seine: Medium scale (between 50 and 200 MT capacity); Purse seine: Using live bait; Purse seine: Catching large fish; Purse seine: Catching small fish;	yes
RR	rod & reel	Rod-and-reel; Rod-and-reel catching large fish; Rod-and-reel catching small fish	yes
SP	sport	Sport: Recreational fisheries (mostly rod and reel); Sport: Hand line	no
TL	tended line	Tended line	no
TN	trammel net	Trammel net	no
TP	trap	Trap; Trap: non-fixed trap	yes
TR	trolling	Troll	yes
TW	trawl	Trawl; Trawl: Mid-water pelagic trawl; Trawl: Midwater paired trawl	yes
UN	Unclassified (surface)	Surface fisheries unclassified; Unclassified: Gears not reported	no

Table 6. The threshold levels selected 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. In the Input data column, the Combined category indicates that the input data are based on both species and fisheries data.

Threshold Level	Input data	Persistence threshold (years)	Catch threshold (percentile)
High	Species	13	0.25
High	Fishery	5	0.1
High	Combined	Species: 13 Fishery: 5	Species: 0.25 Fishery: 0.1

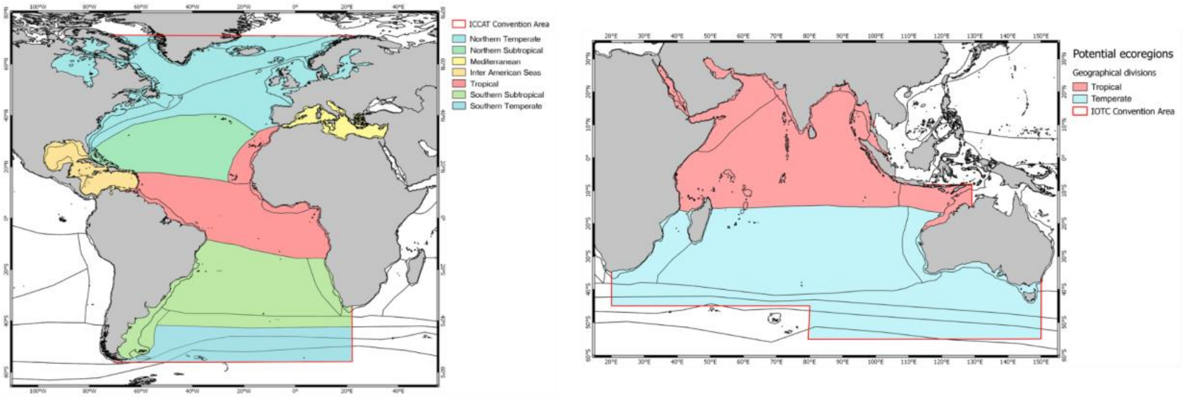


Figure 1. Preliminary candidate ecoregions within the ICCAT (left) and IOTC (left) convention areas derived from an EU project.

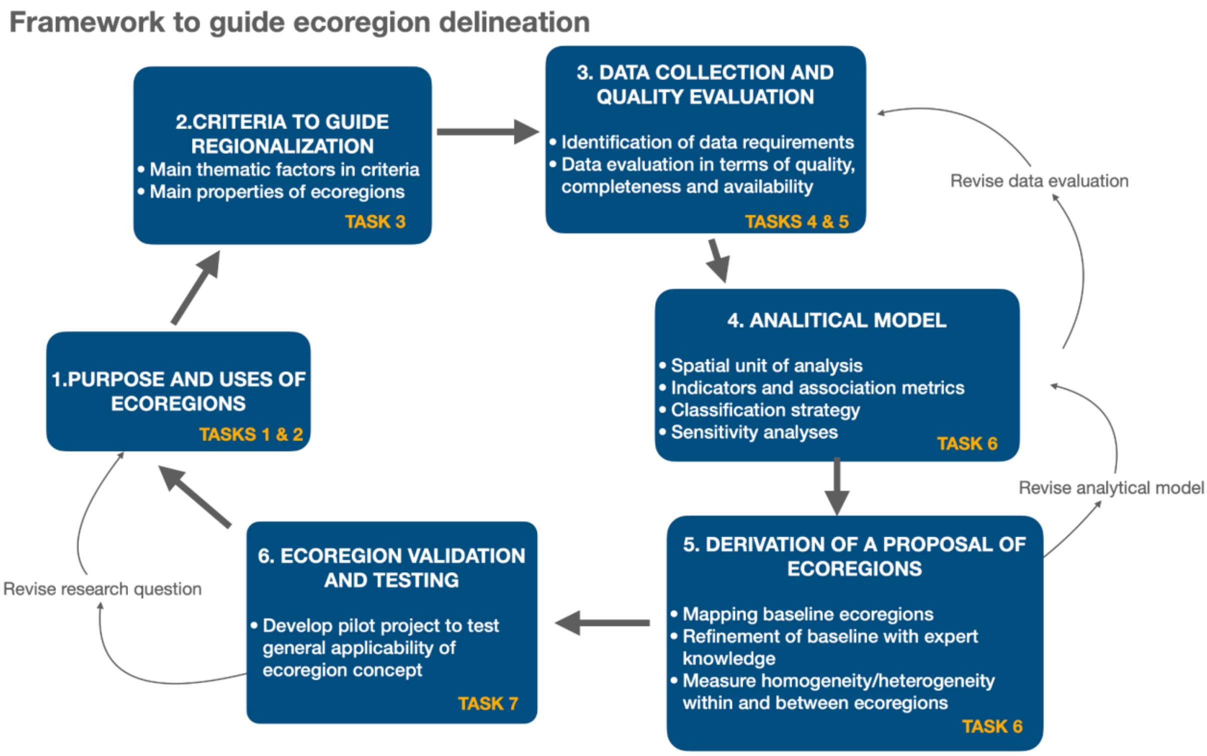


Figure 2. General framework with main steps and key activities guiding the delineation of ecoregions to support EBFM implementation in the context of international tuna fisheries (adapted from Mackey *et al*. 2008). Main tasks addressed in this report and how they relate to the framework are mapped.

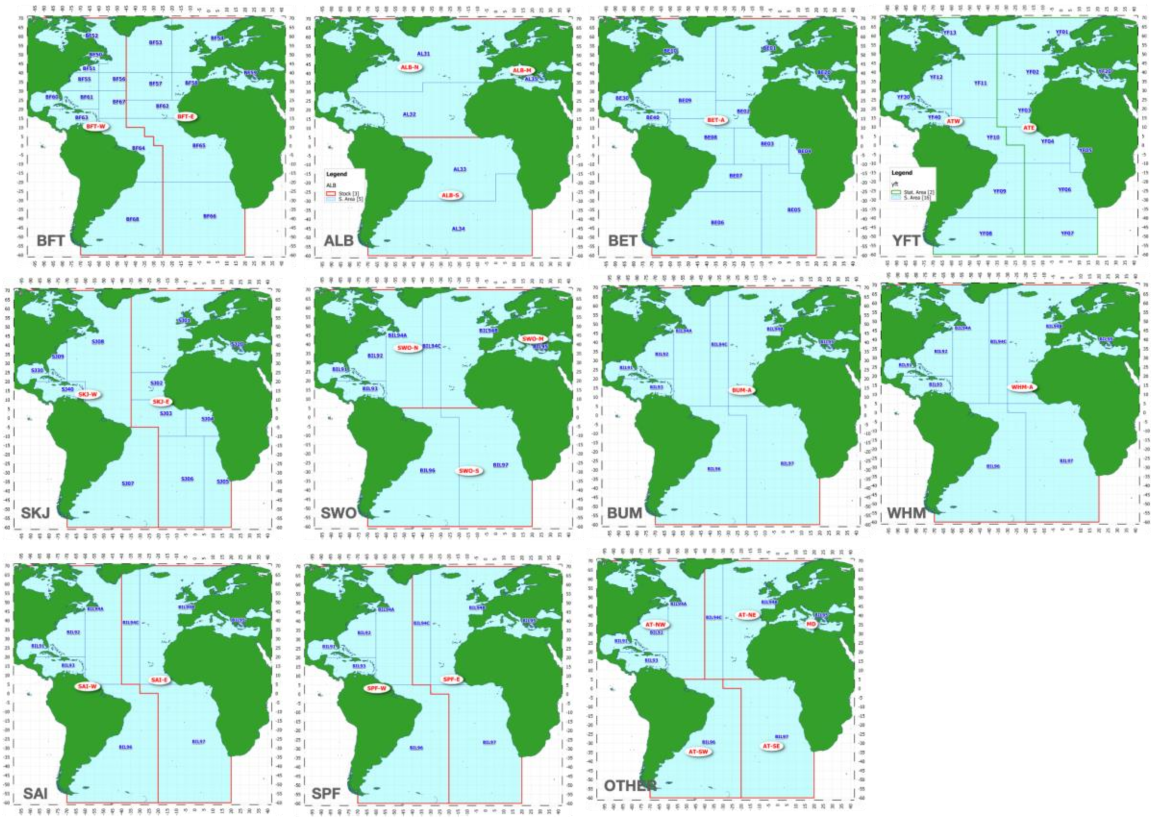


Figure 3. ICCAT Sampling Areas (SA) and ICCAT Stocks/Statistical areas used for the submission of fisheries statistics.

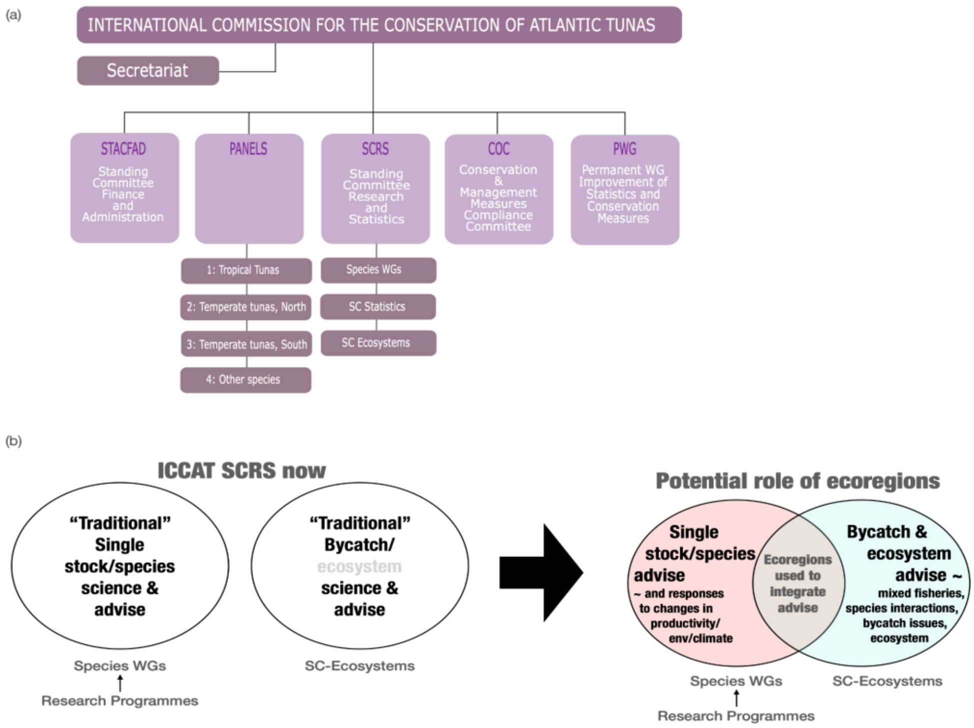


Figure 4. Organogram of Commission structure and illustrative example of how single species/stock science and advice is produced in the SCRS and the potential role of ecoregons to facilitate the integration of advice at more regional scales.

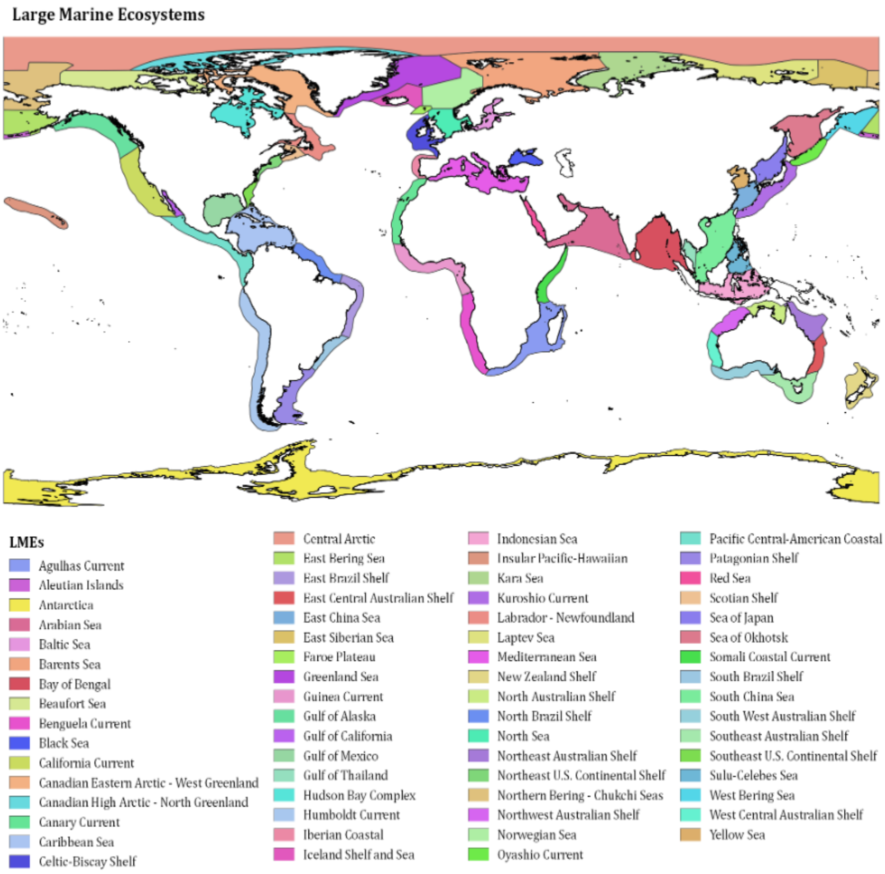


Figure 5. Large Marine Ecosystems.

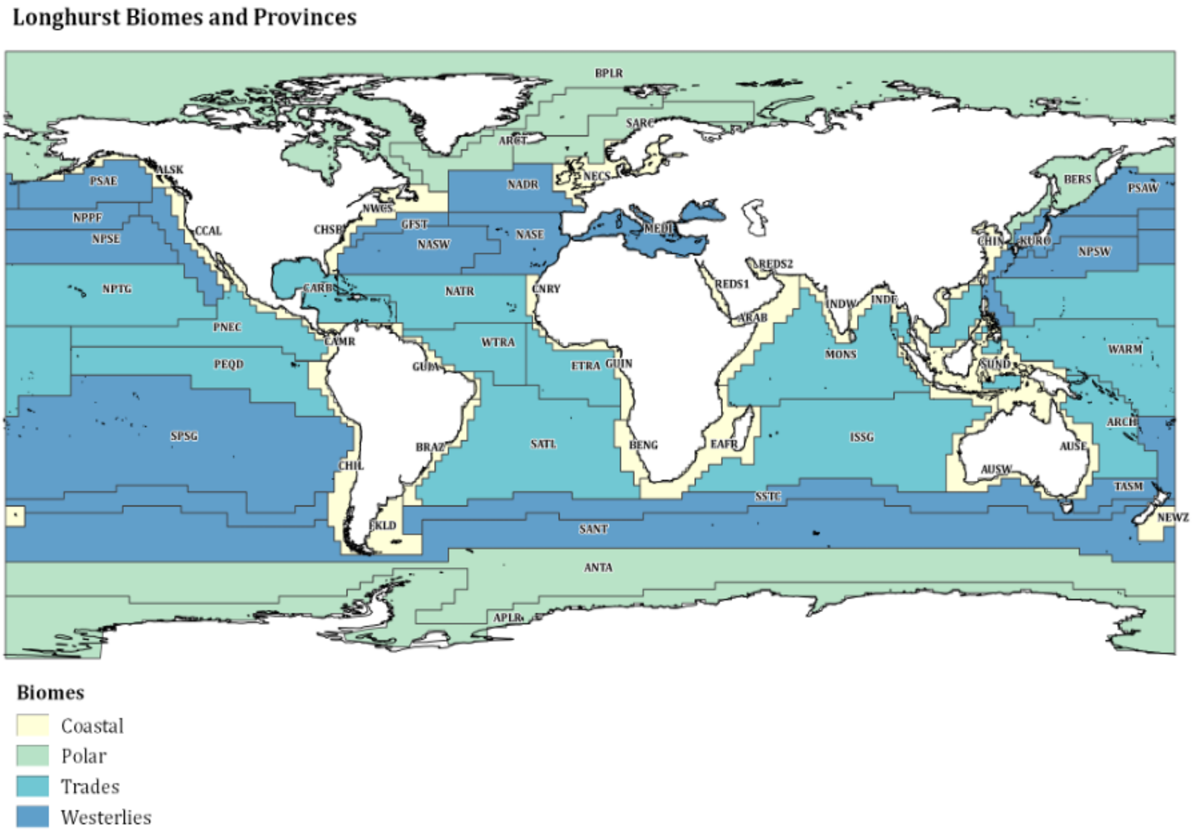


Figure 6. Longhurst biogeochemical provinces (black polygons) and biomes (color coded).

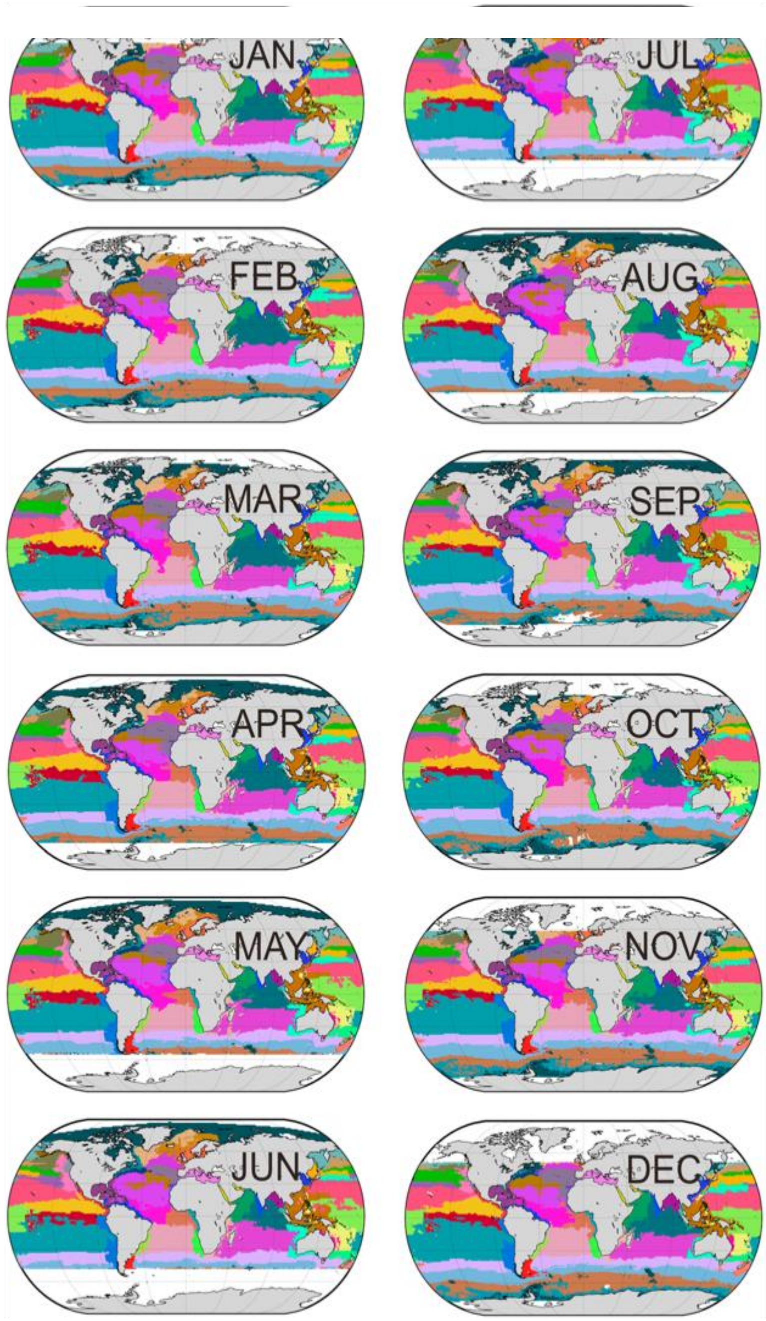


Figure 7. Monthly climatology of the spatial distribution of the Longhurst biogeochemical provinces (computed for the period from September 1997 to December 2007) (Reygondeau *et al* 2013).

