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Preliminary review of ICCAT, IOTC and IATTC progress in applying an ecosystem approach to fisheries management

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ABSTRACT

Tuna and billfish species, the structure of their communities and food webs they form provide and sustain important high-sea ecosystem services for human wellbeing. International agreements such as the UN Fish Stock Agreement and the FAO Code of Conduct have increased the expectations for RFMOs to implement an ecosystem approach to fisheries management. An ecosystem approach would ensure the sustainability of catches without compromising the structure and function of marine ecosystems and ensuring the delivery of ecosystem services. Here, we construct an idealized Driver-Pressure-State-Ecosystem Services-Response (DPSER) conceptual ecological model for a role model tuna RFMO to highlight how this planning tool could potentially be used as a framework to implement an ecosystem approach in tuna RFMOs. We use the DPSER model to assess the progress of ICCAT, IOTC and IATTC in applying an ecosystem approach to fisheries management. We seek to identify what type of research approaches are currently used in each RFMO and identify data and methodological needs, as well as limitations in capacities that hinder the implementation on an ecosystem approach. The three tuna RFMOs have taken steps to apply an ecosystem approach to fisheries management, yet the extent of their ecosystem-related research activities and programs differ markedly and occur under different fundamental research and institutional structures. The three tuna RFMOs have adopted several management measures and actions to mitigate the effects of fishing on target and by-catch species including sensitive species, and no measures to account for the impacts of fishing on the food web structure and trophic relationships and protections of sensitive habitats. The management measures in place to mitigate the impacts of fishing on bycatch and sensitive species have by large not been linked to pre-agreed operational objectives and associated indicators, and are not activated when a predefined threshold is exceeded. In the future, we intend to evaluate the performance and progress of the five tuna RFMOs in applying an ecosystem approach to

fisheries management to find synergies and examples of good practices and opportunities that can be transferred across them.

1. Ecosystem services provided by healthy tuna and billfish species and associated ecosystems

Biodiversity underpins the well-being of human society by supporting ecosystem services (Millennium Ecosystem Assessment 2005). Ecosystem services are the products of healthy, diverse and functioning ecosystems and associated living organisms contributing to human wellbeing (Rogers et al. 2014). There are many types of ecosystem services produced by high sea ecosystems, which can be divided in four main categories: provisioning (of seafood, raw materials, medicinal resources, genetic resources), regulating (of climate, air purification, waste treatment, biological control), habitat (lifecycle maintenance, gene pool protection) and cultural (recreation and leisure, aesthetic information, inspiration for culture, art and design, information for cognitive development) (Figure 1). An increasing number of studies are quantifying how people value and use the ecosystem services provided by the high seas, and demonstrating they are high in economic and social value, and therefore of great importance to humankind (Rogers et al. 2014).

Tuna and billfish species, the structure of their communities and food webs they form provide and sustain many of these high-sea ecosystem services including many of the provisioning, regulating, habitat and cultural services exemplified in Figure 1. Tunas and billfishes are generalist apex and mesopredators in oceanic food webs with wide spread distributions and therefore are key components of pelagic communities and high sea ecosystems (IATTC 2014). Although there are many gaps and uncertainties about the links between the role of tunas and billfish communities as ecological components of pelagic food webs and the ecosystem services they provide and sustain, it is important we start elaborating and quantifying the linkages between the ecological characteristics of these species, their communities and the ecosystem services they sustain.

The most understood ecosystem service provided by tuna and billfish communities is seafood production. Annual catches of tunas and billfishes reached over 6 million tonnes in 2012 worldwide, and contributed up to 9.3% of the annual total marine fish catch (FAO 2012). Tunas and billfishes are also some of the most valuable globally traded commodities. Every year at least 2.5 million tonnes of the global tuna catch is destined to the canning industry and globally around 256 million cases are consumed, valued at US $7.5 billion (Hamilton et al. 2011). Thus, capture fisheries from tuna and billfish species are a major contribution to economic livelihoods and food security in many developed and developing countries. There are more than 80 nations with tuna fisheries, thousands of tuna fishing vessels operating in all the oceans depending on healthy tuna and billfish species and communities for food production and sustainable livelihoods.

The economic and social value of cultural ecosystem services such as recreational and leisure, or asthenic services provided by tuna and billfish communities are less understood. Yet, tunas and billfishes provide valuable recreational services as these fishes are considered valuable sportfishes having an important status in recreational fisheries in many regions of the world. For those countries with good records on the recreational billfish and tuna industry, the aggregate impact in terms of revenue and employment can be significant for the local economies (Ditton and Stoll 2003). Tuna and billfish species can also provide habitat services to other species by maintain the lifecycle of other marine species. For example, the feeding opportunities for some seabirds depend on tuna schools feeding at the surface providing the birds with easy preys (IATTC 2014).

Perhaps the less understood ecosystem service sustained by tuna and billfish communities is regulating services. Tunas and billfishes are large predatory fishes, acting as apex and mesopredators and occupying high trophic levels in oceanic food web. The role of tuna and billfish species in the structure and energy flow in marine food webs is poorly known and by extension, to what extent tuna and billfish population widespread declines have altered the capacity of ocean to support vital ecosystem processes, functions and services by reducing their abundances and modifying species interactions and food web dynamics is poorly known (Kitchell et al. 2006, Hunsicker 2012, IATTC 2014).

2. An ecosystem approach to fisheries management to ensure sustainable ecosystem services – what is the role and expectations of tuna RFMOs?

Managing and preserving biodiversity to sustain the production of all its services is at the core of ecosystem-based management (Palumbi et al. 2009). The goal of ecosystem-based management is to maximize and sustain the delivery and production of ecosystems services. Thus, ecosystem based management requires to frame the management goals with respect to the conservation of ecosystem services and evaluations of their trade offs (Rosenberg and McLeod 2005). In a fisheries management context, the main goal of ecosystem-based management translates into ensuring the sustainability of catches without compromising the inherent structure and functioning of marine ecosystems and their delivery of ecosystem services for human society (Lodge et al. 2007).

In the high sea ecosystems, tuna Regional Fisheries Management Organizations (RFMOs) provide a framework for states to cooperate on the management and conservation of highly migratory species including tuna and tuna-like species and associated ecosystems within their area of jurisdiction. Thus, according to international laws and agreements, RFMOs have management and enforcement mandates to maintain sustainable populations and ensure sustainable fishing operations, taking into account the precautionary approach as well as ecosystem considerations in their management decisions (Meltzer 2009). There are five tuna RFMOs including the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), the Inter-American Tropical Tuna Commission, the Western and Central Pacific Fishery Commission (WCPFC), and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). Although the five tuna RFMOs are increasingly addressing the ecosystem effects of fishing, traditionally all tuna RFMOs have focused most of their resources and capacities to manage target tuna stocks to obtain maximum sustainable yields. Only two of the tuna RFMOs conventions (WCPFC and IATTC), those with most recent or renewed agreements, make explicit reference to the application of an ecosystem approach to fisheries management and the precautionary approach (de Bruyn et al. 2013).