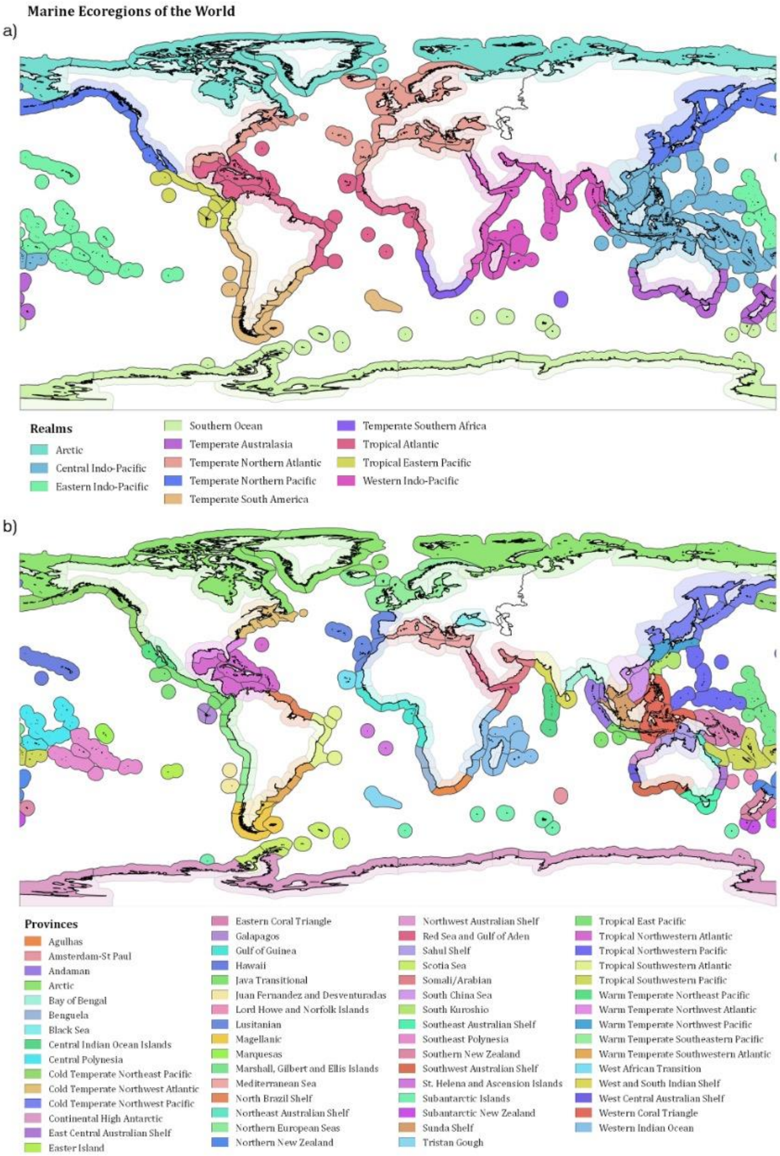


Figure 8. Marine Ecosystems of the World (MEOW). (a) Realms and (b) provinces.

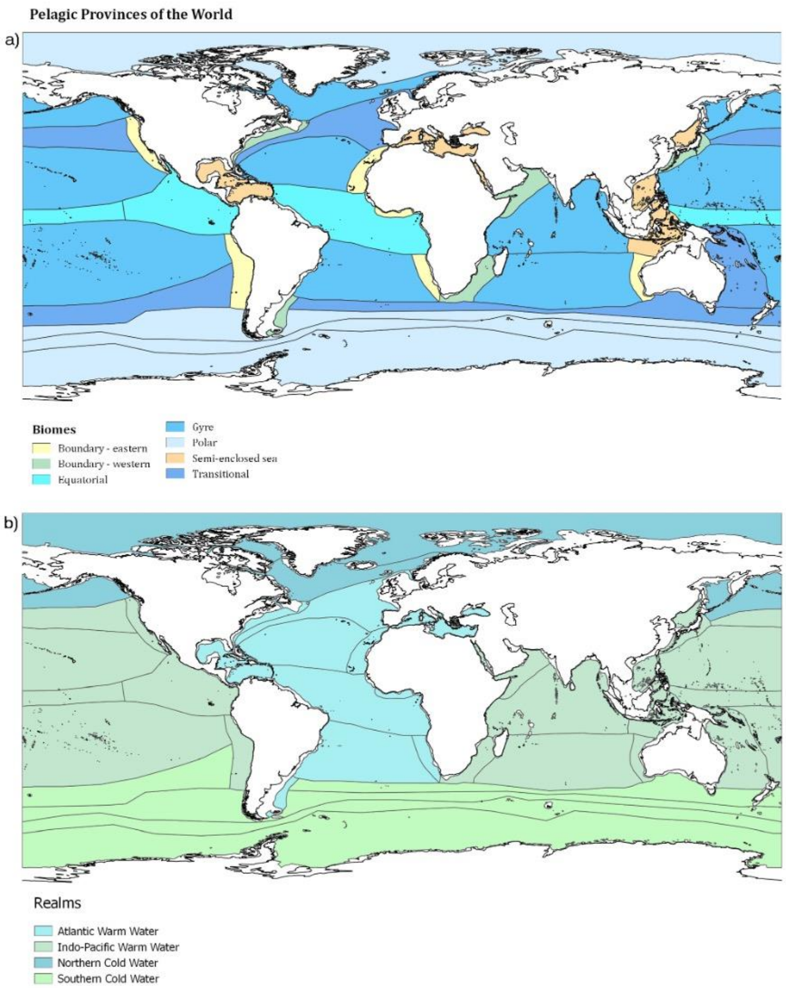


Figure 9. Pelagic Provinces of the World (PPOW). (a) Biomes and (b) Realms.

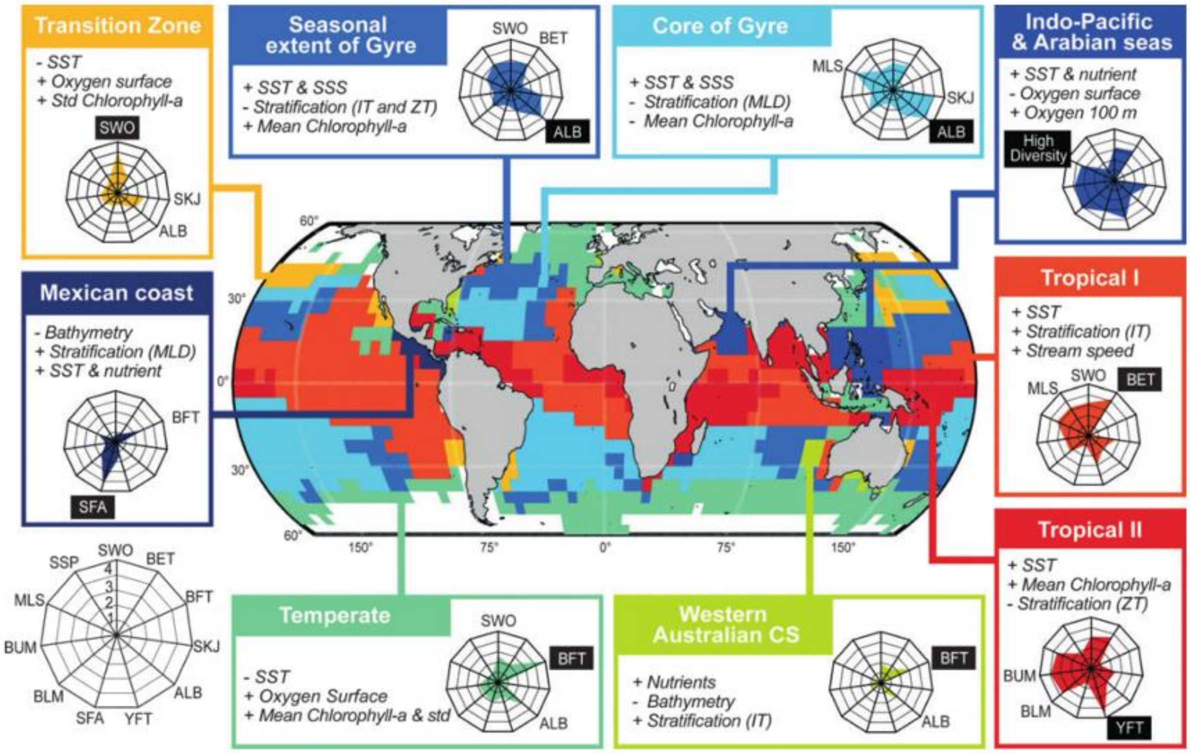


Figure 10. Tuna and Billfish Biogeographical Provinces (Reygondeau *et al* 2012).

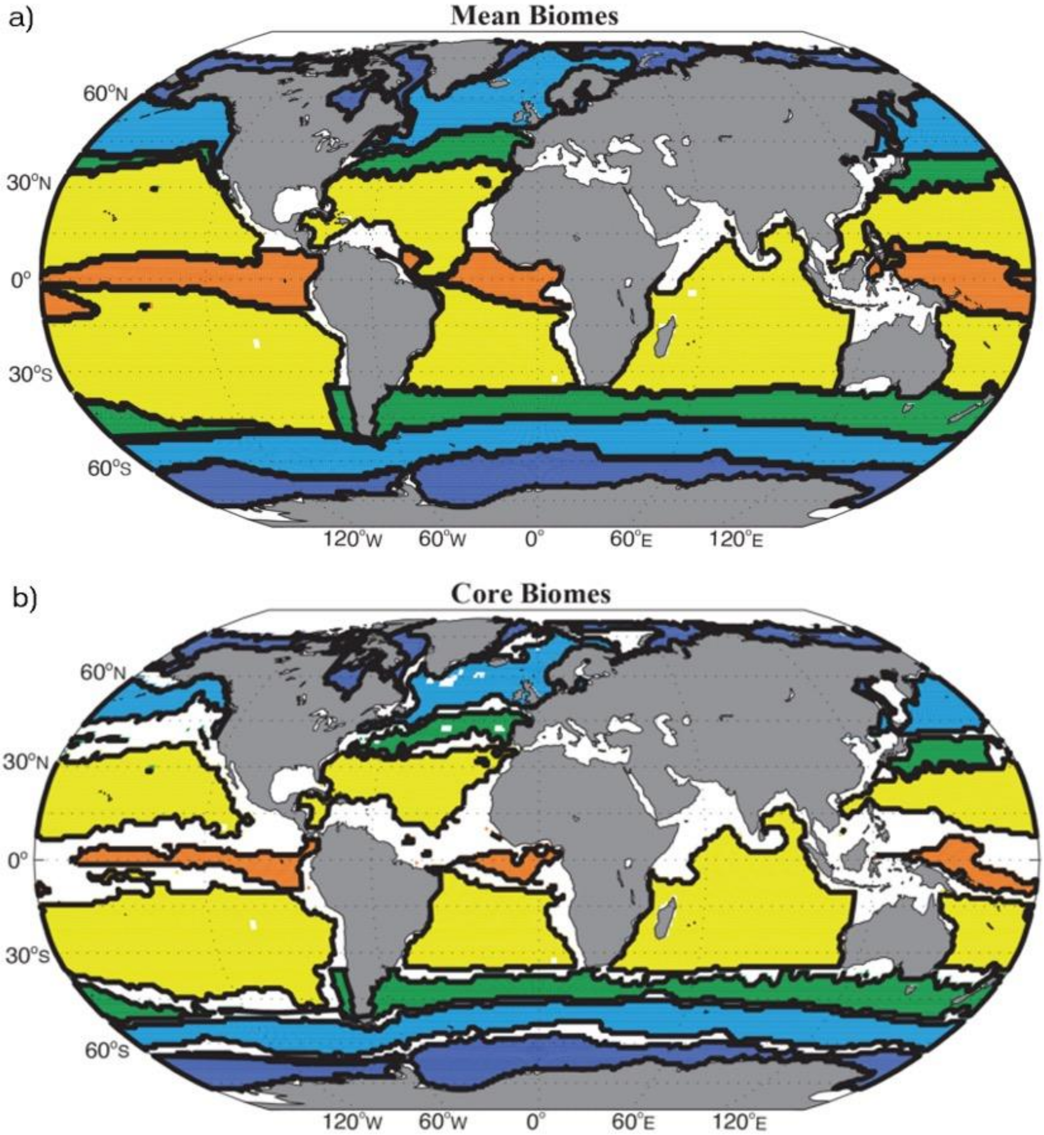


Figure 11. Global open-ocean biomes (a) mean biomes and (b) core biomes showing the interannual variability (Fay and McKinley *et al* 2014).

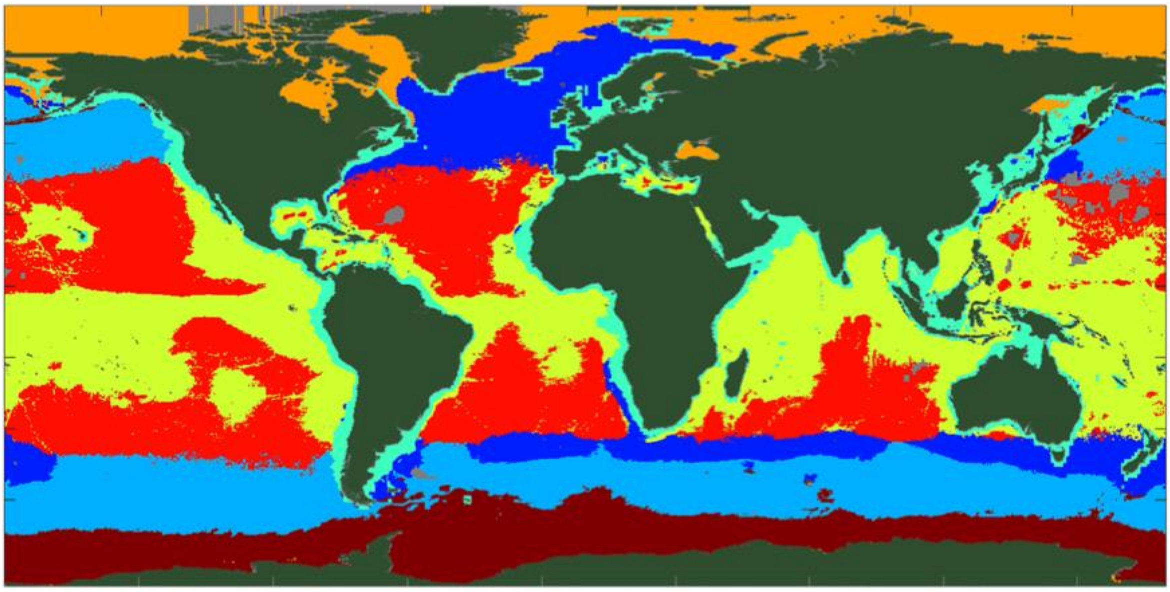


Figure 12. Maps of the seven-clusters marine ecosystem classification based on 20 environmental variables ([Zhao *et al* 2019]).

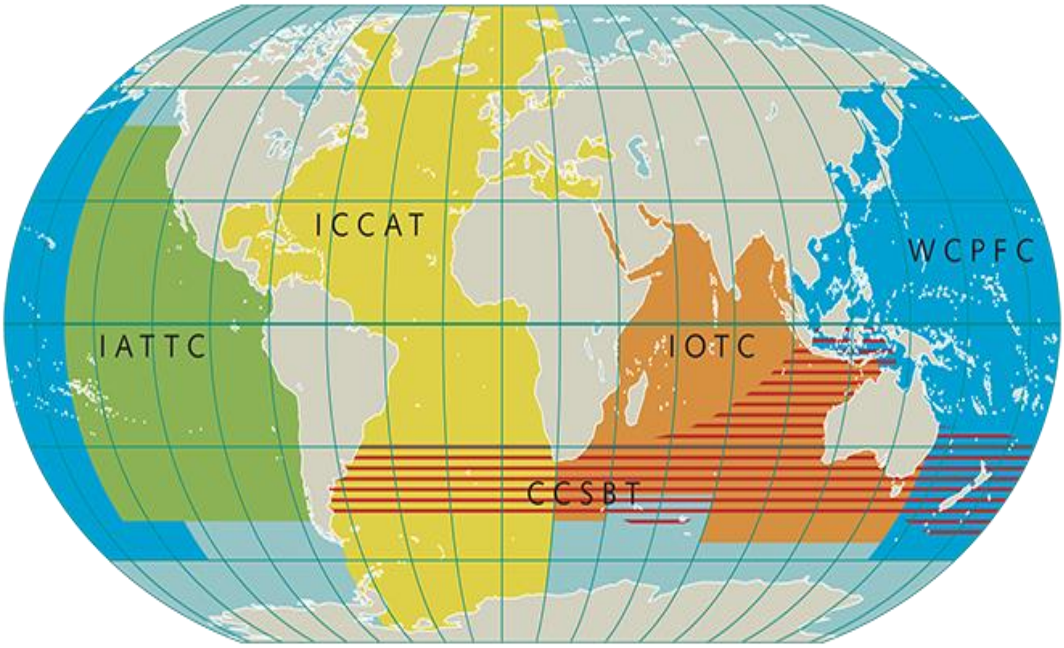


Figure 13. The Regional Fisheries Management Organizations that manage highly migratory tuna and tuna-like species, including ICCAT and CCSBT. Figure credit:
https://worldoceanreview.com/en/wor-2/fisheries/deep-sea-fishing/catching-fish-in-international-waters/

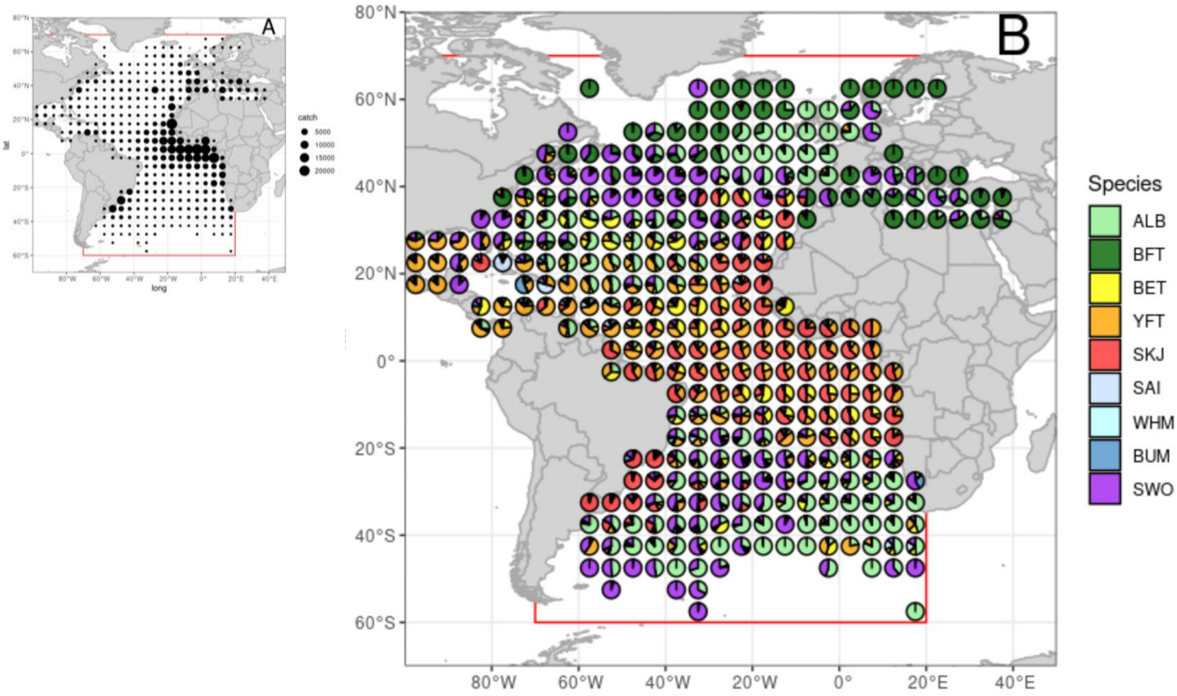


Figure 14. Spatial distribution of catches of the major ICCAT oceanic species (ALB, BET, WHM, BFT, BUM, SKJ, SAI, SWO, and YFT, see Table 4 for species codes) in the ICCAT convention area. (A) The median annual raised catch (MT; over 2006-2020) of the major ICCAT oceanic species as available in the CATDIS dataset. Circles are proportional to the average quantity of the catch in each grid cell over the period and (B) proportional catches of each species in each 5x5 grid scaled to unity.