Over the last decades, the development of international policy regarding the protection and management of highly migratory marine species including tunas and tuna-like species has grown and changed substantially. Multiple binding treaties and agreements have been adopted and entered into force. The UN Fish Stock Agreement (UNFSA), and the FAO Compliance Agreement are the key legal binding instruments governing the management of highly migratory species (Meltzer 2009). These binding pieces of international law together establish the core principles and minimum standards making reference for the first time to the application of the Precautionary Approach and the Ecosystem Approach to Fisheries Management. These binding international laws are supported by a series of non-legally binding international agreements, norms and guidelines, which were created to support and drive the implementation of the principles set in the laws. These include the FAO Code of Conduct for Responsible Fisheries and the FAO International Plans of Action (IPOAs) for sharks, seabirds, capacity and illegal, unreported and unregulated fisheries, which main role is to support the implementation and enforcement of the UNFSA. These international laws and agreements are slowly changing the expectations of fisheries management, and the expectations and role of RFMOs in accounting for ecosystem considerations in their management decisions (Lodge et al. 2007). Now, there is an increasing recognition and further expectations of the need for tuna RFMOs to expand their focus to ensure they manage their fish stocks without compromising the ability to maintain a balance delivery of all ecosystem services provided by tuna species and associated marine ecosystems (Pikitch et al. 2004, Lodge et al. 2007). It is widely recognized that the sustainable use and exploitation of marine fisheries is linked to the ecological sustainability of marine ecosystem processes and structure, and the ecosystem services they provide (Gilman et al. 2014).

3. An Ecosystem Approach to Fisheries Management: Theory and towards practice.

3.1. Operational frameworks to implement an ecosystem approach to fisheries management: DPSIR framework and IEA framework

The importance of implementing an ecosystem approach to manage fisheries is widely accepted. Some RFMOs have expanded their mandates and taken steps to incorporate ecosystem based management in their fisheries management strategies. Yet, in practice it has been proven challenging to successfully implemented it. This is in part due to the difficulties of breaking with traditional management, connecting multiple disciplines and establishing realistic ecosystem reference point indicators, but also due to the perception that it is too complicated and that it requires endless high detailed information (Tallis et al. 2010).

Nevertheless, several strategies and frameworks have been developed to make the implementation of an Ecosystem Approach to Fisheries Management (EAFM) more operational. These frameworks follow a series of well-designed steps and guidelines that are now being used in a variety of contexts and regions around the world, and proving that the implementation of EAFM can be feasible. Next we describe briefly two complementary frameworks or conceptual models, the Integrated Ecosystem Assessment (IEA) framework developed by NOAA in the US (Figure 2) (Levin et al. 2009, Tallis et al. 2010), and the Driver-Pressure-State-Ecosystem services-Response (DPSER) Conceptual Model (Figure 3) (Kelble et al. 2013). These frameworks are being applied together in a variety of contexts, with varying data quality and governance structure, and are slowly making progress and showing that ecosystem based management can be feasible to manage fisheries from a range of starting points and governance contexts.

The Integrated Ecosystem Approach (IEA) framework outlines an iterative process of seven steps for planning and implementing an EAFM, including: scoping, defining indicators, setting thresholds, conducting risk analysis, management strategy evaluation, monitoring and evaluation (Figure 2) (Levin et al. 2009, Tallis et al. 2010). Defining and identifying the ecological objectives is the first step in the IEA and in most cases it is also the most challenging. Reaching agreement on a common set of operational objectives may be a time consuming political step. It is difficult to reach consensus among the various stakeholders where commonly multiple interest collide. The second step involves defining and choosing indicators associated with the operational objectives to characterize and track the status and trends in the state of the ecosystem towards achieving the pre-agreed objectives. The third step in the IEA framework consists in setting indicator thresholds to evaluate progress towards the ecosystem management goals. The forth step consist in conducting risk analyses to analyze and quantify the links between the pressures affecting the ecological state of the ecosystem, the indicators measuring the change in the ecosystem state, and the value of the ecosystem services. Management strategy evaluation is step number 5, and it uses the main linkages to evaluate the impacts of several fishing strategies and regulation responses on the state of the ecosystem and derived range of ecosystem services. The lasts steps consist in close monitoring of the indicators and evaluation of strategies to ensure the loop of the IEA is closed (Figure 2). Most important, the IEA framework can be applied in a variety of contexts, which can vary widely in data availability and quality, governance structure and time frame for implementation. For detail guidelines of how to apply ecosystem based management using the IEA framework see Tallis et al 2010.

The Driver-Pressure-State-Ecosystem service-Response (DPSER) conceptual model (Kelble et al. 2013) (Figure 3) consists in a planning tool that allows identifying the full range of interaction between humans and the ecosystems including the main drivers and pressures influencing the state of the ecosystem, their ecological effects, and identify indicators best suited to monitor these effects and the linkages among them. Then, based on the state of the ecosystem, it allows identifying responses or management strategies to ensure sustainable levels of the ecosystem services desired by society. This planning tool facilitates the identification of society preferences and uses of ecosystem services. It naturally places the ecosystem services, what we aim to protect as a society, as the main driver in the framework, and naturally links the other modules to the management response (Kelble et al. 2013). In many cases, building a conceptual ecological model using the DPSER framework can be a good starting option to make operational the first three steps of the IEA framework. The construction of a conceptual ecological DPSER model, with the involvement of all the major stakeholders, facilitates the initial phases of the scoping process to pre-established operational objectives. It also facilitates choosing the most appropriate indicators associated to those operational objectives to track the ecosystem state towards achieving the pre-agreed objectives and choosing the thresholds to facilitate reporting and provoke management actions.

3.2. Tuna RFMOs progress towards implementing an EAFM

To our knowledge the IEA framework and the DPSER conceptual model framework have not been used yet as a planning tool to develop an ecosystem management strategy in any of the tuna RFMOs. Yet many of the current practices, research products and programs conducted by the tuna RFMOs in support of an ecosystem approach can take the place of some of the steps formulated in the IEA and DPSER approaches. Next, we first attempt to build a very general DPSER conceptual ecological model for what it could be considered to be a “role model” tuna RFMO. The conceptual ecological model is based on a review of the best practices in which different RFMOs are addressing ecosystem based management and implementing the precautionary approach (Lodge et al. 2007). With this general idealized DPSER model, we pretend to highlight how this planning tool could potentially be used as a framework to facilitate the implementation of an ecosystem approach in tuna RFMOs. Second we evaluate the progress of tuna RFMOs in applying an ecosystem approach to fisheries against this idealized role model RFMO. We present a preliminary review based of the current approaches, research and best practices of three tuna RFMOs as case studies, ICCAT, IATTC and IOTC to evaluate their progress in applying an EAFM. Ultimately, we aim to identify what type of different research approaches are currently used in each RFMO, identify data and methodological needs, and limitations in capacities that hinder process, and identify synergies, example of good practices and opportunities that can be transferred across the tuna RFMOs.