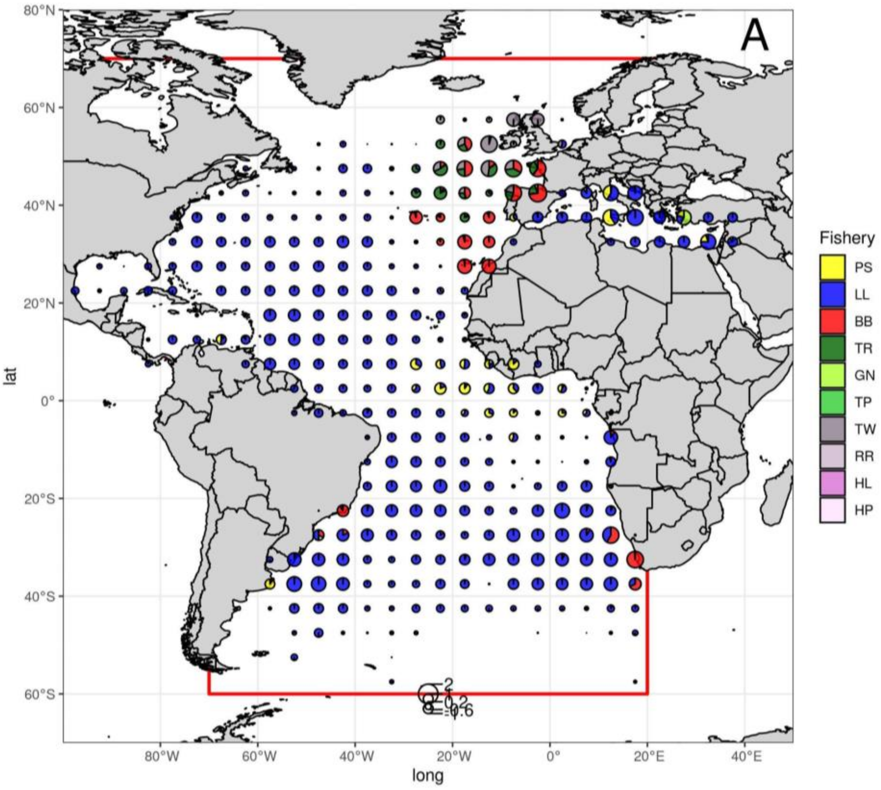


Figure 15A. The log of the catch (t) of **albacore tuna (ALB)** by fishery. Blue line delineates the stock boundaries (North Atlantic stock, South Atlantic stock and Mediterranean stock).

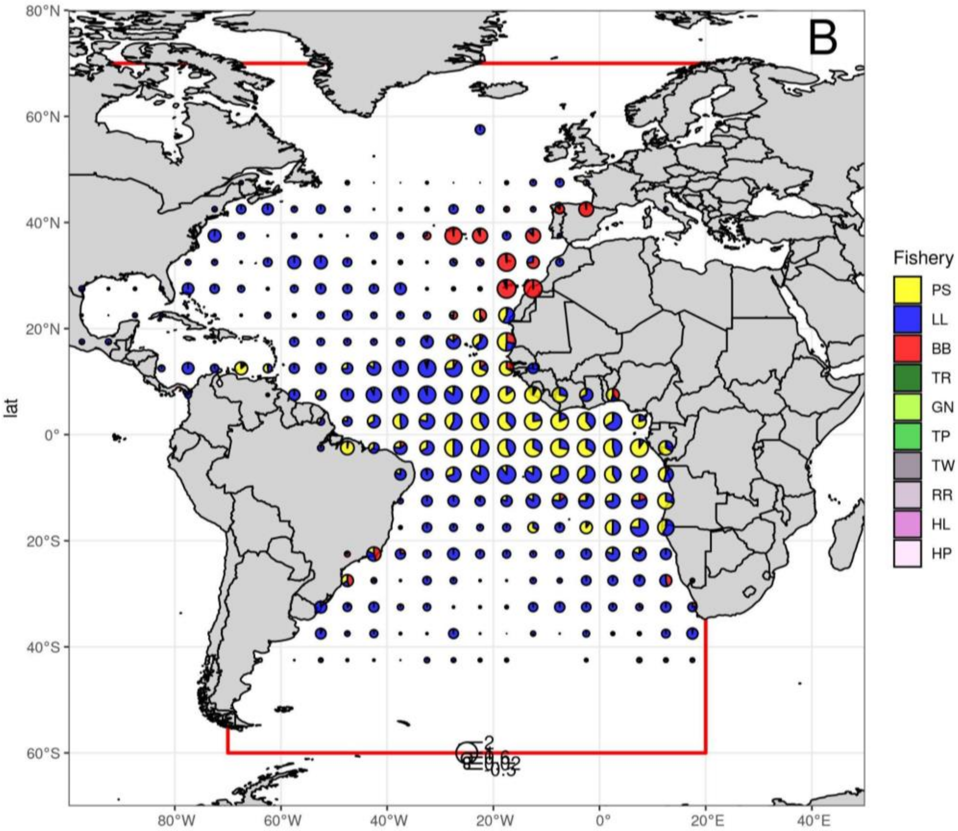


Figure 15B. The log of the catch (t) of **bigeye tuna (BET)** by fishery. Blue line delineates the stock boundaries (Atlantic bigeye tuna stock).

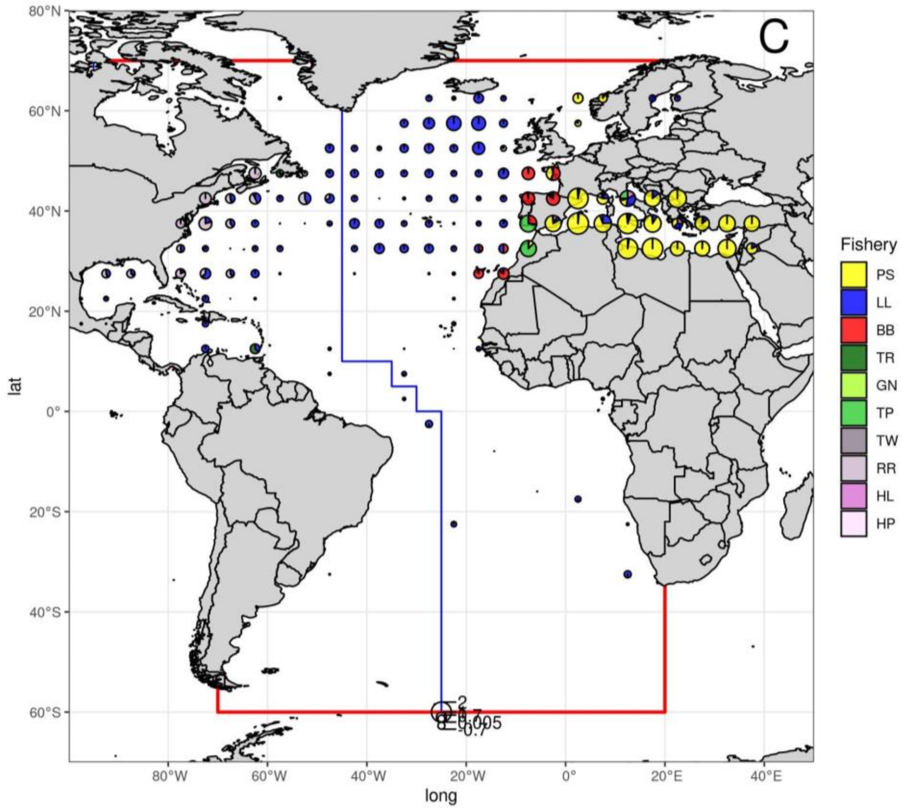


Figure 15C. The log of the catch (t) of **Atlantic bluefin tuna (BFT)** by fishery. Blue line delineates the stock boundaries (Eastern Atlantic stock, Western Atlantic stock).

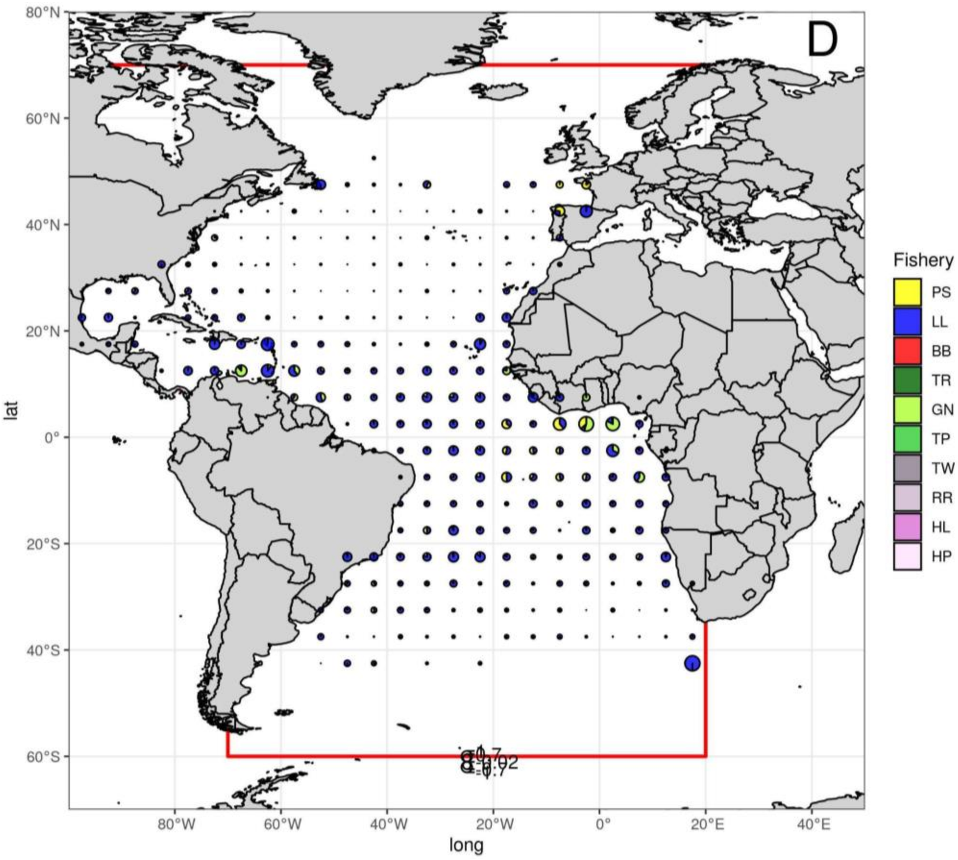


Figure 15D. The log of the catch (t) of **blue marlin (BUM)** by fishery. Blue line delineates the stock boundaries (Atlantic blue marlin stock).

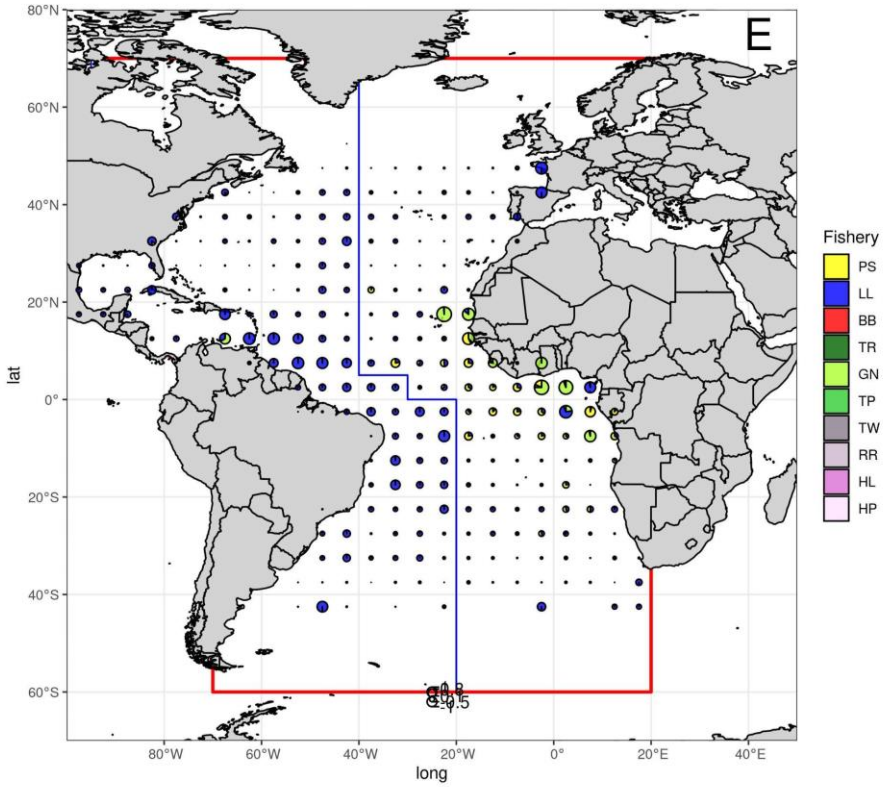


Figure 15E. The log of the catch (t) of **Atlantic sailfish (SAI)** by fishery. Blue line delineates the stock boundaries (Western Atlantic stock and eastern Atlantic stock).

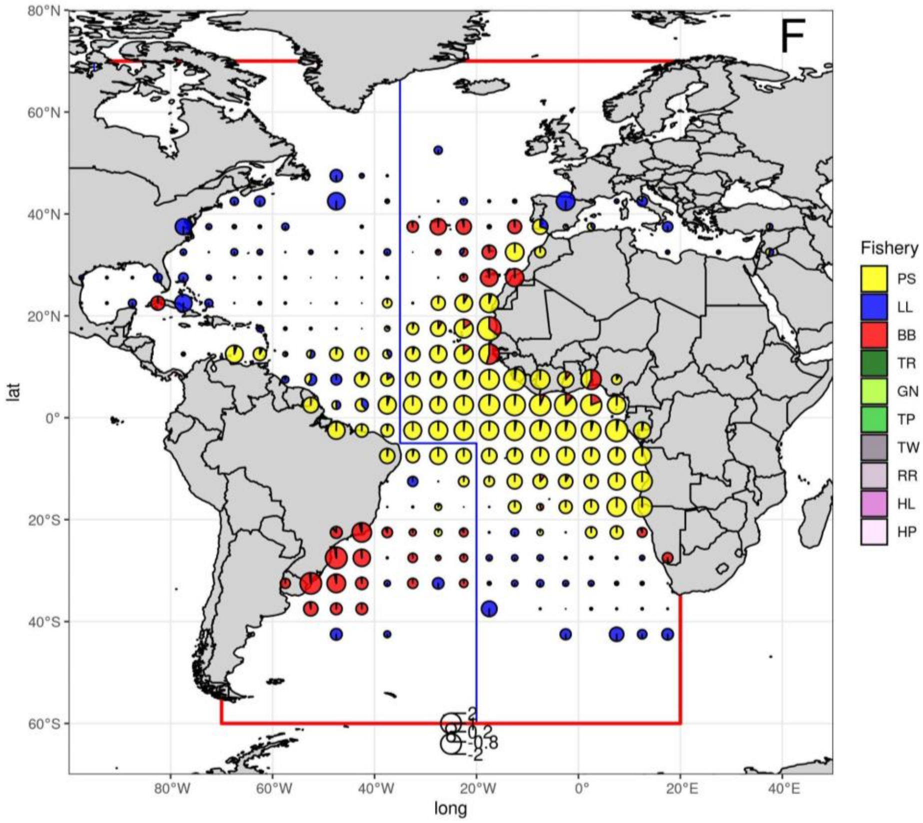


Figure 15F. The log of the catch (t) of **skipjack tuna (SKJ)** by fishery. Blue line delineates the stock boundaries (Western Atlantic stock and eastern Atlantic stock)

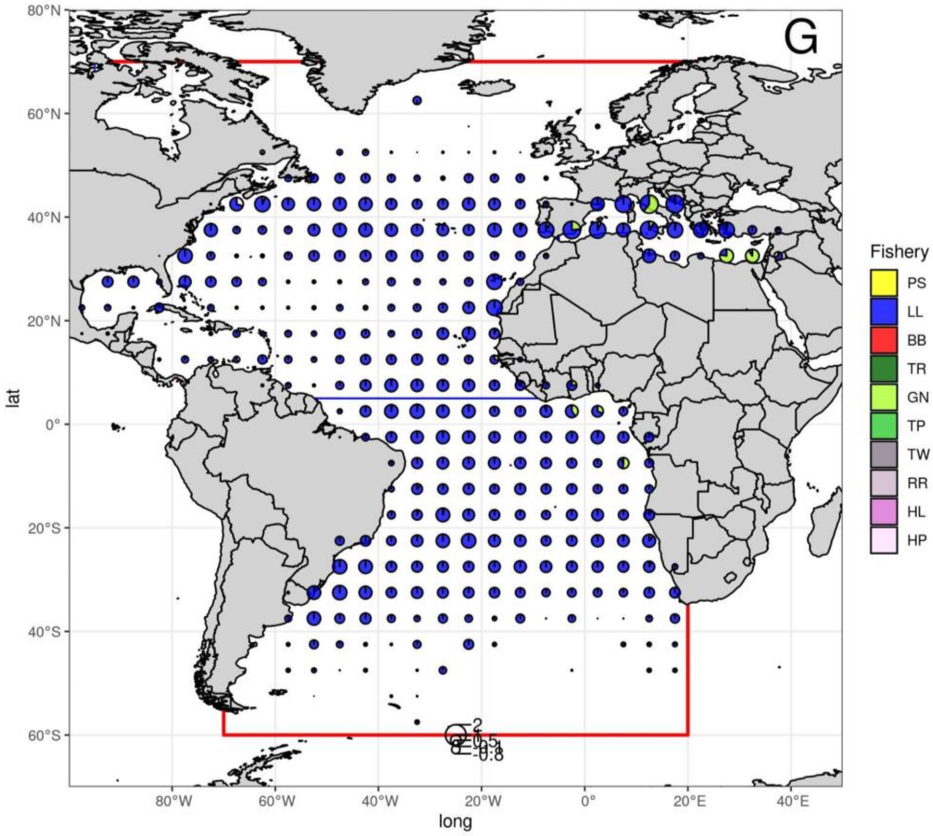


Figure 15G. The log of the catch (t) of **swordfish (SWO)** by fishery. Blue line delineates the stock boundaries (North Atlantic stock, South Atlantic stock and Mediterranean stock).