3.2.1 Conceptual ecological model based on the DPSER framework for a model tuna RFMO

To demonstrate the utility of the DPSER framework, we constructed what it could be the basis of an ecological conceptual model for a role model tuna RFMO (Figure 4; Table 1). The DPSER conceptual ecological model illustrates the main elements and linkages to take into account in an ecosystem approach to fisheries management in the pelagic ecosystem. First, the DPSER model illustrates the main pressure in the high seas, which is fishing. Fishing impacts the state of tuna species and associated ecosystems, which in turn affects the ecosystem services that benefit human society. Since the commencement of industrial fisheries in the 1950s, commercial fishing has been identified as the primary pressure affecting tuna and billfish populations and associated ecosystems (Collette et al. 2011). However, climate change is arising now as another potential major pressure on the state of tuna and associated ecosystems (Bell et al. 2013). When applying an ecosystem approach to fisheries management, there are multiple elements and attributes that could be measured and monitored to characterize the state of tunas and associated ecosystems. For practical reasons, RFMOs have traditionally addressed the EAFM by managing and assessing the state of the following four ecological elements: (1) targeted and commercially retained species (2) bycatch species and protected or threatened species, (3) trophic interactions and (4) habitats (Lodge et al. 2007). By dividing the application of an ecosystem approach to fisheries in four main practical ecological elements, it allows an RFMO to identify operational objectives, associated indicators and thresholds for each element, and develop management responses and strategies for each of them (Lodge et al. 2007). In the DPSER ecological conceptual model, we illustrate the four ecological elements to be addressed by a role model tuna RFMO in practice to fully implement an EAFM (Figure 4, Table 1). We also show examples of quantitative ecological indicators that potentially could be used to assess the state of each of the four ecological elements. Last, we show examples of what common management responses are used in fisheries management to minimize the impacts of fishing on the state of target fish populations and associated species and ecosystems.

Overall, this general idealized DPSER conceptual ecological model for a role model RFMO illustrates the main pressure affecting the state of tunas and associated species and ecosystems, and provides an opportunity to evaluate the performance of tuna RFMOs in applying an ecosystem approach to fisheries for each of these elements. In order to evaluate the progress of tuna RFMOs in applying an ecosystem approach to fisheries against this idealized role model RFMO, we mainly focused on reviewing the current practices under each of the four focal ecological elements mostly used in practice to address and apply the EAFM (Table 1 and Figure 4). For each ecological element, we evaluated (1) whether an operational objectives have been defined (2) whether there are measurable indicators associated to the operational objectives to track the state and trend of each ecological element, (3) whether thresholds for those indicators have been defined to activate management action, and (4) whether there are measures and management responses to ensure that those thresholds are not exceeded.

3.2.2. Evaluation of progress towards implementing the ecological elements of ecosystem based management: ICCAT, IOTC and IATTC as a case study

Before we review the progress of tuna RFMOs in applying an EAFM, it is important to highlight that the establishment of some tuna RFMOs predate the UN Fish Stock Agreement (which entered into force in 2001), and have different fundamental institutional structures to undertake and integrate ecosystem related research. ICCAT was established in 1969 and its Convention Agreement only makes explicit reference to maintain the populations at levels which permit the maximum sustainable yield, with no reference to the precautionary approach or the ecosystem approach to fisheries management. ICCAT has a Standing Committee on Research and Statistics (SCRS), which is responsible for developing and recommending to the Commission policy advice concerning fishing activities and the stocks are fished in the convention area. The SCRS relies on the research conducted by several Species Working Groups, the Sub-Committee on Statistics, and the Sub-Committee on Ecosystems. The SCRS relies on the mandatory fisheries data collected by Member States and submitted to the ICCAT Secretariat and on the research conducted by government and academic institutions from member States. In 2005, the Sub-committee on Ecosystems was created for the purpose of coordinating and integrating ecosystem-related monitoring, research, modeling and advice activities in support of an EAFM in ICCAT. Previous to 2005, there existed two separate Working Groups, one dealing with bycatch assessments and mitigation measures, and the second dealing with broader ecosystem issues and oceanographic factors affecting tuna biology and fisheries. These two working groups were merged to create the 2005 formed Sub-Committee on Ecosystems. The Sub-Committee on Ecosystems meets once a year to tackle ecosystem and bycatch related research and associated activities as required by the SCRS to fulfill its advisory role to the Commission. The work conducted depends on the priorities set by the Commission, which until now has focused more on bycatch and mitigation research activities. Currently there also exist a separate Shark Species Working Group and Small Tunas Working group complementing the by-catch work of the Sub-Committee on Ecosystems. Every year, the Sub-Committee on Ecosystems prepares a report summarizing the main research activities conducted during the year and prepares a series of recommendations for the SCRS regarding bycatch issues and progress of implementing an EAFM.

IOTC was established in 1993 and its Convention Agreement makes explicit reference to the management, conservation and optimum utilization of stocks covered by in the agreement, with no reference to the precautionary approach or the ecosystem approach to fisheries management. Similar to ICCAT, IOTC has a Science Committee, which is responsible for developing advise on data collection, on the status of the stocks and on management issues to the Commission. The Scientific Committee relies on the scientific input and research conducted by several Working Parties (WP), including the WP on Data Collection and Statistics, on Methods, on Temperate Tunas, on Tropical Tunas, on Neritic Tunas, on Billfish and on Ecosystems and Bycatch. The Scientific Committee and Working Parties rely to conduct their tasks on the mandatory collection of data by Member States which is submitted to the IOTC Secretariat, and on the research conducted by government and academic institutions from Member States.
In 2005, the Working Party on Bycatch met for the first time. In 2007, this Working Party was renamed as the WP on Ecosystem and Bycatch and expanded its terms of reference to coordinate

and integrate ecosystem-related monitoring, research, modeling and advice activities in support of an ecosystem approach to fisheries in IOTC. The work conducted depends on the priorities and requests set by the Commission, which similar to ICCAT, until now has focused more on bycatch and mitigation research activities. Every year, the Working Party on Ecosystem and Bycatch prepares a report summarizing the main research activities conducted during the year and prepares a series of recommendations for the Scientific Committee and Commission regarding bycatch issues and progress of implementing an EAFM in the IOTC convention area.