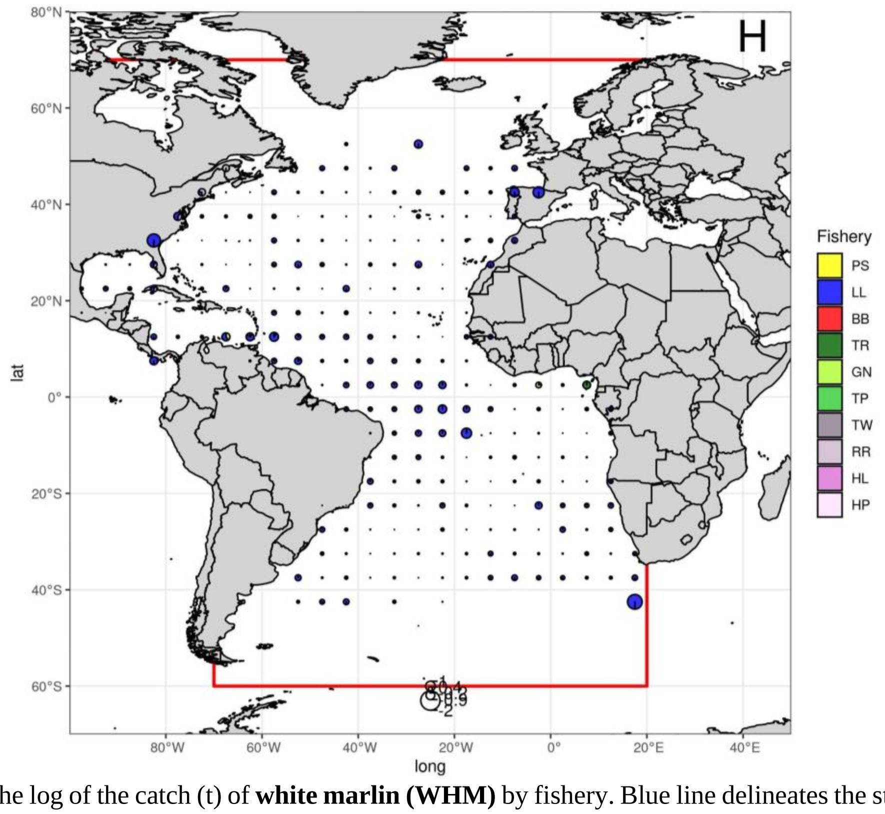


Figure 15H. The log of the catch (t) of **white marlin (WHM)** by fishery. Blue line delineates the stock boundaries (Atlantic white marlin stock).

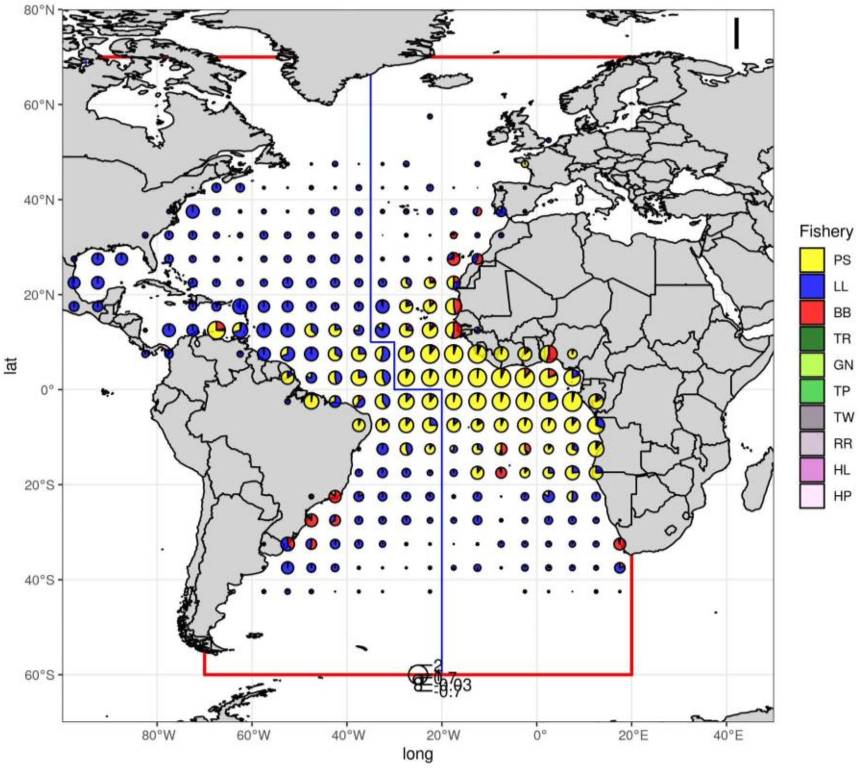


Figure 15I. The log of the catch (t) of **yellowfin tuna (YFT)** by fishery. Blue line delineates the stock boundaries (Western Atlantic stock and eastern Atlantic stock, yet the stock assessment is done at the basin scale).

Figure 15. The spatial distribution of the log of the median annual catch (MT) over 2006-2020 for each of the major ICCAT species as available in the CATDIS database (**Table 3** for data information, **Table 4** for species codes). Pies are proportional to the log of the median annual catch with the different pie slices representing the different fisheries that report catches of these species (see **Table 5** for gear codes). The red polygon represents the ICCAT convention area, and the blue polygons represent the ICCAT stock boundaries for each species.

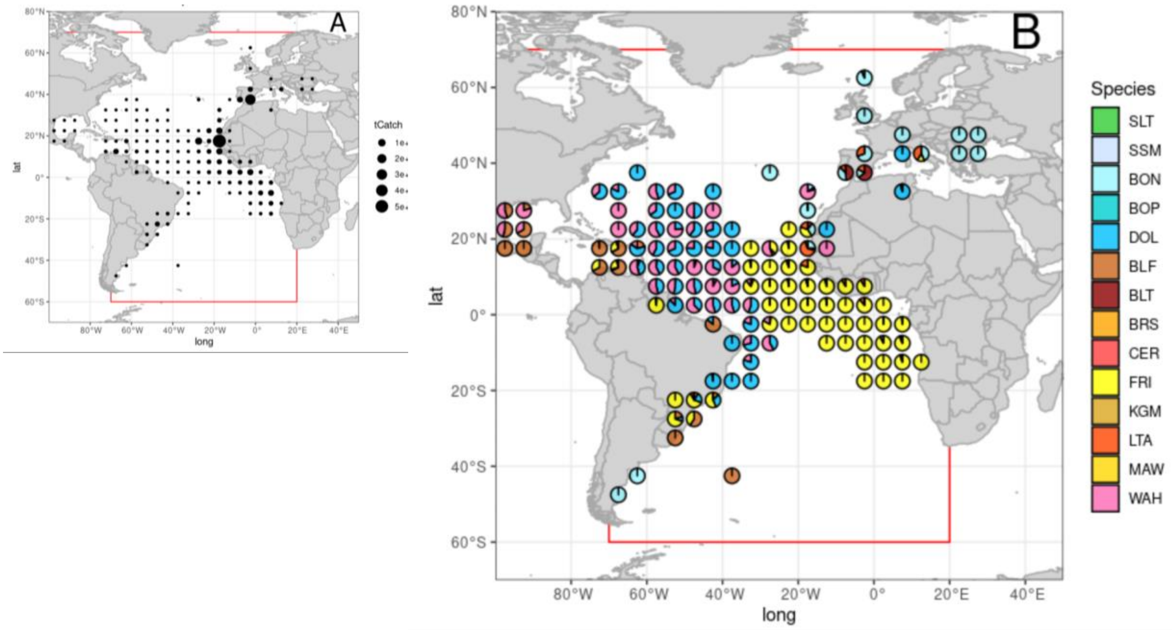


Figure 16. Spatial distribution of catches of the small ICCAT tuna species (see **Table 4** for species codes) in the ICCAT convention area. (A) The median annual raised catch (MT; over 2006-2020) of the small ICCAT tuna species as available in the T2CE dataset (see **Table 3** for data information). Circles are proportional to the average quantity of the catch in each grid cell over the period and (B) proportional catches of each species in each 5x5 CWP grid scaled to unity.

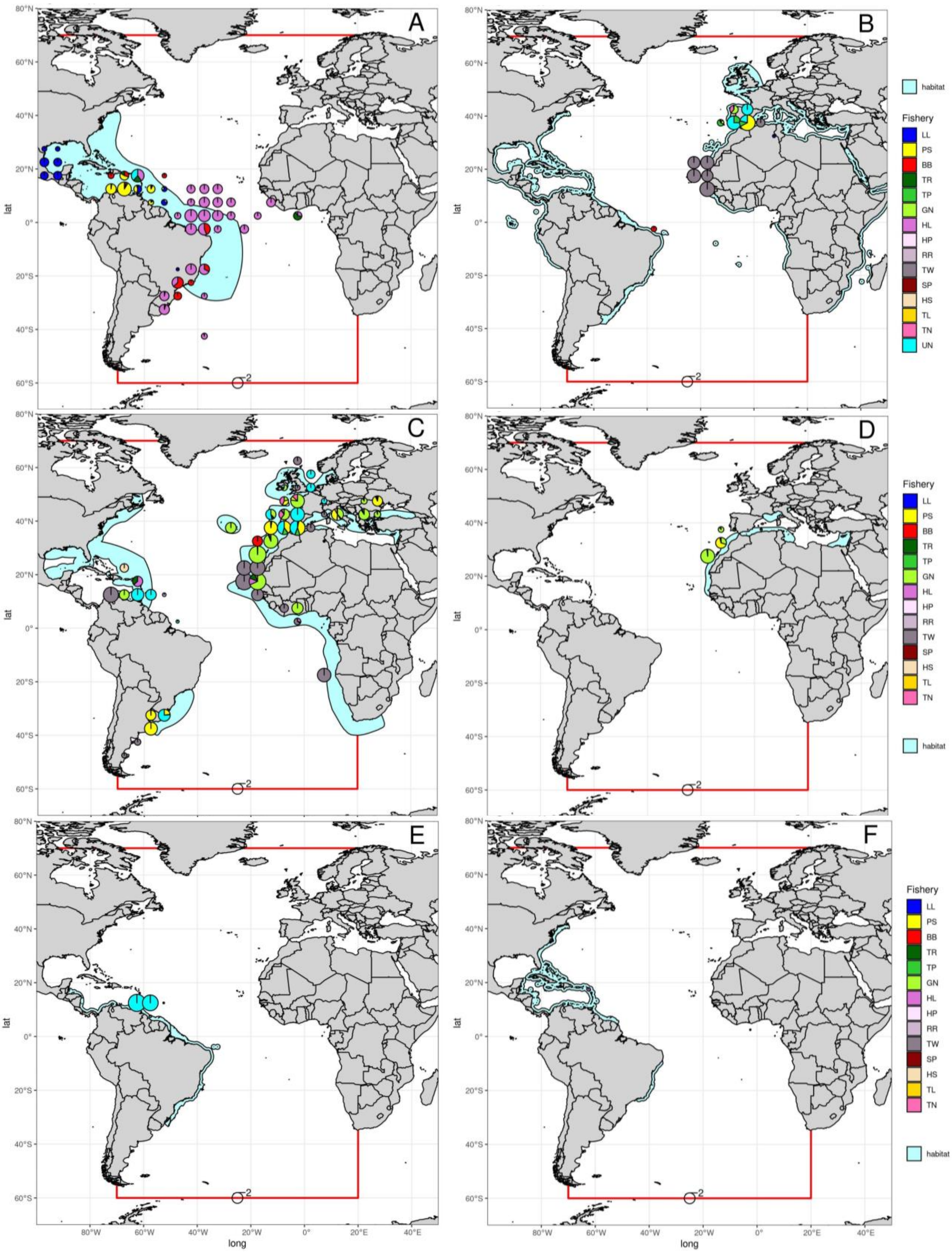


Figure 17A-F. The log of the catch (t) of A) **blackfin tuna (BLF)** and B) **bullet tuna (BLT),** C) **Atlantic bonito (BON)**, D) **plain bonito (BOP)**, E) **serra Spanish mackerel (BRS)**, and F) **cero (CER)** by fishery.

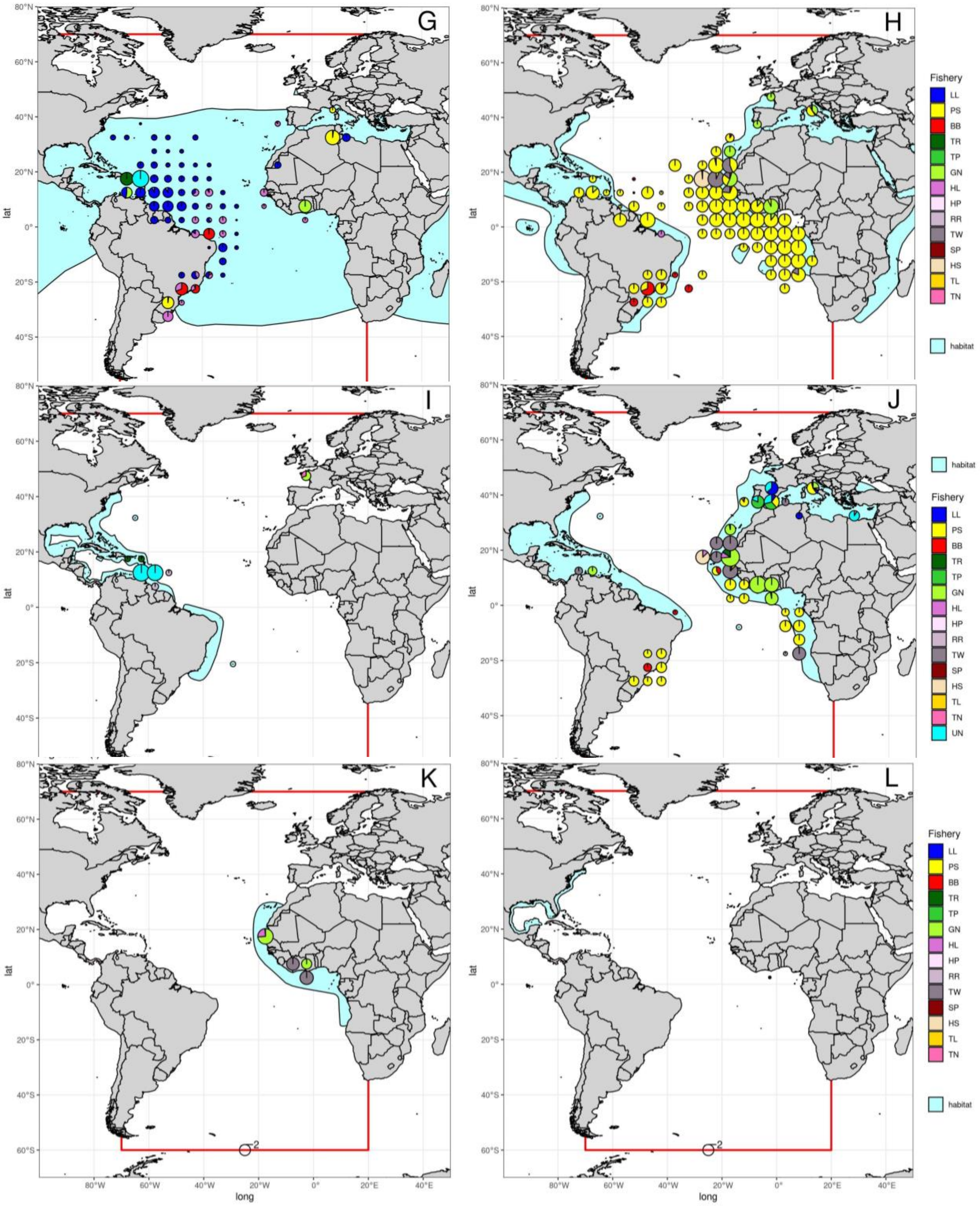


Figure 17 G-L-. The log of the catch (t) of, G) **common dolphinfish (DOL)**, H) **frigate tuna (FRI),** I) **king mackerel (KGM)**, J) **little tunny (LTA),** K) **West African Spanish mackerel (MAW)**, L) **Atlantic Spanish mackerel (SSM)** and M) **wahoo (WAH)** by fishery.

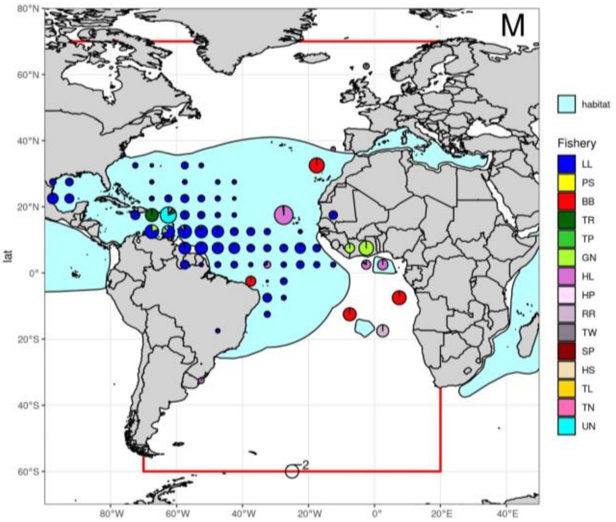


Figure 17M. The spatial distribution of the log of the median annual catch (MT) over 2006-2020 for each of the ICCAT neritic species of tunas, bonitos and Spanish mackerels as available in the Task 2 catch and effort database (**Table 3** for data information, **Table 4** for species codes). Pies are proportional to the log of the median annual catch with the different pie slices representing the different fisheries that report catches of these species (see **Table 5** for gear codes). The red polygon represents the ICCAT convention area, and the blue polygons represent the geographic range of species (Source: The IUCN of Threatened Species).