IATTC, established in 1949, has recently amended its Convention Agreement which makes explicit reference to the adoption of conservation and management measures, as necessary, to ensure the sustainable use of fish stocks and dependent and associated species belonging to the same ecosystem that are affected by fishing. It also makes reference to the precautionary approach. IATTC has its own scientific capacity that carries out research, planning, execution, analysis and delivery of management advice to comply with the convention goals. IATTC has four main research programs including a Stock Assessment Program, the Biology and Ecosystem Programm, the combined Bycatch and International Dolphin Conservation Program, and the Data Collection and Database Program. All the programs conduct an extensive range of research activities to support an EAFM. The research programs are supported by a relative large group of permanent staff of the Secretariat, which are in charge to carry out the research, analysis and advise for the Comission. In the 1980s, the IATTC began to conduct some research on ecosystem issues, yet most of the ecosystem-related monitoring and research started at the end of the 1990s when IATTC became part of the International Dolphin Conservation Program (IDCP). Every year, the IATTC staff prepares an Ecosystem Consideration Report summarizing the impact of tuna fisheries on target and bycatch species (tunas, billfishes, marine mammals, sea turtles, sharks and other teleost). This report also includes pertinent information on other major ecosystem components including forage organisms, trophic interactions, ecosystem modeling, ecological risk assessment and construction of aggregate indicators to track changes in the ecosystem. It also has a section summarizing the actions by IATTC addressing ecosystem considerations.

Regardless their Convention Agreements making reference or not to the precautionary approach to fisheries management and the inclusion of ecosystem considerations, in practical terms the three RFMOs have taken some steps to apply an EAFM, yet to different extents. Next we review the current approaches, research and best practices of each tuna RFMO under each of the four focal ecological elements mostly used to address and apply the EAFM in practice. We mainly used the information provided by the annual Report of ICCAT Sub-Committe on Ecosystems, annual Report of IOTC Working Party on Ecosystems and Bycatch and the annual Report of IATTC Ecosystem Consideration, as well as other related reports published in the RFMO webpages.

Ecological element 1 of an EAFM: target and commercially retained species.

ICCAT

Operational objectives: The management objective regarding target species is to maintain population of tunas and tuna-like species at levels that permit the maximum sustainable yield.

Indicators: The majority of target stocks (all principal market tuna stocks, some billfish and shark stocks, and none of the small tuna stocks) have been evaluated with fisheries stocks assessments to determine the effects of fishing on the individual stocks and determine their exploitation status. Indicators of population size and fishing mortality over time and associated fisheries reference points (Bmsy and Fmsy) are available for these assessed stocks.

Thresholds: Limit reference points associated with the biomass and fishing mortality rate indicators have not been adopted for any of the target stocks. Fmsy is used as a target reference point. However, limit reference points have been proposed and harvest control rules are being defined and are under development for north Atlantic albacore and swordfish.

Responses and management measures: Several conservation measures have been put in place to maintain target species at levels that permit maximum sustainable catches including TACs for bigeye tuna, yellowfin tuna, and north and south Atlantic albacore, north and south swordfish, white and blue marlin, and bluefin tuna; a capacity limitation scheme for bigeye tuna, temporary time-area closure for bigeye tuna and yellowfin tuna that also affects skipjack, and bluefin tuna; minimum size limits for swordfish, marlins and bluefin tunas; and rebuilding plan for bluefin tuna. Management strategy evaluation is increasingly being considered to inform decision-making.

IOTC

Operational objectives: The management objective regarding target species is to promote cooperation among its Members with a view to ensuring, through appropriate management, the conservation and optimal utilization of stocks of tuna and tuna-like species covered by the Convention Agreement and encouraging sustainable development of fisheries based on such stocks.

Indicators: Yellowfin, bigeye and skipjack and albacore tuna stocks, some billfish and small tuna stocks, and none of the shark stocks have been evaluated with fisheries stocks assessments to determine the effects of fishing on the individuals stocks and their exploitation status. Indicators of population size and fishing mortality over time and associated fisheries reference points (Bmsy and Fmsy) are available for some of these assessed species.

Thresholds: Interim limit and target reference points associated with the biomass and fishing mortality rate indicators have been adopted for bigeye, yellowfin skipjack and albacore tunas. Limit reference points have not been adopted for the rest of the target stocks for which reference points based on maximum sustainable yield remain to be used as targets.

Responses and management measures: There are no quota conservation measures established by the IOTC for the main target tuna species including bigeye, yellowfin, skipjack and albacore tunas, and either for the rest of the target species. There is a capacity limitation scheme for countries fishing in the IOTC area and temporary time-area closure for purse seiners and longliners. A resolution in 2014 calls for members to implement a quota allocation systems based on the recommendations from the Scientific Committee, however, it was not specified how this will be done.

IATTC

Operational objectives: The overall management objective regarding target species is to ensure the long-term conservation and sustainable use of fish stocks in accordance with the relevant rules of the international law, and be precautionary when information is uncertain by applying the precautionary approach.

Indicators: The majority of target stocks (tropical tuna stocks, some billfish and shark stocks, and none of the small tuna stocks) have been evaluated with fisheries stocks assessments to determine the effects of fishing on the individuals stocks and their exploitation status. Indicators of population size and fishing mortality over time and associated fisheries reference points (Bmsy and Fmsy) are available for these assessed species. There are also indicators of the biomass of the stocks compared to the estimated of what the biomass might have been in the absence of fisheries.

Thresholds: Interim limit and target reference points associated with the biomass and fishing mortality rate indicators have been adopted for bigeye, yellowfin and skipjack tunas. Limit reference points have not been adopted for the rest of the target species for which reference points based on maximum sustainable yield remain to be used as targets.

Responses and management measures: Several conservation measures have been put in place including time-area closures for purse seiner catching bigeye, yellowfin and skipjack tuna, catch limits for bigeye for some fishing gears. There is also in place a capacity limitation program for large purse seine fisheries and close regional vessel registry.

Ecological element 2 of an EAFM: bycatch and threatened species.

ICCAT

An extensive regional bycatch program is not in place to monitor non-target species that are either retained or discarded by ICCAT fisheries. Instead Member States are mandated to monitor and collect data on bycatch species during their fishing operations and through the implementation of national observer programs and submit it to the ICCAT Secretariat. In many cases the data collected by the Member States are not available at the ICCAT Secretariat for use, hindering research activities of the Sub-Committee on Ecosystems to asses the overall impact of tuna fisheries on bycatch species in the ICCAT area and, hence the advisory role of the Scientific Committee to the Commission as requested by many ICCAT resolutions and recommendations. In many cases, when the data is available, the data may not be comparable across regions due to different standardization and collecting protocols. The Sub-Committee on Ecosystems, continues to recommend standardized data collection procedures and scientific observers and logbooks which permit quantifying the total catch (landings and discards), its composition, its disposition by tuna fishing fleets and its comparison across regions. The group also recommends the identification and evaluation of indicators, including single and multispecies indicators, to track the impact of ICCAT tuna fisheries on bycatch species as part of an EAFM.