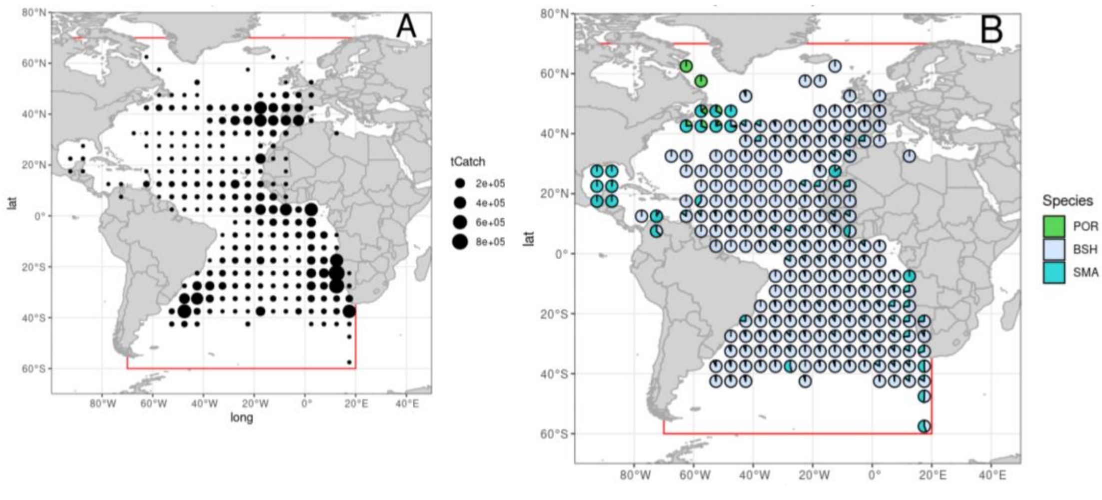


Figure 18. Spatial distribution of catches of the shark species (see **Table 4** for species codes) caught by ICCAT fisheries (Convention area delineated by the red polygon). (A) The median annual raised catch (MT; over 2006-2020) of the shark species as available in the T2CE dataset (see **Table 3** for data information). Circles are proportional to the median quantity of the catch in each grid cell over the period and (B) proportional catches of each species in each 5°x5° CWP grid scaled to unity.

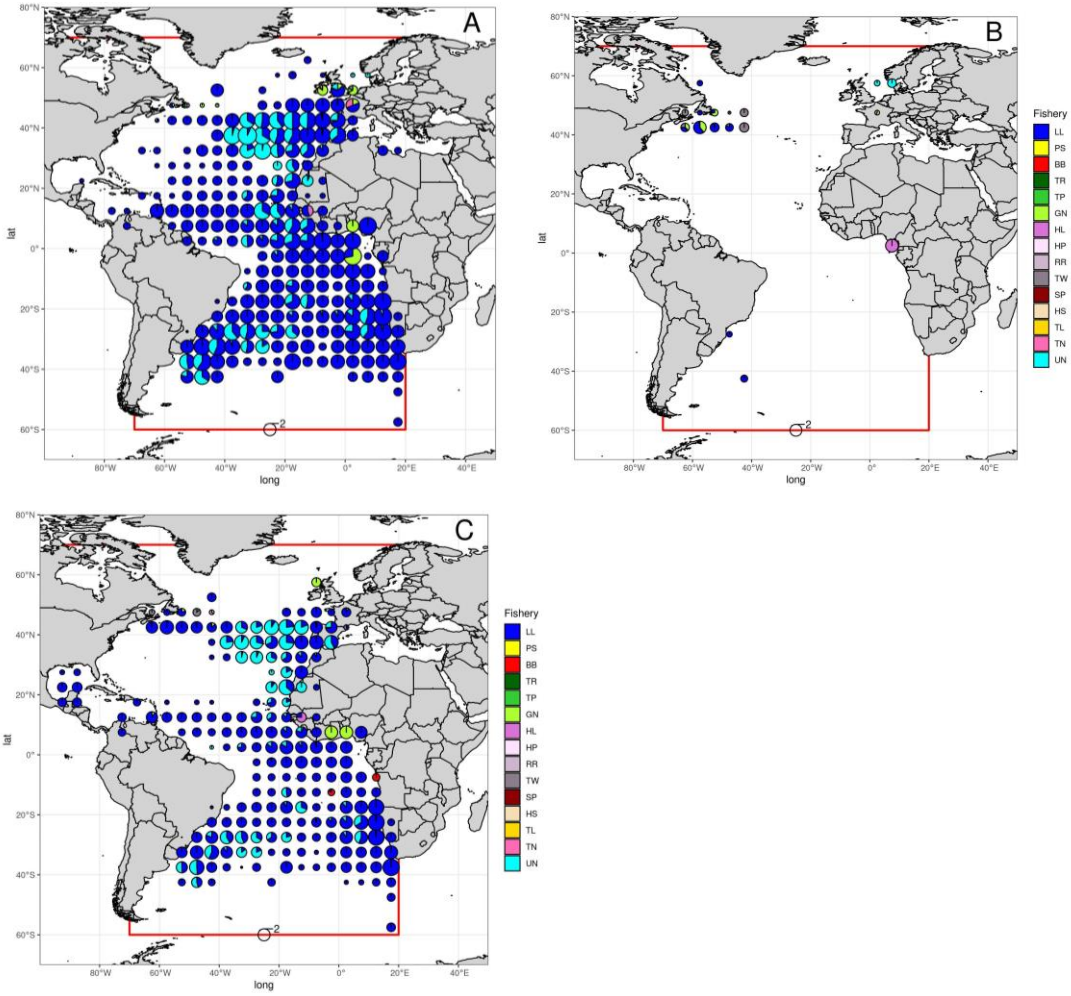


Figure 19. The spatial distribution of the log of the median annual catch (MT) over 2006-2020 for each of the ICCAT shark species as available in the Task 2 catch and effort database A) **blue shark BSH**, B) **porbeagle shark POR**, and C) **shortfin mako shark SMA** (**Table 3** for data information, **Table 4** for species codes). Pies are proportional to the log of the median annual catch with the different pie slices representing the different fisheries that report catches of these species (see **Table 5** for gear codes). The red polygon represents the ICCAT convention area.

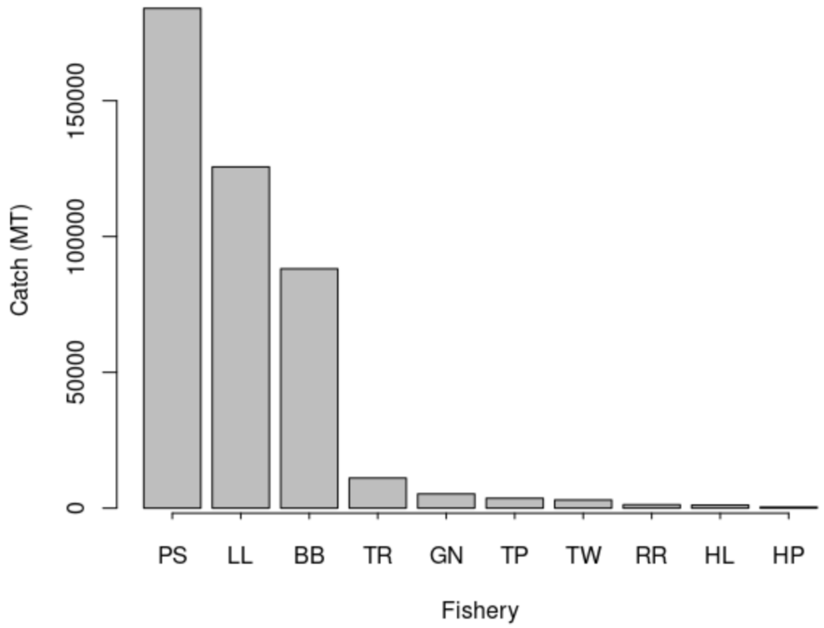


Figure 20. Major ICCAT fisheries by fishing gear (see **Table 5** for gear codes) ordered by their contribution to the overall raised catch (MT) from 2006-2020.

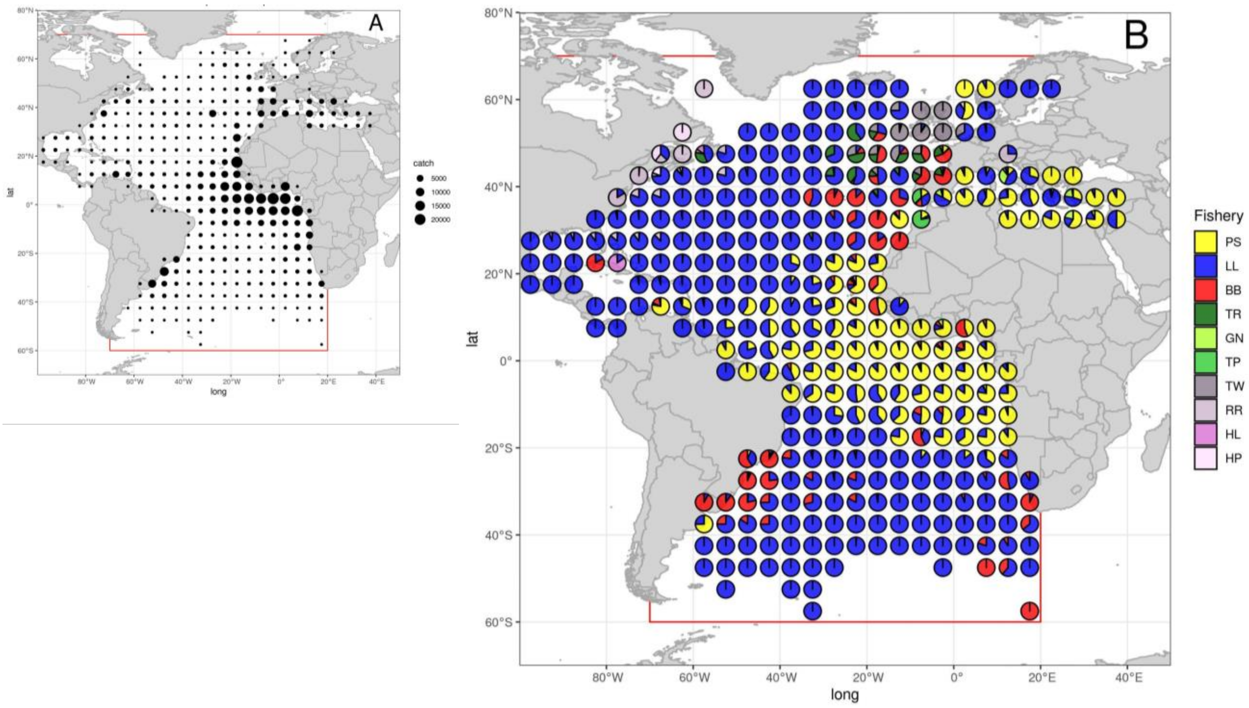
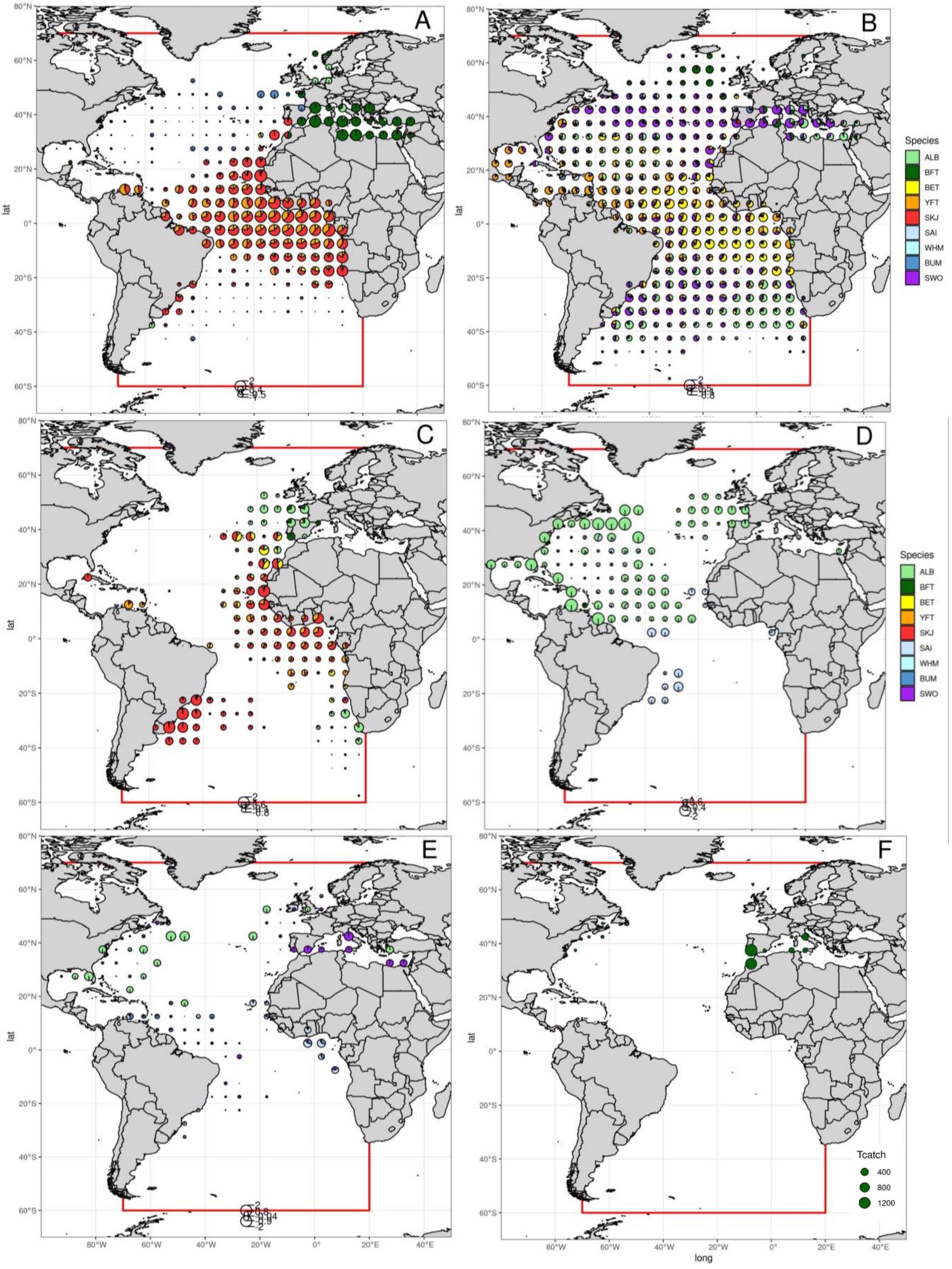


Figure 21. Spatial distribution of catches caught by ICCAT fisheries (see **Table 5** for fishery codes) (convention area delineated by the red polygon). (A) The median annual raised catch (MT; over 2006-2020) of the major ICCAT oceanic species as available in the CATDIS dataset. Circles are proportional to the average quantity of catch in each grid cell over the period. (B) proportional catches of each fishery in each 5x5 grid scaled to unity.


A
B
C
D
E
F
Species
ALB
BFT
BET
YFT
SKJ
SAI
WHM
BUM
SWO
Tcatch
400
800
1200
lat
long
80°N
60°N
40°N
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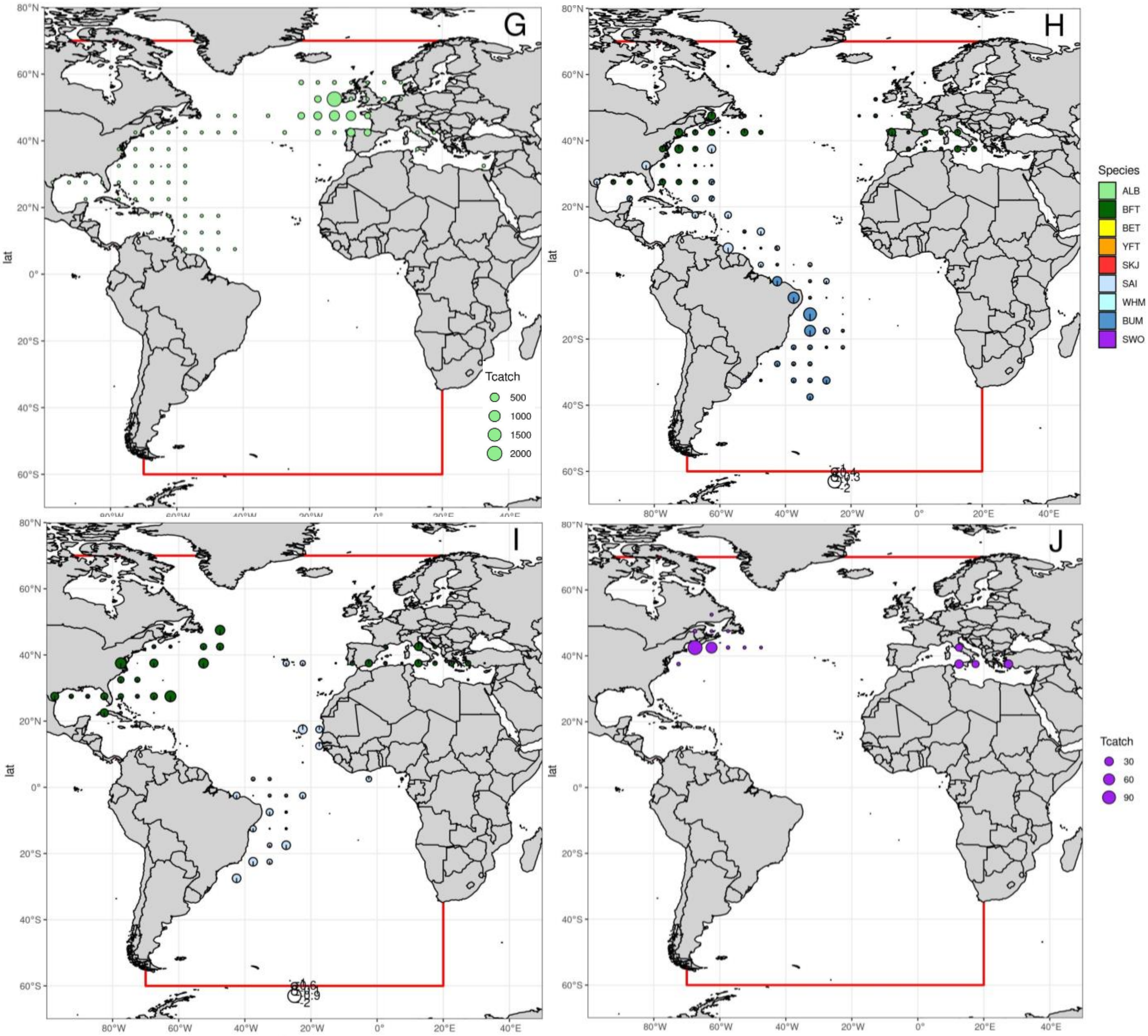

Figure 22A-F. The log of the catch (t) of A) **purse seine (PS)**, B) **longline (LL),** C) **baitboat (BB)**, and D) **trolling (TR),** E) **gilnnet (GN)**, F) **trap (TP)** G) **Trawling (TW)**, H) **rod and reel (RR)** , I) **handline (HL)**, and J) **harpoon (HP)** by species.

Figure 22A-J. The spatial distribution of the log of the median annual catch (MT) over 2006-2020 for each of the ICCAT fisheries as available in the raised CATDIS database (**Table 3** for data information, **Table 5** for fishery codes), with the exception of F, G, and J which plot unlogged data. Pies in A-E,H, and I are proportional to the log of the median annual catch with the different pie slices representing the different species reported in the catches of these fisheries (see **Table 4** for species codes) while circles in F, G, and J are proportional to the median annual catch with colors representing the different species reported in the catches of these fisheries. The red polygon represents the ICCAT convention area.