Operational objectives: There are no clear objectives in place to mitigate the impacts of fisheries on bycatch species. The ICCAT Convention Agreement does not contain any specific provisions concerning the impact of fisheries on non-target species and conservation of biodiversity.

Indicators: No indicators have been linked to operational objectives. Yet, the ongoing research activities by the Sub-Committee on Ecosystems have the potential to produce a series of indicators to track the impacts of fisheries on bycatch species. These research activities include:

-ICCAT Sub-Committee on Ecosystems is currently working to complete en Ecological Risk Assessment for sea turtles to assess the impact of longline and purse seine fisheries on turtle populations. This analysis follows the Commission request to assess the impact of ICCAT fisheries on sea turtle populations. Currently further work is necessary to improve the assessment.

-ICCAT Sub-Committee on Ecosystems routinely evaluates studies on the incidental catch rates of sea turtles, bycatch mitigation strategies and safe-release protocols for turtles in the ICCAT area. Several recommendations on safe-release protocols have been put forward to reduce mortality of sea turtles in ICCAT fisheries.

-ICCAT Sub-Committee on Ecosystems has conducted an assessment on the interactions of seabirds with ICCAT tuna fisheries. The ICCAT bird assessment objectives included to identify seabird species most at risk, collate available data, analyze time area overlap between the seabirds and fisheries, review existing by-catch rate estimates, estimate total annual seabird by-catch rates in the ICCAT fisheries and assess the likely impacts of this by-catch on seabird populations. The group has conducted a qualitative Ecological Risk Assessment for more than 60 populations of birds impacted by ICCAT longline tuna fisheries, and proceeded with quantitative assessments of the fishing impacts for key selected populations for which there were sufficient data on bird distribution and demography (Tuck et al. 2011).The lack of sufficient bycatch rate data by fleet and area hindered some of the Subcommittee's efforts to quantify the impact of ICCAT tuna fisheries on some other seabird populations. Research also is being conducted on improvement of mitigation measures.

-ICCAT Shark Working Group has also conducted an Ecological Risk Assessment for 16 sharks species (20 stocks) which provides a species level index of vulnerability of shark species to overfishing. The group has also conducted fisheries stock assessment for three sharks species (blue shark, shortfin mako, and porbeagle). These assessments have produced indices of abundance (CPUEs) and quantified the impact of fishing with regard to reference points (Bmsy and Fmsy) for these three species of sharks.

-A Ecological Risk Assessment including several taxonomic groups of species has also been conducted to assess the relative risk of both target and bycatch species being negatively impacted by two tuna fleets managed by ICCAT, the EU purse seine and US longline fisheries (Arrizabalaga et al. 2011). This productivity-susceptibility analysis created a index of vulnerability to overfishing in longline and purse seine fisheries for species in several taxonomic groups including the target tuna species, as well as bycatch species such as billfishes, other teleost, sharks, skates, rays, turtles, seabirds, and marine mammals. This risk assessment has been used to establish research and management priorities in ICCAT.

Thresholds: No thresholds have been linked to associate indicators. Limit and target reference points have not been defined or adopted for any of the bycatch species.

Responses and management measures: There has been no management responses linked to any pre-established indicators and associated operational objectives. Yet, ICCAT has an extensive list of management measures to mitigate the effects of fishing on by-catch species including sensitive species. The qualitative ecological risk assessments conducted for several taxonomic groups including target and bycatch species have been decisive to establish priorities and management action to mitigate the impact of ICCAT tuna fisheries on sensitive bycatch species such as birds, turtles and sharks which generally lack quality data for more quantitative assessments.

We briefly list a series of measures adopted in the ICCAT convention area to mitigate the impact of tuna fisheries on other sensitive species: measure to encourage the implementation of the FAO International Plan of Action on seabirds and sharks, including a resolution to monitor the interactions between tuna fisheries and seabirds and turtles; measure to initiate the assessment of the impact of the incidental catch of sea turtles resulting from ICCAT fisheries; measures to reduce seabird and turtle mortality on longline fisheries; measure to improve the safe release of sea turtles and to encourage the use of circle hooks to reduce sea turtle mortalities; measure to establish the mandatory use of tori lines for longliners operating below 20^{o} south; measure to assess the efficacy of the seabirds bycatch mitigation measures; measure to encourage contracting parties to collect information on shark bycatch; measure to ban on shark finning with a limit on a 5% ratio (not allowed to have a on board fins that total more than 5% of the weight of sharks on board); measures to prohibit the retention on board of silky shark, oceanic whitetip shark, bigeye thresher shark, and hammerhead sharks; measure to mandate the assessment on shortfin mako and blue sharks, yet the quality of the data and assessment are insufficient to generate the assessment and provide management recommendations; measure to rebuilding plans for blue and white marling.

IOTC

An extensive regional bycatch program is not in place in the IOTC convention area to monitor the impacts of tuna fisheries on non-target species that are either retained or discarded by IOTC fisheries. Instead Member States are mandated to monitor and collect data on bycatch species during their fishing operations, and through the implementation of National observer programs (with a minimum of 5% coverage per gear type), which derived data must be submitted to the IOTC Secretariat. Data reporting by the large majority of Member States to the IOTC Secretariat has been historically very low and it remains very low. Data paucity is particularly acute from the National observer programs. Up to the year 2014, only two or three IOTC Member States have achieved a minimum of 5% minimum of observer coverage for a gear type. Moreover, in those cases where bycatch data may be available, they data may not be submitted to the IOTC Secretariat, and when submitted, the data may not be comparable across regions due to different standardization and collecting protocols. The paucity of quality data held by the IOTC Secretariat have partially hindered all the research activities conducted by the Working Party of Ecosystems and Bycatch (WPEB) and the Scientific Committee to asses the overall impact of tuna fisheries on bycatch species and their interactions at any scale or level of accuracy in the IOTC area and, hence its advisory role to the Commission as requested in several IOTC resolutions and recommendations. The WPEB reiterates every year the recommendation to address the lack of data submission and lack of implementation of National observer programs by Member States, and recommends training for Member States on data collection methods, species identification and implementation of mitigation measures.

Operational objectives: There are no clear objectives in place to mitigate the impacts of fisheries on bycatch species. The IOTC Convention Agreement does not contain any specific provisions concerning the impact of fisheries on non-target species and conservation of biodiversity.

Indicators: No indicators have been linked to operational objectives. The low level of bycatch data has hindered any efforts of the WPEB to develop and test indicators, including single species and multispecies indicators, to track the impact of IOTC fisheries on bycatch species including sharks, seabirds, turtles and marine mammals, as part of an EAFM. Despite the paucity of catch data to estimate bycatch levels for any species or taxonomic group of species in the IOTC area, and paucity of catch-effort and size data to calculate indicators of species status, the WPEB have a series of ongoing research activities that have the potential to produce a series of indicators to track the impacts of fisheries on bycatch species. The main research activities include:

-A Ecological Risk Assessment including several taxonomic groups of species was conducted to assess the relative risk of both target and bycatch species being negatively impacted by various tuna fleets managed by IOTC, purse seine and longline fisheries (Murua et al. 2009). This productivity-susceptibility analysis created an index of vulnerability to overfishing in longline and purse seine fisheries for species in several taxonomic groups including the target tuna species, as well as bycatch species such as billfishes, other teleost, sharks, skates, rays, turtles, seabirds, and marine mammals. This risk assessment has been used to establish research and management priorities in IOTC.

-The WPEB conducted a preliminary Ecological Risk Assessments for shark species in 2012, as determined by a susceptibility and productivity analysis (Murua et al. 2012), in order to rank their relative vulnerability to logline and purse fisheries in the IOTC area. An ERA for sharks in gillnet fisheries is still missing driven by a lack of data availability. The preliminary Ecological Risk Assessment allowed identifying the 10 most vulnerable sharks species to longline and purse seine fisheries, which has been used to set research priorities within the WPEB, and provide advise on shark management to the Commission.

-The WPEB is currently prioritizing the development of indicators of stock status for three relatively data-rich species of sharks (blue shark, oceanic white tip shark and shortfin mako). The indicators of stocks status consist in evaluating the temporal patterns of several standardized CPUE from several longline fleets for these three species of sharks which is work in progress. The development of the 2014 Multiyear Shark Research Program, initiated by the IOTC Secretariat and shark experts in the WPEB, will facilitate the development of stock assessments and status indicators for shark species caught by IOTC fisheries and improving the collaboration and cooperation among IOTC researchers.

-A preliminary Ecological Risk Assessment, as a susceptibility and productivity analysis, was conducted in 2013 for all six species of marine turtles found in the IOTC area to evaluate their interactions with longline, purse seine and gillnet fisheries (Nel et al., 2013). The WPEB plans to review it and updated periodically as relevant information becomes available.

-A Preliminary Ecological Risk Assessment, as a susceptibility and productivity analysis, was conducted in 2010 for seabirds to evaluate the risk of seabirds from bycatch in longline fisheries in the IOTC area. 40 seabird populations were identified as High Priority. The ERA was conducted by the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and BirldLife International (BirdLife). The WPEB recommended to undertake a Level 2 ERA for those species identified as High Priority, and to conduct a Level 3 assessment for a smaller number of species where data availability permits it.

-Currently marine mammals are a lower priority than sharks, seabirds and turtles for the WPEB. Yet the WPEB encourages research on the interaction IOTC fisheries with marine mammals, and it periodically reviews data and information presented to the group on the interactions of fisheries with marine mammals and on depredation events to quantify the economic impacts of depredation on several fisheries. WPEB has noted that gillnets are a major impacts on marine mammals, which needs to be addressed to understand the ecosystem effects of these fleets.

-The WPEB annually reviews the progress on the development and implementation of the FAO National Plan of Actions (NPOA) for sharks, and seabirds of each Member State. The WPEB recognized that the NPOA for sharks and seabirds are an important framework that should facilitate the collection of data for these species, and the implementation of management measures in compliance of IOTC resolutions. Although there are not formal requirements for the states to conduct FAO NPOA for turtles, the WPEB reviews national plans and management strategies for sea turtles for each Member States, to provide technical advice for their development, competition and implementation.

-The WPEB reviews periodically new data, studies and other information regarding bycatch mitigation research, guidelines of identification of species and best practices for handling and releasing bycatch, and also studies evaluating the performance of current bycatch mitigation measures for species of sharks, turtles and seabirds, with a view of developing further technical advise to modify current resolutions and draft new recommendations.

Thresholds: No thresholds have been linked to associate indicators. Limit and target reference points have not been defined or adopted for any of the bycatch species.

Responses and management measures:
There has been no management responses linked to any pre-established indicators and associated operational objectives. Yet, a series of conservation and management measures have been adopted to mitigate the effects of fishing on by-catch species including sensitive species. The ecological risk assessments conducted for several taxonomic groups of target and bycatch species have been decisive to establish research priorities and put in place management measures for by-catch species generally lacking quality data to conduct quantitative stock assessments. The WPEB also reviews periodically the current conservation and management measures relevant to bycatch species in light of new data, studies and other information presented to the group.

Next, we briefly list a series of measures adopted in IOTC to mitigate the impact of IOTC tuna fisheries on sensitive bycatch species. These include: measure to establish minimum reporting requirements for sharks, calls for full utilization of sharks and includes a ratio of fin-to-body weight for shark fins retained onboard a vessel; measure to prohibit the retention of the three species of Thresher shark; measure to prohibit the retention of oceanic whitetip sharks; measure to put in place a programme comprising national observer schemes to collect verified catch data and other scientific data; measure to mitigate the interactions between cetaceans and purse seine fishing gear, and whale shark and purse seiners; measure to ban the use of large-scale driftnets on the high seas within the IOTC area of competence; measure to establish data reporting for sharks, seabirds, turtles, marine mammals; measure to mitigate and reduce the interaction with seabirds and longliners; measure in support of the FAO IPOAs for seabirds, sharks, capacity and IUU; measure to set the procedures on a fish aggregating devices (FADs) management plan.

IATTC

An extensive regional bycatch program is in place to monitor non-target species that are either retained or discarded. The bycatch monitoring program is comprehensive for the large purse-seine fisheries with a 100% observer coverage under the Agreement on the International Dolphin Conservation program (AIDCP). The bycatch monitoring program is not complete for the rest of fisheries including small purse seiners, pole and line and longline fisheries. Although there have been studies investigating the interactions and quantifying the bycatch of on non-target species by longline fishing gears, few comparable data for longline fisheries exists in the IATTC area to generalize the impacts of longliners on non-target species. Spatial information of bycatch rates has been collected to evaluate measures to reduce bycatches, such as closures, effort limits, *etc*.

Operational objectives: The convention objectives request for a reduction of bycatch and to monitor and adopt measures related to dependent or associated species. It also includes the implementation of the precautionary approach.

Indicators: The IATTC Ecosystem and Bycatch Programs have developed a series of indicators to track the impacts of fisheries on bycatch species, including species-level indicators for several species in several taxonomic groups, and aggregated indicators describing changes in the communities.