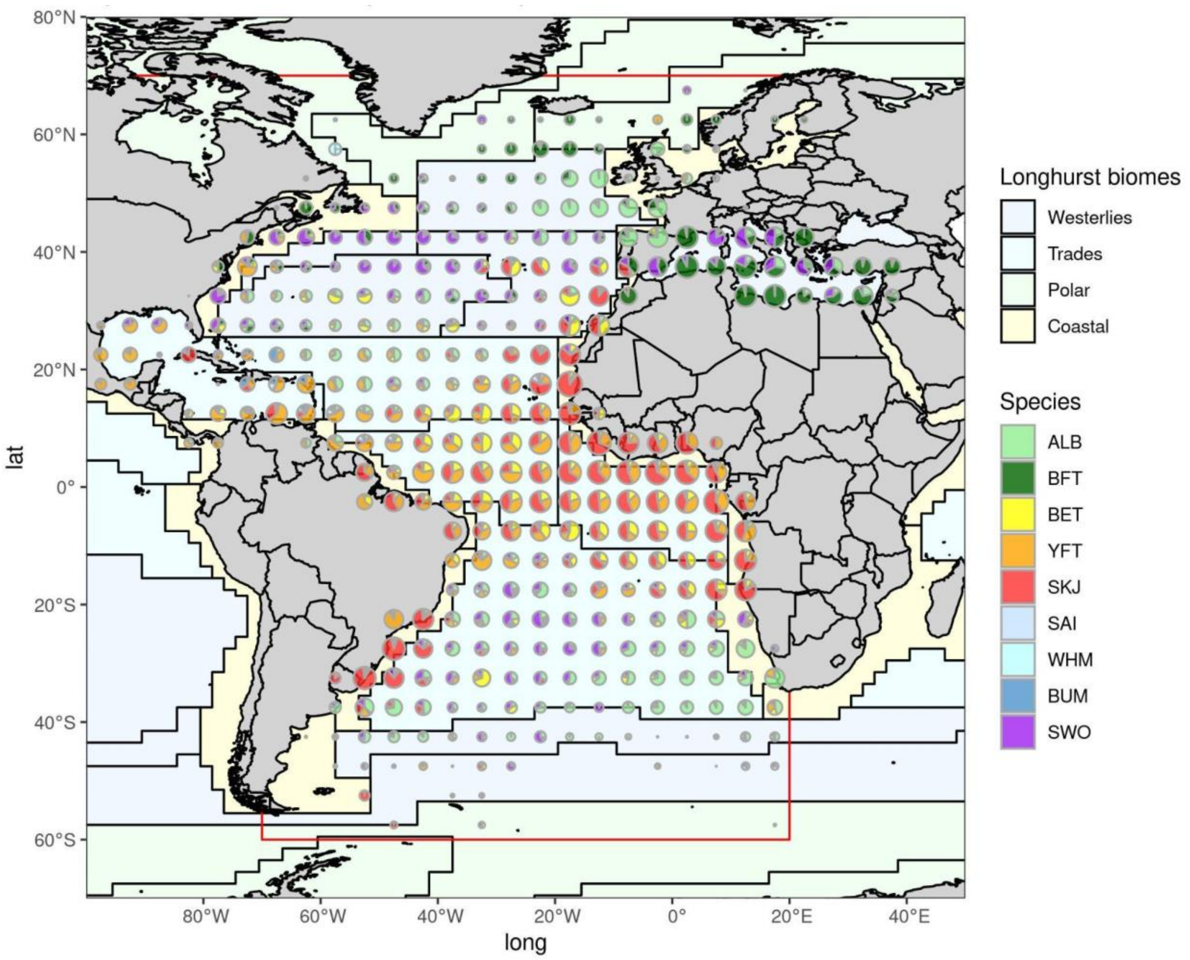

Figure 23. The spatial distribution of the raised median annual catch (2006-2020) of the major oceanic tuna and billfishes species (see **Table 4** for species codes) overlapping with the Longhurst provinces (in black). Pie slices represent the proportion of the total catch of each species per grid cell and pie sizes represent the log of the median annual catch (MT). Longhurst provinces are filled according to their biome and the ICCAT convention area is outlined in red. See **Figure 27** for province names.

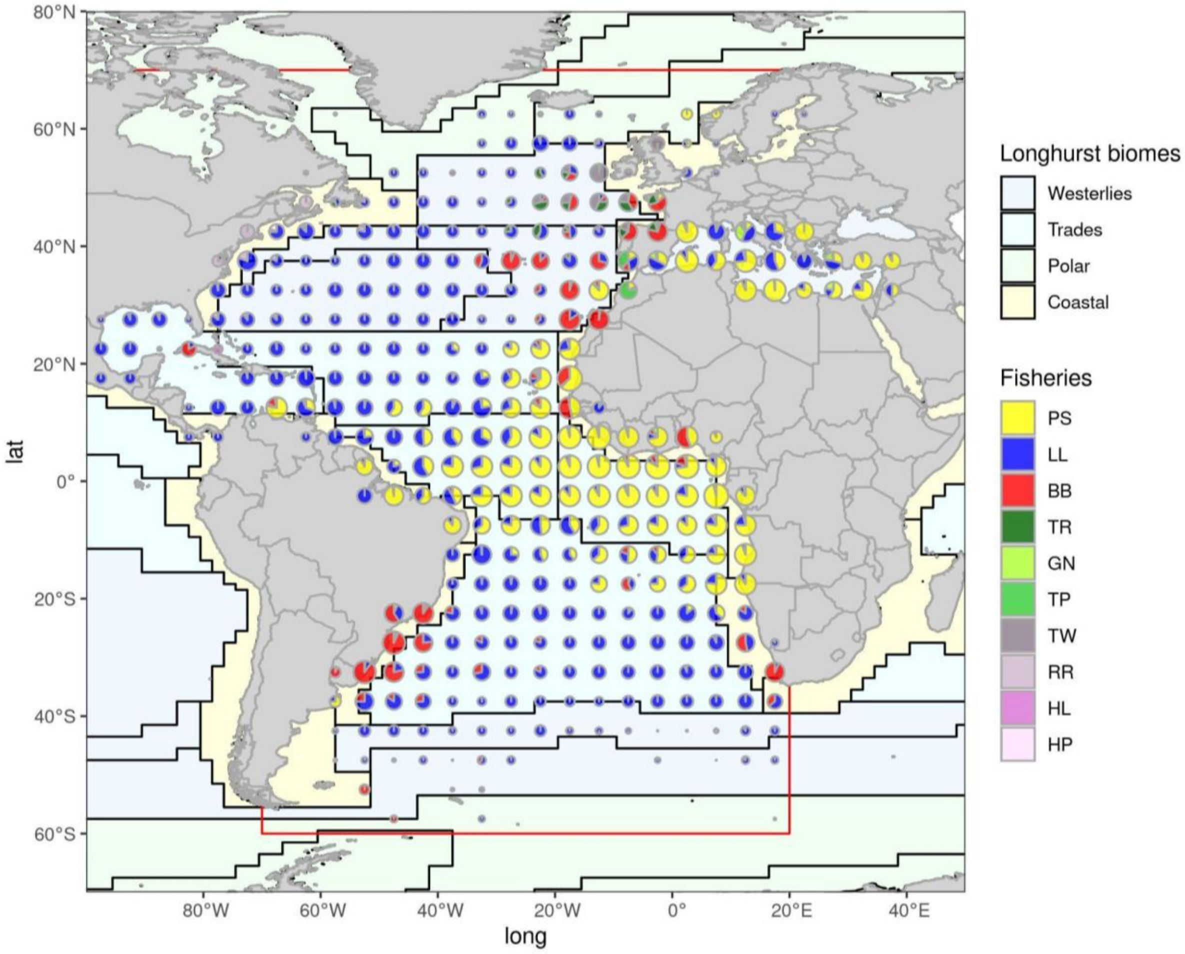

Figure 24. The spatial distribution of the raised median annual catch (2006-2020) of the major fisheries (see **Table 5** for fisheries codes) overlapping with the Longhurst provinces (in black). Pie slices represent the proportion of the total catch of each fishery per grid cell and pie sizes represent the log of the median annual catch (MT). Longhurst provinces are filled according to their biome and the ICCAT convention area is outlined in red. See **Figure 27** for province names.

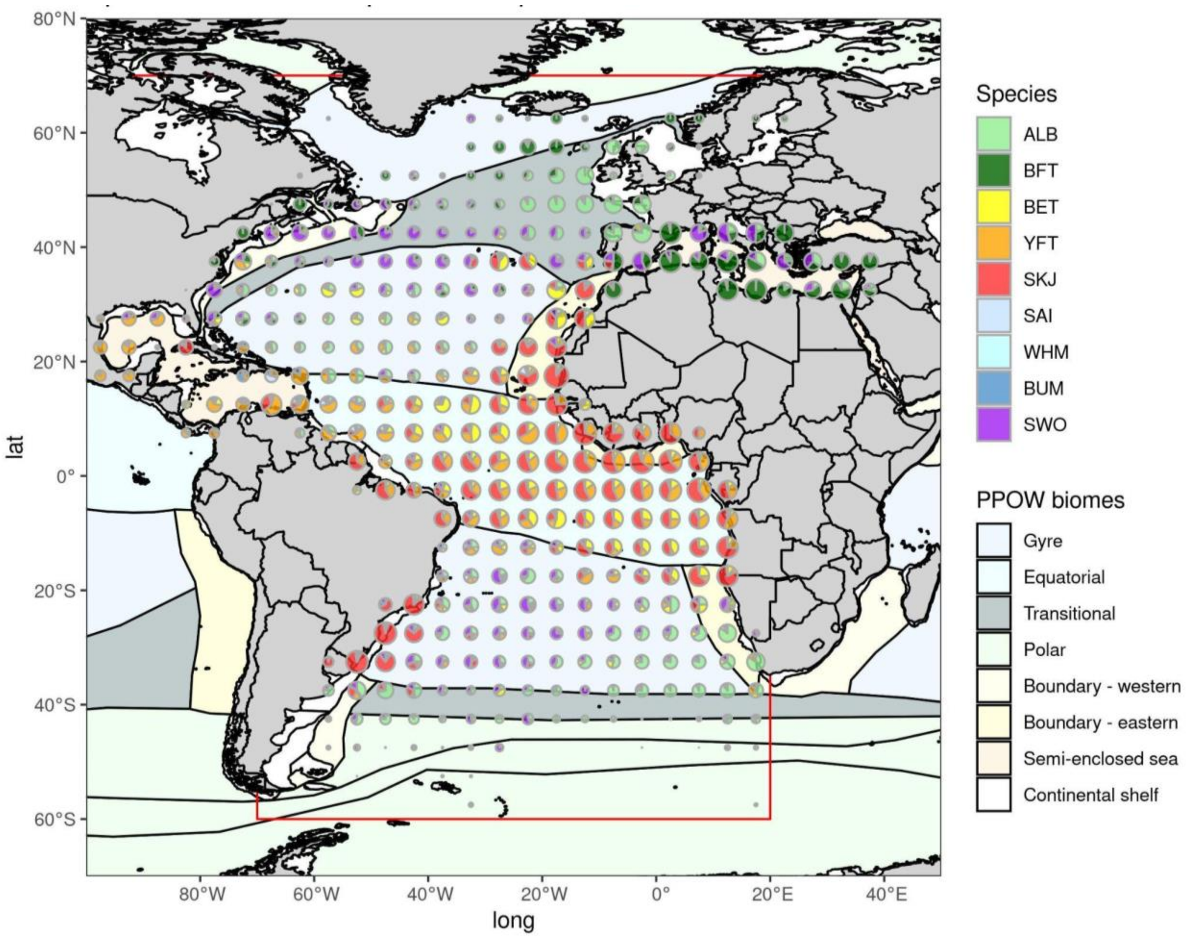

Figure 25. The spatial distribution of the raised median annual catch (2006-2020) of the major oceanic species (see **Table 4** for species codes) overlapping with the PPOW provinces (in black). Pie slices represent the proportion of the total catch of each species per grid cell and pie sizes represent the log of the median annual catch (MT). PPOW provinces are filled by their biome, noting that PPOWs do not include the continental shelf, which here is displayed in white. The ICCAT convention area is outlined in red. See **Figure 27** for province names.

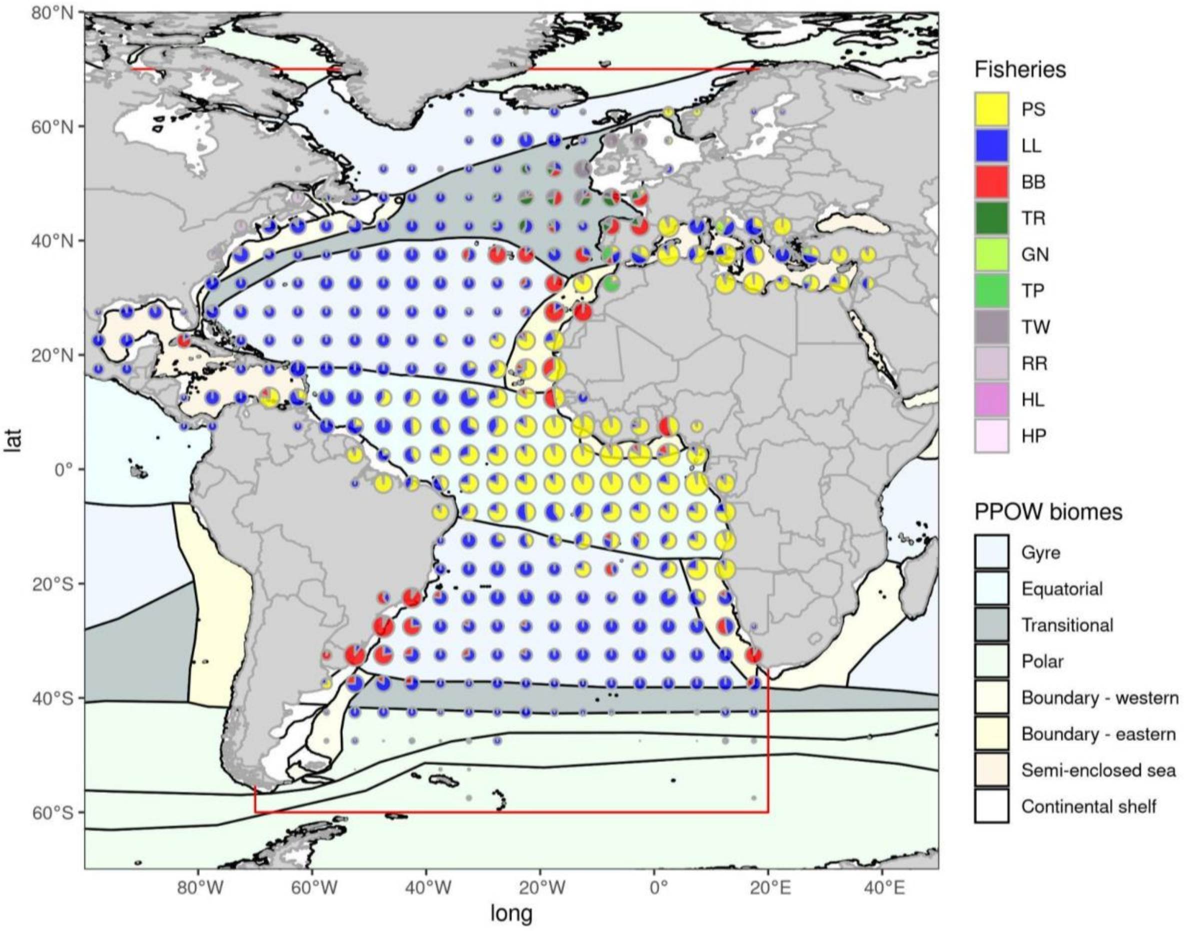

Figure 26. The spatial distribution of the raised median annual catch (2006-2020) of the major fisheries (see **Table 5** for fisheries codes) overlapping with the PPOW provinces. Pie slices represent the proportion of the total catch of each fishery per grid cell and pie sizes represent the log of the median annual catch (MT). PPOW provinces are filled by their biome, noting that PPOWs do not include coastal provinces, which here are displayed in white. The ICCAT convention area is outlined in red. See **Figure 27** for province names.

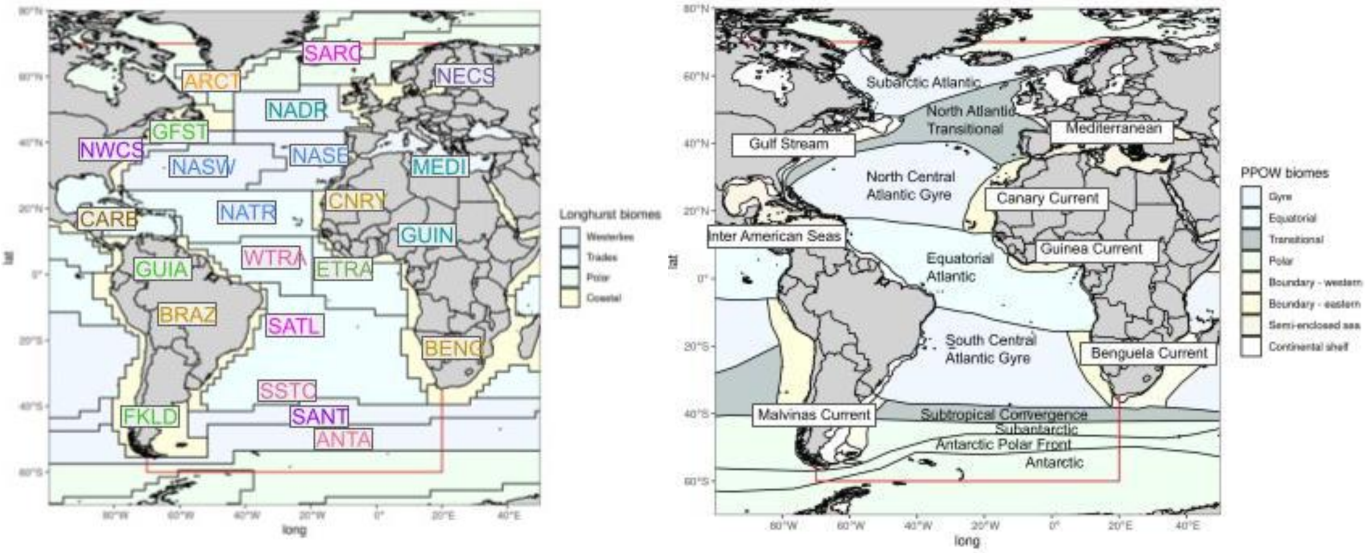

Figure 27. The Longhurst and PPOW biogeographical provinces with their province's names. Province colors correspond to each classifications' biome.