The aggregate multi-species indicators consist in:
- Yearly catch rates (retained and discards) by type of purse seine fisheries and pole and line fisheries. These catch rates are used as relative indices of abundance and have been calculated since the 1990s.
- Yearly mean trophic level of the catches (retained and discards) by type of purse seine fisheries and pole and line fisheries. These are available since the 1990s.
- Index of vulnerability to overfishing for 33 incidentally caught species of fishes, mammals, and turtles for three types of purse seine fisheries. The ecological risk assessment has not been conducted for longline and pole-and line fisheries.

The single species-level indicators consist in:
For dolphins
-Trends of population size for several dolphin species, together with information on their distribution, herd size and herd composition, are available from several years spanning almost 20 years.
-Incidental mortality rates for dolphins in the large purse fisheries have been estimated several times since the 1970s.

For birds
-Population status and trends for some birds species have been estimated since the 1980s.

For sharks
-Catch rates, which are used as relative indices of abundance, are available for several sharks species from the large purse fisheries differentiating by major types (sets on floating objects, sets on dolphins, unassociated sets). This data is incomplete for the rest of fisheries, including small purse-seiner, pole and line and longline fisheries.
-Formal fisheries stock assessments have been conducted for several sharks species, blue shark and silky shark, to assess the impact of bycatch on the status of the stocks.

For turtles
-Information on the incidental mortality rates for turtles in longline fisheries is scarce, and sporadic in time and space.

Thresholds: No thresholds have been linked to associated indicators, except for the incidental mortality limits for dolphins to levels that are insignificant relative to stock sizes in the eastern Pacific ocean purse-seine fishery under the AIDCP.

Responses and management measures: The IATTC has a long list of management measures and actions to mitigate the effects of fishing on by-catch species including sensitive species. Yet, there is only one management measure that is linked to a pre-agreed operational objective and associated indicators, and is activated when a predefined threshold is exceeded. This is a management measure to limit the incidental mortality rates of dolphins and thus, minimize the impact of IATTC large purse seine vessels on dolphin populations. Since the 1980s the Agreement on the International Dolphin Conservation program (AIDCP) to reduce or eliminate that impact of purse seine fisheries on dolphins has had considerable success. In purse seine fisheries, dolphin mortality is managed and closely monitored by AIDCP to reduce mortality levels approaching zero with mortality limits, real time 100% observer coverage and reporting, dolphin safety gear, and training program for vessels. This program was key to allow for a transition in the IATTC from just promoting the conservation of dolphins in tuna fisheries to have pre-agreed management rules and responses to ensure a predefined objective is achieved. The rest of measures are a set of actions attempt to mitigate the effects of fishing in the ecosystem and protect sensitive species but there are not pre-established criteria linking objectives, to indicators and limits to decision rules to drive pre-established management actions.

We briefly list a series of actions and measures taken in the IATTC convention area:
For all fisheries
For large purse seiners it is required a 100% observer coverage. For large longliner it is required a 5% observer coverage.

For turtles
Programs to mitigate the impact of tuna fishing on turtles that requires data collection, mitigation measures, industry education, capacity building and reporting. Provisions on releasing and handling of sea turtles captured in purse seines. Provisions on implementing observing programs for all the fisheries that have impacts on sea turtles.

For birds
Measure to reaffirm the importance for implementing the International Plan of Action for reducing incidental catch of seabirds in longline fisheries by all fishing states. Large longline vessels are required to have a set of specified mitigation measures.

For sharks
Required International Plan of Action to reduce incidental catch of sharks. Prohibits retaining onboard, transshipping or selling oceanic whitetip shark. Live release of other sharks and rays.

Ecological Element 3 of an EAFM: Trophic relationships.

ICCAT

Research activities on food web interactions, diet analysis, ecosystem modeling, and development of indicators to track ecosystem change or impacts of fishing on ecosystems are scarce in the ICCAT area. No formal mechanisms exist to accommodate food web interactions and ecosystem modeling into the current management of ICCAT target species. Nevertheless, the Sub-Committee on Ecosystems recommends the identification and evaluation of ecosystem indicators, including single and multispecies indicators, for use as part of a ecosystem approach to fisheries management, especially focusing on interpretation of the indicators, robustness, responsiveness and associated reference points. The group has also expressed value and interest in conducting research on multi-species and multi area stock assessments to evaluate management objectives for multiple stocks and evaluate species interactions, as well as food web interactions and ecosystem models as an element of an EAFM. Yet, there is limited information to describe trophic interactions and understand the impacts of fishing climate variability of high and medium trophic level species as well as the importance on forage species to the survival of target higher trophic level species. The Sub-committee on Ecosystems recommends research on ecosystem modeling (e.g Ecopath, SEAPODYM, etc.). Some recent efforts have been initiated to apply ecosystem modeling to Atlantic pelagic ecosystems e.g. (Lefort et al. 2014)

Operational objectives: There are no clear objectives in place to maintain the structure and functioning of marine food webs and ecosystem health. The ICCAT Convention Agreement does not contain any specific provisions concerning the conservation of biodiversity and minimization of impacts of ICCAT fisheries on dependent species and ecosystems.

Indicators: No indicators have been linked to operational objectives.

Thresholds: No thresholds have been linked to associate indicators.

Responses and management measures: No specific measures strictly to protect the structure and functioning of marine food webs.

IOTC

Research activities and practices to address the importance of trophic interactions in the development of an ecosystem approach to fishery management have been relatively rare in the

IOTC area. Specifically, research activities on species relationships, food web interactions, diet analysis, ecosystem modeling, and development of indicators to track ecosystem change or impacts of fishing on ecosystems are very scarce in in the IOTC area. Nevertheless, the Working Party on Ecosystems and Bycatch, as stated in its terms of reference, encourages research on ecosystem approaches, modeling of potential benefits at the ecosystem level of alternative management strategies, on diet studies to investigate the trophic interactions among predators and prey species interacting with IOTC fisheries, on multi-species interactions to understand ecosystem variability since populations explosions of mantis shrimps, swimming crabs and lancetfish have been documented in the western Indian Ocean. Furthermore, the WPEB also encourages the development of mechanisms to better integrate ecosystem considerations into the scientific advice provided by the Scientific Committee to the Commission. A formal mechanism does not exist to accommodate multispecies and food web interactions and ecosystem modeling into the current management of IOTC target species.

Operational objectives: There are no clear objectives in place to maintain the structure and functioning of marine food webs and ecosystem health. The IOTC Convention Agreement does not contain any specific provisions concerning the conservation of biodiversity and minimization of impacts of IOTC fisheries on dependent species and ecosystems.

Indicators: No indicators have been linked to operational objectives.

Thresholds: No thresholds have been linked to associate indicators.