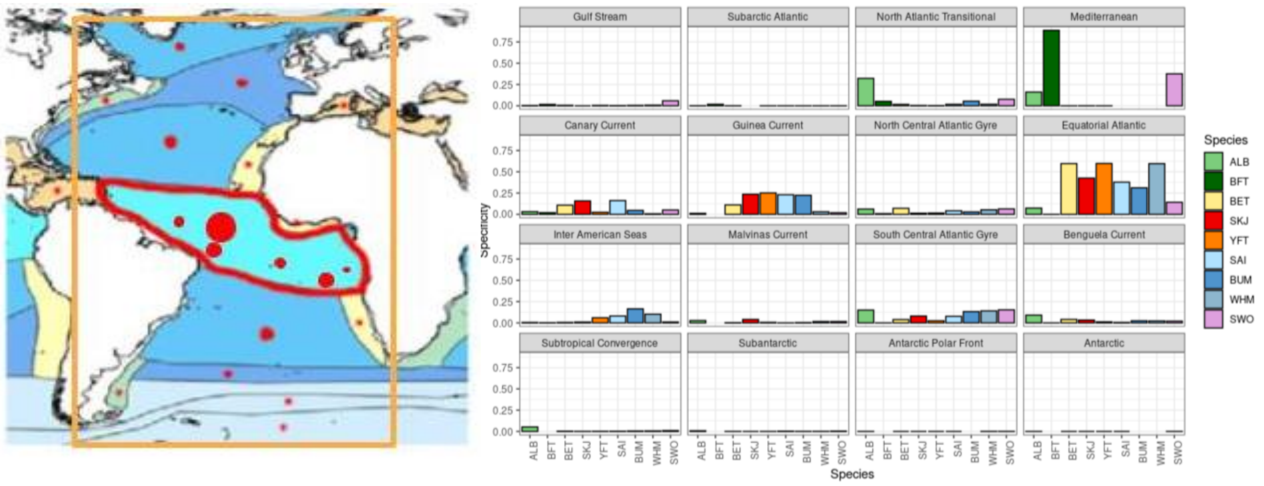

Figure 28. Specificity indicator. (left) A schematic of the calculation of the specificity indicator whereby the sum of the catch of species i in a single province j (e.g. that outlined in red) is divided by the sum of the catch of species in all provinces (outlined in orange polygon). (right) An example of the specificity indicator calculated on ICCAT species in PPOW provinces.

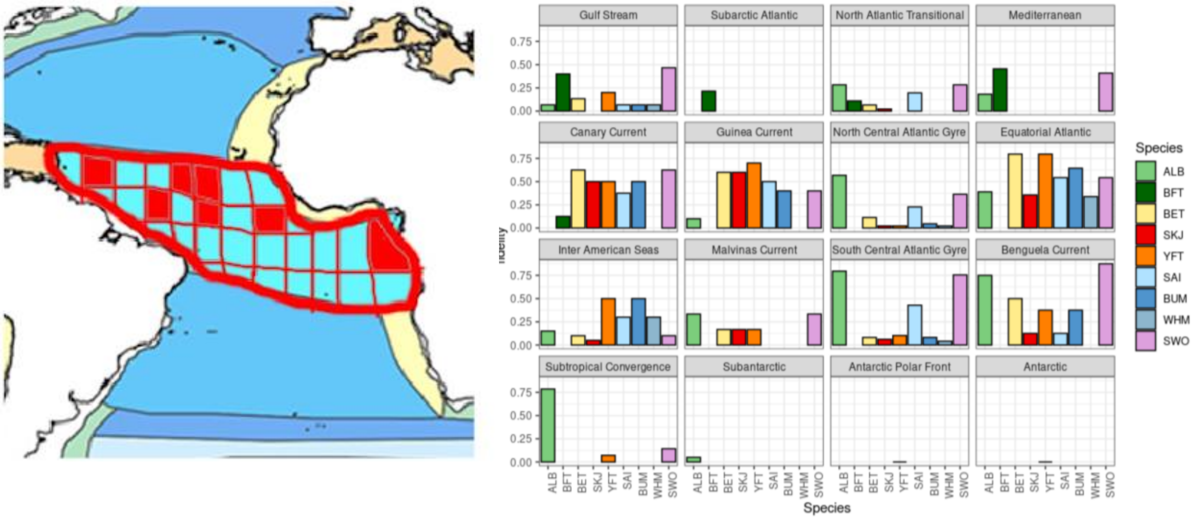

Figure 29. Fidelity indicator. (left) A schematic of the calculation of the fidelity indicator whereby the sum of the grid cells where a catch of species i is present in province j (e.g. red grid cells) divided by the total number of cells in province j (e.g. that outlined in red). (right) An example of the fidelity indicator calculated on ICCAT species in PPOW provinces.

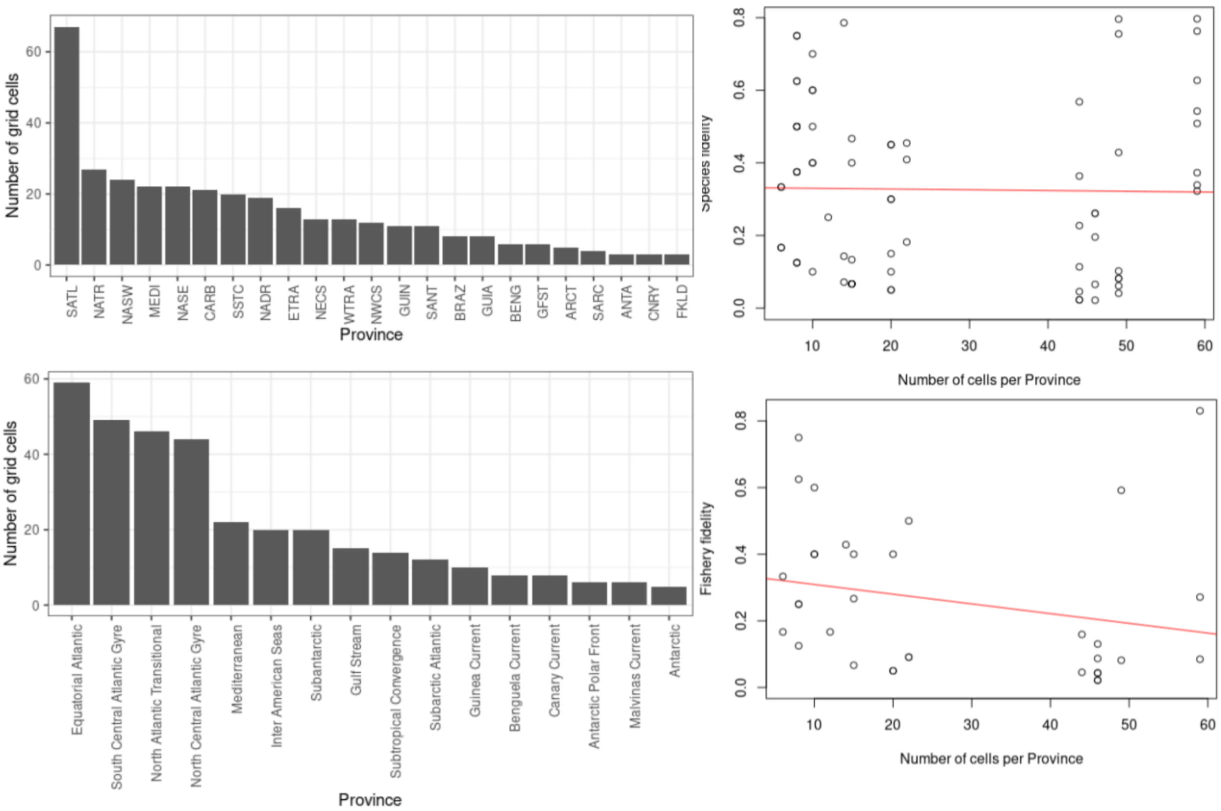

Figure 30. The number of grid cells per Longhurst province (top left), PPOW (bottom left) and the number of grid cells per PPOW province regressed against the fidelity indicator for species (top right, $r^2<0.0001$) and fisheries (bottom right $r^2<0.06$). The red line represents the linear model. Regressions against the Longhurst provinces are not displayed, but have similar results (i.e. no significant relationship).

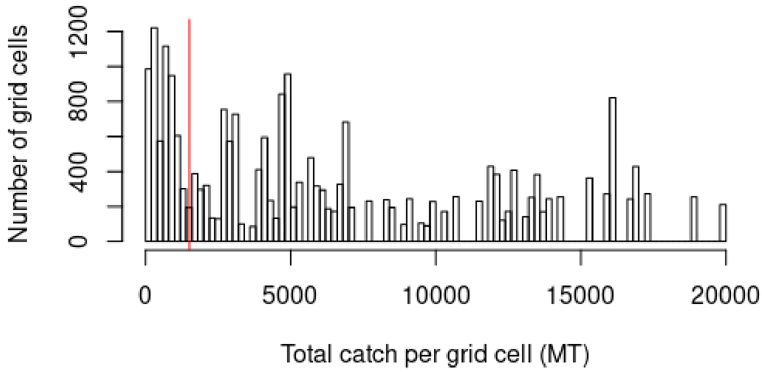

Figure 31. The calculation of the catch threshold using YFT as an example. The plot shows the frequency of the total catch per grid cell for YFT throughout the Indian Ocean, and the catch threshold of 0.25 percentile as indicated by the red vertical line. This 25th percentile for YFT is 1504 MT. Only grid cells with catch > 1504 MT are included when estimating the fidelity indicator.

Figure 32. The fidelity of species (top) and fisheries (bottom) for a province with no thresholds (left) and high thresholds (right) of persistence and catch applied (see **Table 6**). The subplots are arranged starting from the top left plot in a clockwise fashion for the provinces around the Atlantic Ocean starting with the Gulf Stream (see **Figure 27**).

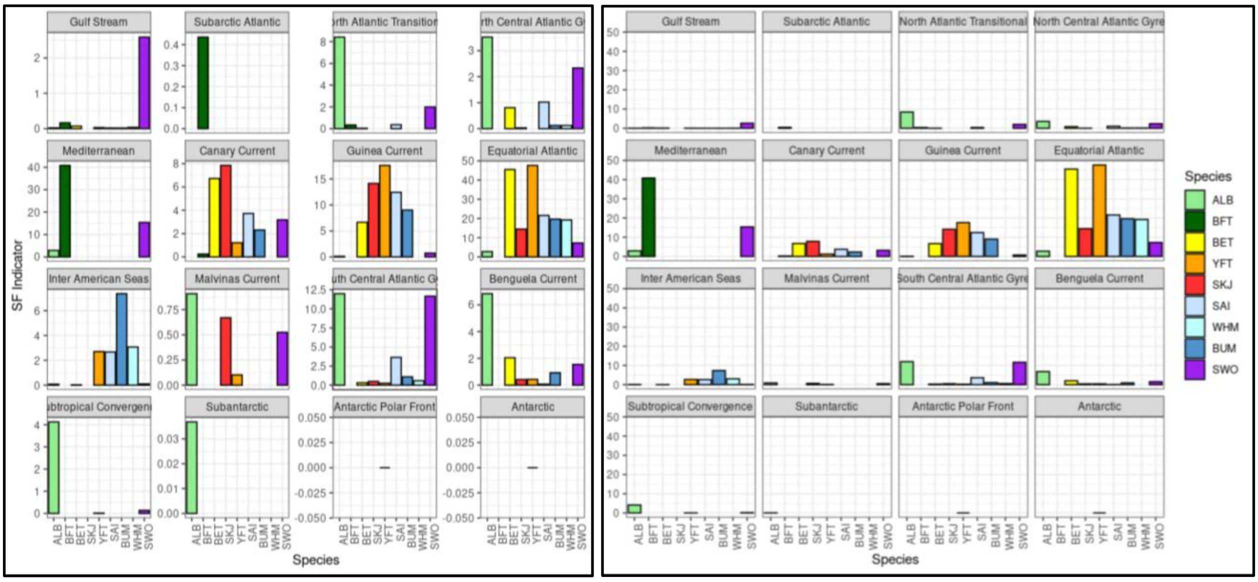

Figure 33. The specificity-fidelity (SF) indicator for species in the Longhurst provinces (top) and PPOWs (bottom). Right- and left-hand panels contain the same values, but those on the left use a free scale y-axis and those on the right use a fixed-scale y-axis. Subplots indicate the individual province names as in **Figure 27** and are ordered from west-to-east and north-to-south as far as possible starting from the province along the eastern USA coast.

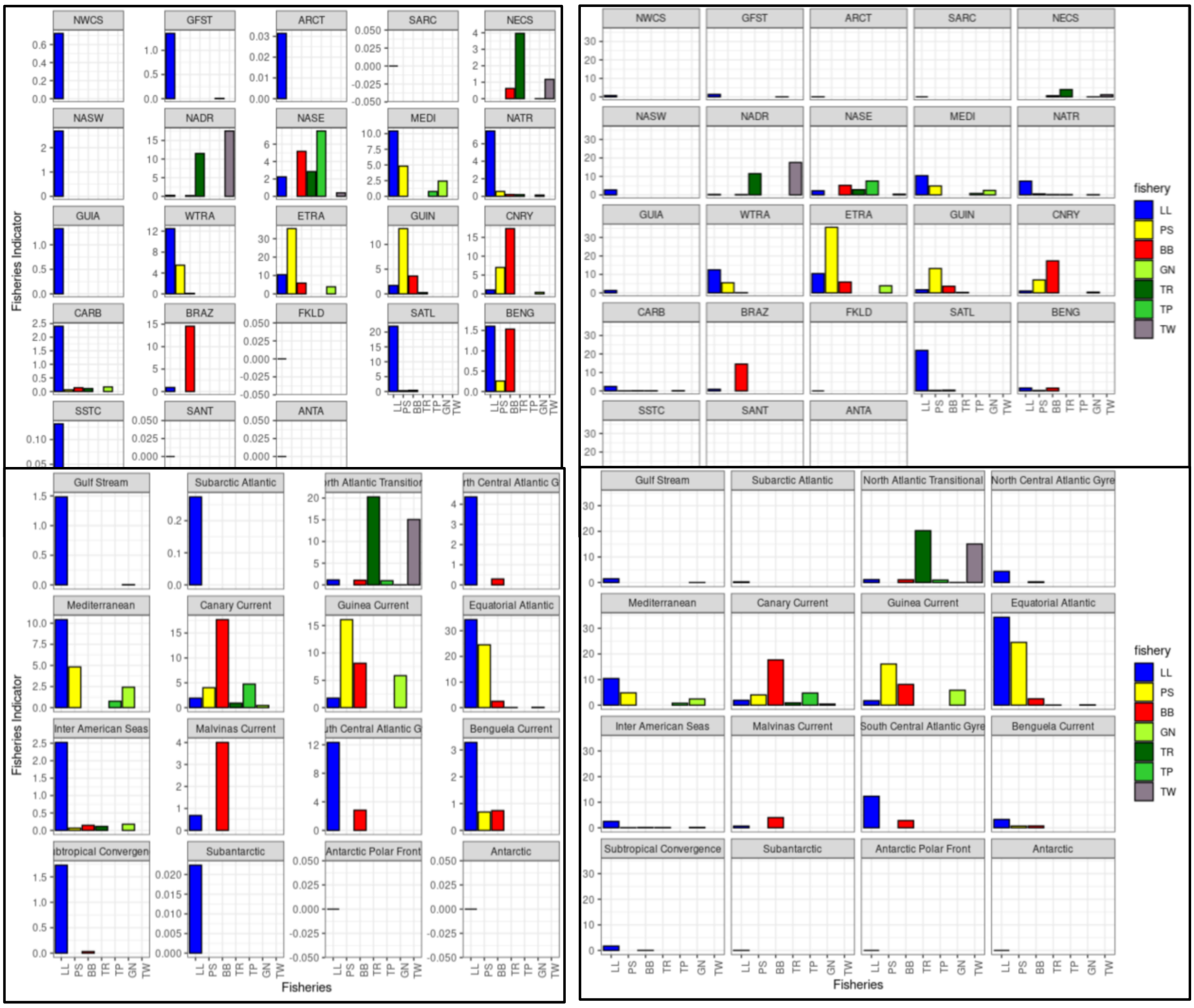

Figure 34. The specificity-fidelity (SF) indicator for fisheries in the Longhurst provinces (top) and PPOWs (bottom). Right- and left-hand panels contain the same values, but those on the left use a free scale y-axis and those on the right use a fixed-scale y-axis. Subplots indicate the individual province names as in Figure 27 and are ordered from west-to-east and north-to-south as far as possible starting from the province along the eastern USA coast.

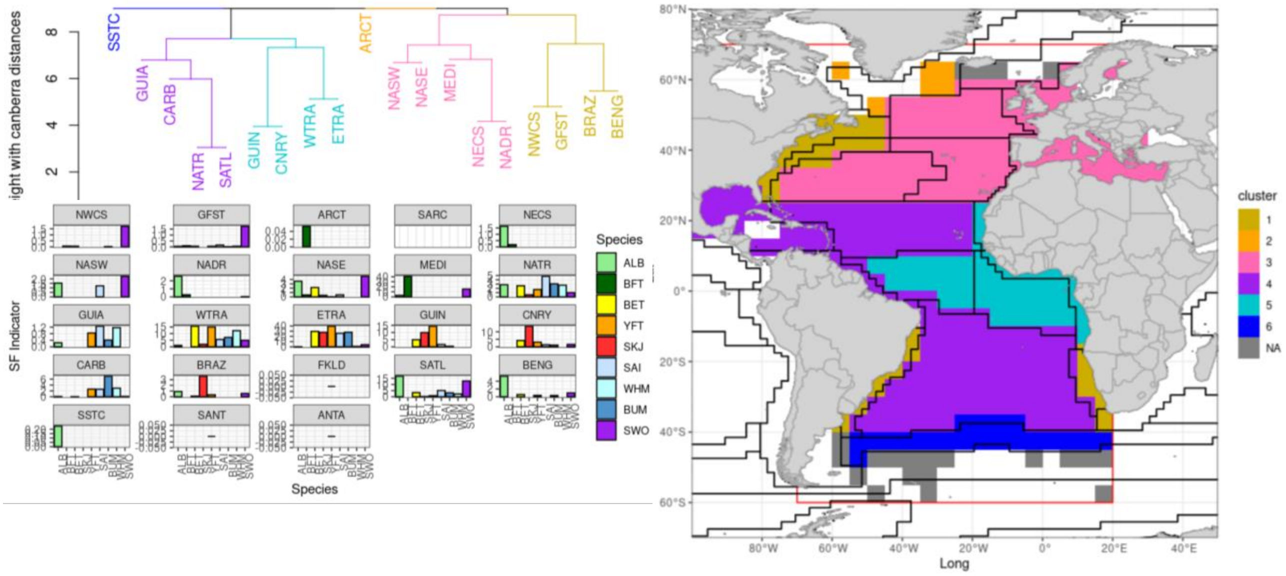

Figure 35. The cluster analysis results for the species-based SF indicator for the Longhurst provinces. Each panel includes the dendrogram (top left) with colors corresponding to the clusters in the map (right). The SF indicator with free y-axes by province is displayed as a reference (bottom left). The SF indicator with fixed y-axis is in **Figure 33**.

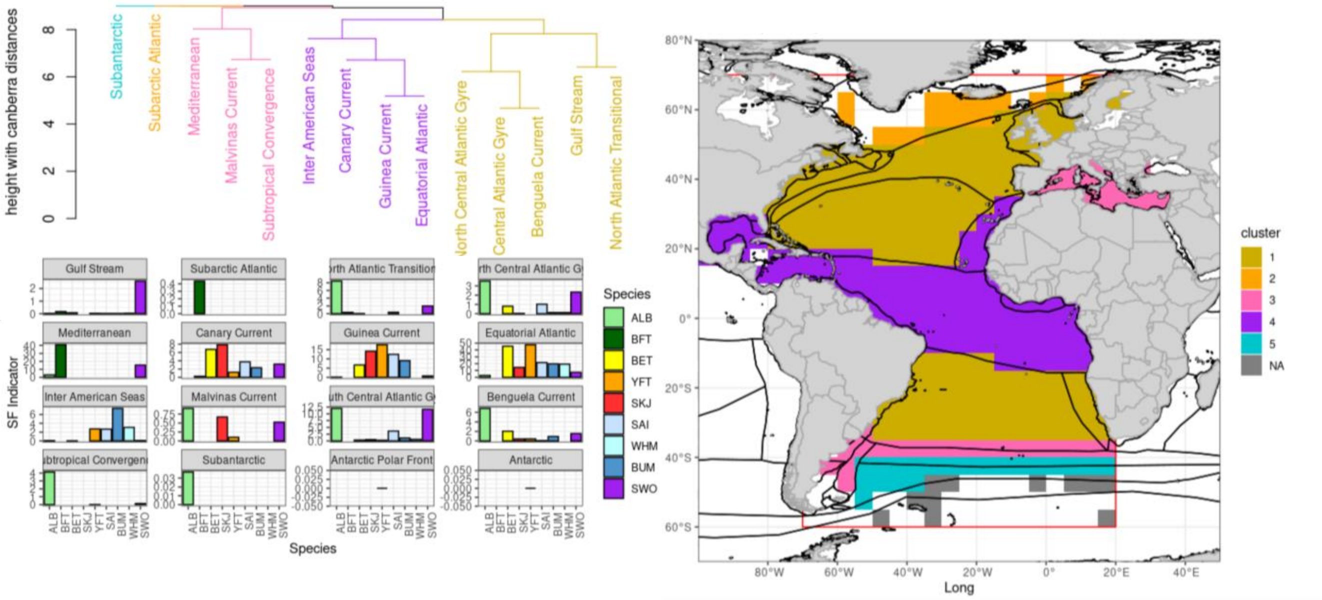

Figure 36. The cluster analysis results for the species-based SF indicator for the PPOW provinces. Each panel includes the dendrogram (top left) with colors corresponding to the clusters in the map (right). The SF indicator with free y-axes by province is displayed as a reference (bottom left). The SF indicator with fixed y-axis is in **Figure 33**.

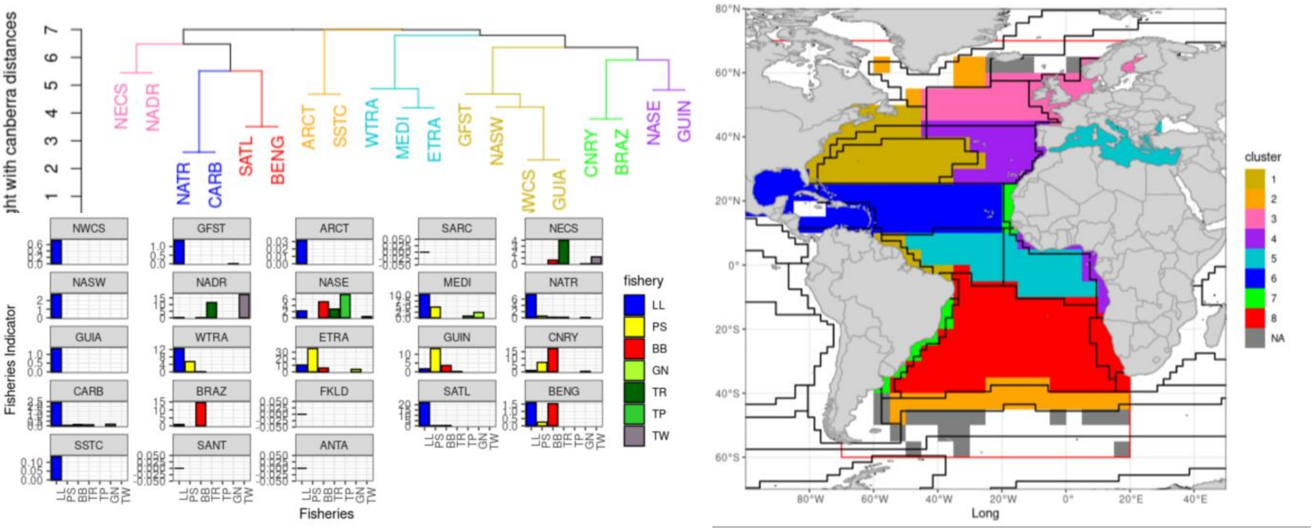

Figure 37. The cluster analysis results for the fishery-based SF indicator for the Longhurst provinces (top three panels) and the PPOW provinces (bottom three panels). Each panel includes the dendrogram (top left) with colors corresponding to the clusters in the map (right). The SF indicator with free y-axes by province is displayed as a reference (bottom left of each panel). The SF indicator with fixed y-axis is in **Figure 34**.

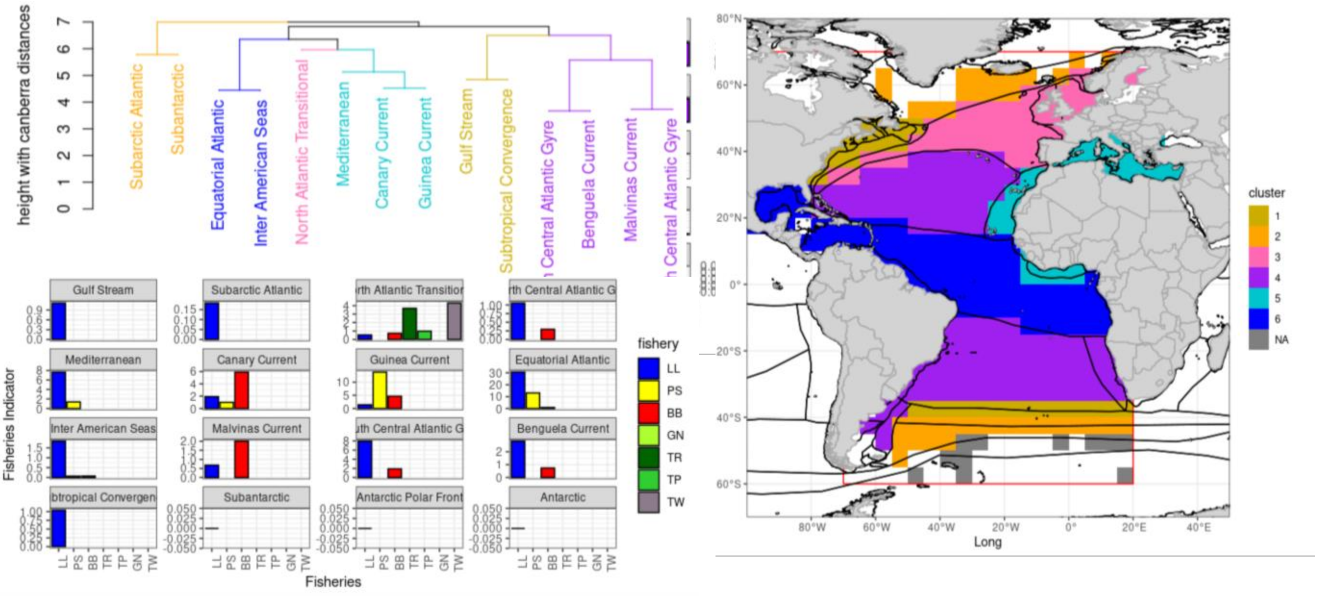

Figure 38. The cluster analysis results for the fishery-based SF indicator for the Longhurst provinces (top three panels) and the PPOW provinces (bottom three panels). Each panel includes the dendrogram (top left) with colors corresponding to the clusters in the map (right). The SF indicator with free y-axes by province is displayed as a reference (bottom left of each panel). The SF indicator with fixed y-axis is in **Figure 34**.

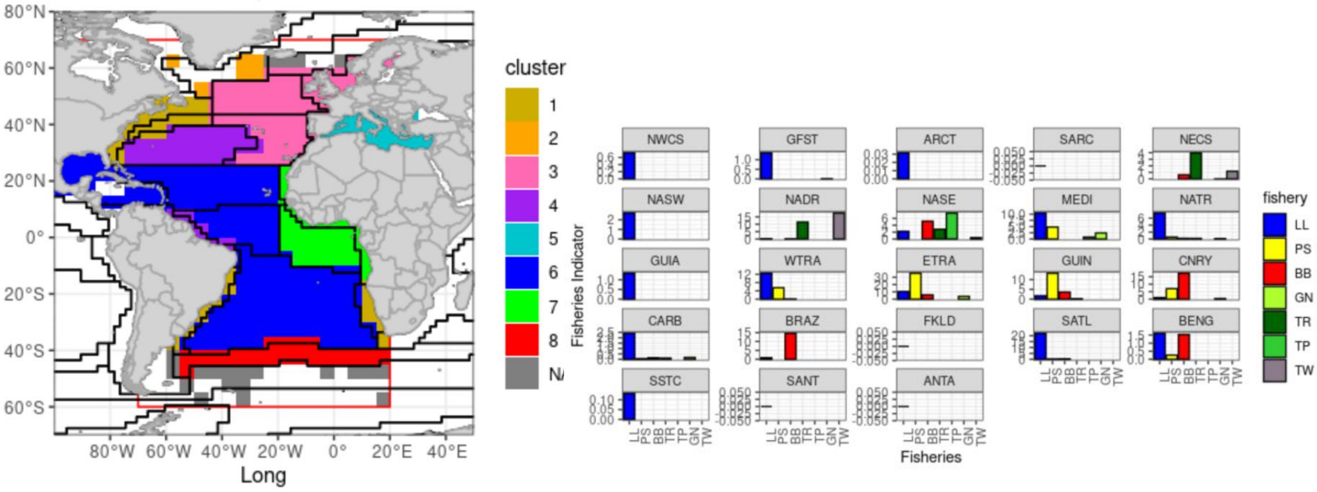

Figure 39. The cluster analysis results for combined (species and fishery) SF indicator for the Longhurst provinces, including the dendrogram (top left) with colors corresponding to the clusters in the map (bottom left). The SF indicator by province for species (top right) and fishery (bottom right) with free y-axes are displayed as a reference.

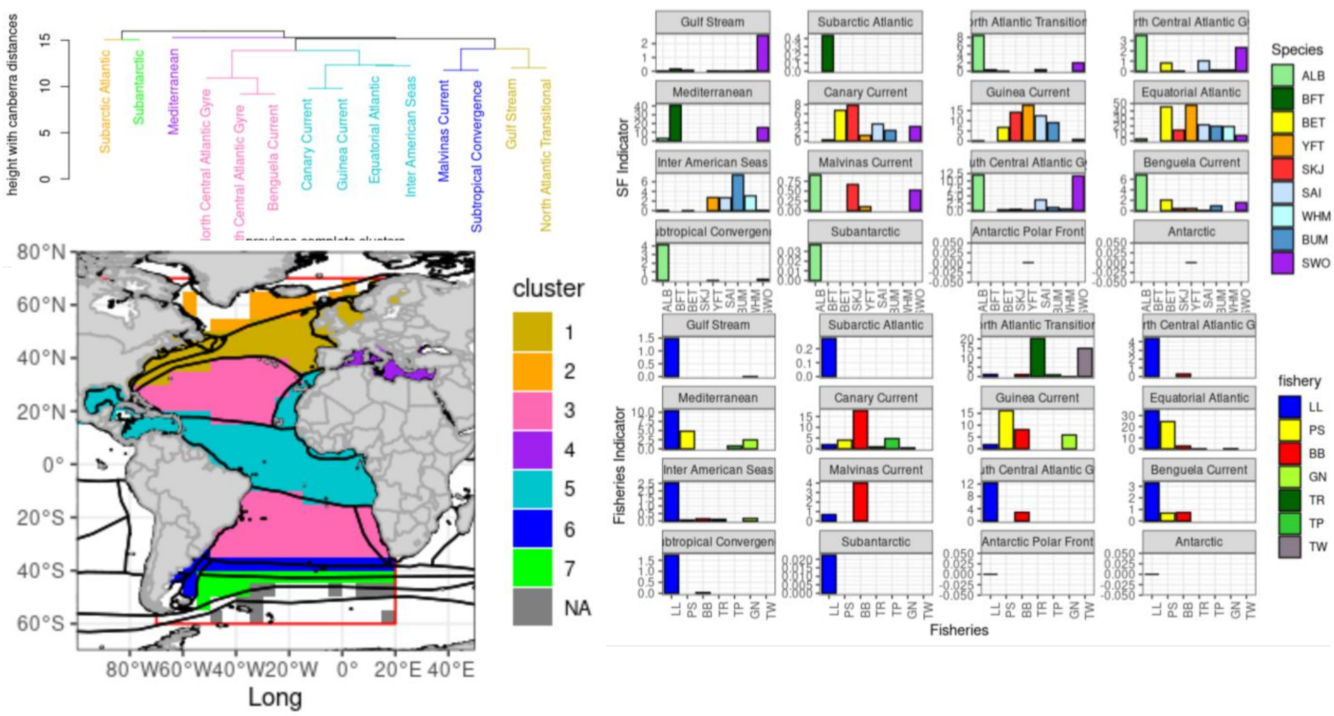

Figure 40. The cluster analysis results for the combined (species and fishery) SF indicator for the PPOW provinces, including the dendrogram (top left) with colors corresponding to the clusters in the map (bottom left). The SF indicator by province for species (top right) and fishery (bottom right) with free y-axes are displayed as a reference.

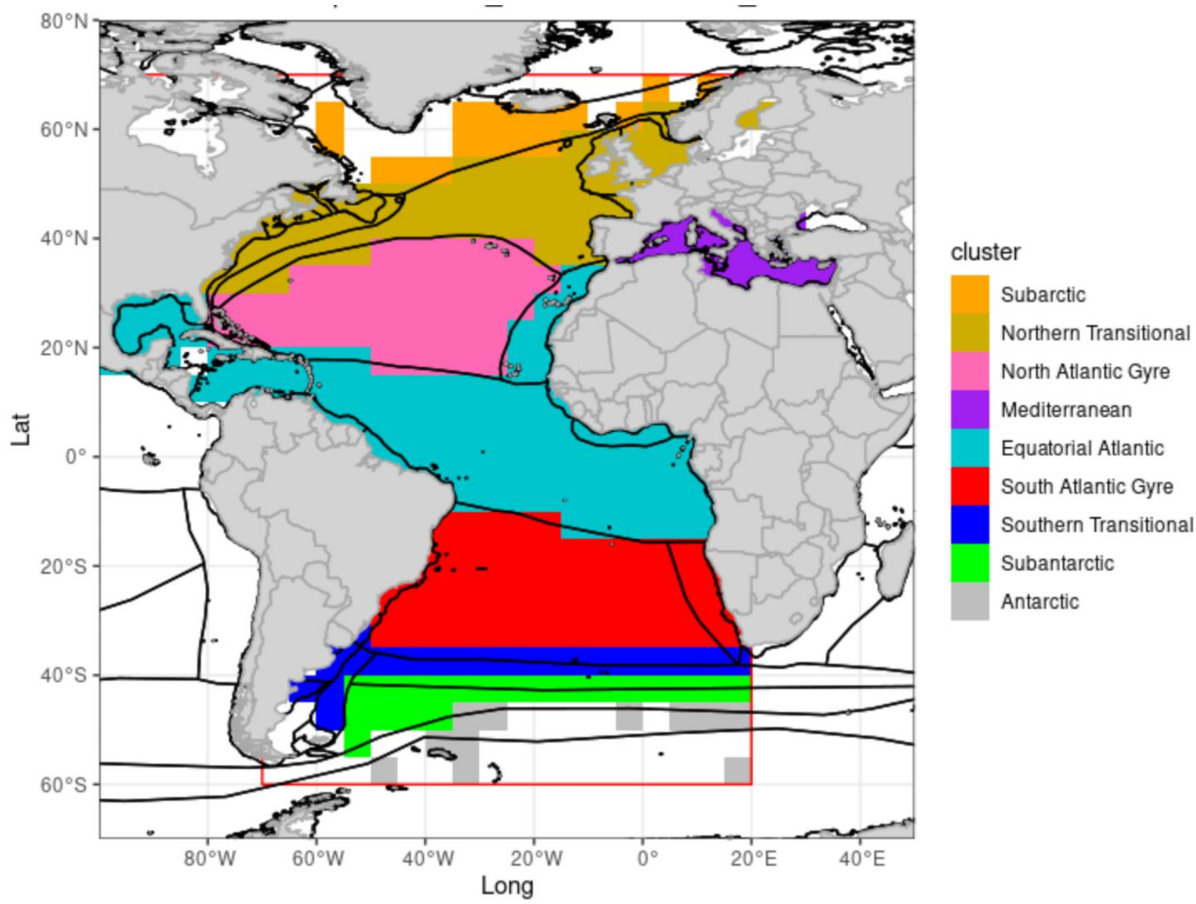

Figure 41. The baseline ecoregion proposal was derived from the cluster analysis on the combined species- and fishery-based SF indicator for the PPOW provinces (**Figure 40**), which was selected as the most representative clustering result that adheres best to the criteria (**Table 1**) and main properties of ecoregions for this study. The clusters in **Figure 40** were further modified for geographically continuity, and the southernmost cluster is proposed as an additional ecoregion. The final baseline ecoregion proposal comprises nine different ecoregions.

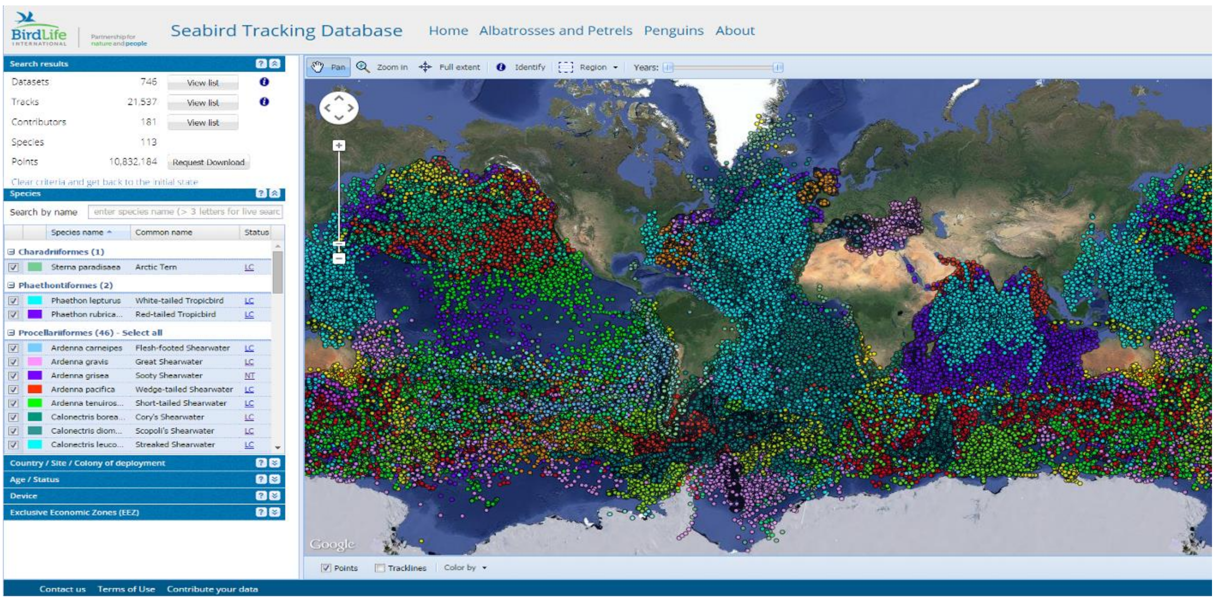

Figure 42. Seabird tracking database (Source: Birdlife International).