Responses and management measures: No specific measures strictly to protect the structure and functioning of marine food webs.

IATTC

IATTC recognize the value of investigating the ecosystem effects of fishing by understanding the food web structure, trophic relationships and interactions involving species impacted directly and indirectly by fishing. A significant research program and research activities have been developed since the 1980s to understand and describe the trophic structures and interactions that involve the species impacted by fishing, including the likely effect of fishing on other dependent species, dependent predators or pray species.

These main research activities include:
-Development of a food-web model of the pelagic ecosystem in the tropical east Pacific ocean including the main functional species and group of species to describe trophic links, biomass flows through the food web.

-Development of multi-species pelagic ecosystem models in the tropical east Pacific ocean to investigate how fisheries and climate variability impact species at the upper and middle trophic levels and to understand the main trophic links and biomass flows through the food web.

-Diet studies of stomach contents and stable isotope analysis for multiple species including yellowfin, skipjack and bigeye tunas, dolphins, pelagic sharks, billfishes, dorado, wahoo, rainbow runner and others. These diet studies are critical to investigate the key trophic connections in the pelagic eastern Pacific ocean, which forms the basis for representing food web interactions in the ecosystem models. It is worth to highlight a comprehensive decadal analysis of the predation by yellowfin tuna completed in 2013.

-The NMFS has recorded data on the distributions and abundance of the large variety of prey species in the IATTC area including lantern fishes, flyingfishes and some squids during 1886-1990, and 1998 and 2000. These studies have been important to investigate the key trophic connections in the pelagic eastern Pacific ecosystem.

-Some research and monitoring has been conducted to investigate the role of squids as key prey and predator and their distributions in response to environmental variability in the pelagic eastern Pacific ecosystem.

Operational objectives: No clear operational objective to manage the impact of fisheries on the structure and functioning of marine food webs.

Indicators: Several indicators or metrics to measure ecosystem change and sustainability are routinely calculated. These include:
- the mean trophic level of the organisms taken by a fishery (model derived)
- yearly mean trophic level of the catches (retained and discards) by type of purse-seine fisheries and pole and line (1993-2010)

Thresholds: Ecosystem-level metrics or thresholds have not been defined. Yet, IATTC does not take into account the information derived from ecosystem indicators to set reference points, catch levels or other fisheries management measures.

Responses and management measures: There are not management measures in place to account for the impacts of fishing on the food web structure and trophic relationships.

Ecological Element 4 of an EAFM: Habitats.

ICCAT

Research activities and practices to address the importance of habitat preferences in the development of an ecosystem approach to fishery management have been relatively scarce in the ICCAT area. We summarize briefly the type of research activities that have been conducted in the ICCAT area that facilitates and recognizes the importance of habitat in the development of an ecosystem approach:

-The ICCAT Sub-Committee on Ecosystem has started a collaborative research program to map the relative significance of the Sargasso Sea to ICCAT species as essential habitat for tunas and tuna like species. The Sargasso Sea may play a fundamental role in the trophic web of highly migratory species in the northwest Atlantic. Potentially it could be a case study in implementing an ecosystem based management approach within ICCAT in collaboration with other research institutions. This analysis follows the Commission request to assess the importance of the Sargasso Sea for tuna and tuna-like species.

-Tagging studies are also reveling information on seasonal migrations, habitat utilization, breeding migration, migration corridors, hot spots, and physical oceanographic patterns that are important to understand how Atlantic bluefin and other tunas use the open ocean environment e.g. (Block et al. 2001, Galuardi and Lutcavage 2012).

-There is an increasing use of ecosystem and habitat models such as SEAPODYM and APESCOM to investigate the dynamics and spatial distributions of target species and their responses natural climate and climate change in the ICCAT area (Schirripa et al. 2011, Lefort et al. 2014, Lehodey et al. 2014).

-Some habitat studies have been conducted to document habitat preferences and identify most important variables driving the spatio-temporal distributions of some ICCAT target species (Arrizabalaga et al. 2014).

Operational objectives: There are no clear objectives to address the importance of habitat in the development of an ecosystem approach.

Indicators: No indicators have been linked to operational objectives.

Thresholds: No thresholds have been linked to associate indicators.

Responses and management measures: There are not specific measures strictly for habitat protection in response to pre-agree operational objectives. Yet there has been a series of measures related to the protection and assessment of essential habitats for tuna and tuna-like species. These include a measure to assess the available data and information concerning the Sargasso Sea importance to tuna and tuna-like species and ecologically associated species.

IOTC

Research activities and practices to address the importance of habitat preferences in the development of an ecosystem approach to fishery management have been relatively rare in the IOTC area. Nevertheless, the Working Party on Ecosystems and Bycatch recognizes the importance of habitat in the development of an ecosystem approach to fisheries and, as stated in its terms of reference, encourages a series of research activities. These include: the evaluation of the effect of oceanographic and climatic factors on the abundance, distribution and migration of IOTC target and non target species; characterization of main feeding and reproductive habitats for IOTC species.

We summarize briefly the type of research activities that have been conducted in the IOTC area that facilitates and recognizes the importance of habitat in the development of an ecosystem approach:

-Environmental factors are accounted for in several CPUE standardization techniques, particularly for target species in the Japanese longline fisheries.

-Some habitat studies have been conducted to document habitat preferences and identify most important variables driving the spatio-temporal distributions of some IOTC target species (Arrizabalaga et al. 2014).

Operational objectives: There are no clear objectives to address the importance of habitat in the development of an ecosystem approach.

Indicators: No indicators have been linked to operational objectives.

Thresholds: No thresholds have been linked to associate indicators.

Responses and management measures: There are not specific measures strictly for habitat protection in response to pre-agree operational objectives.

IATTC

IATTC recognize the value of conducting studies on the effects of environmental conditions and climate variability on the distribution, abundance, recruitment and dynamics of tunas and billfishes. There is a research program in place to monitor the ocean environment. The ocean environment is monitored regularly at several time scales, from seasonal to interannual to decadal scales. This information is used to measures changes in the biological production, expansion of the oxygen minimum zone and suitable habitat and its effect on the distribution, abundance, recruitment and dynamics of tunas and billfishes. Some stock assessments have incorporated oceanographic information to explore how it may affect the recruitment dynamics of species. For many years the NMFS has been collecting larval fish samples with surface net tows in the EPO to investigate the occurrence, abundance and distributions of the key taxa in relation to the environment. Several studies using satellite and at-sea observation data have identified the importance of the IATTC area as critical foraging areas for several bird species including the waved, black-foored, laysan and black-browed albatrosses. Despite the existence of a strong research program to understand the effects of environmental conditions and climate variability on the distribution, abundance, recruitment and dynamics of tunas and billfishes, IATTC has not in place clear operational objectives to address the importance of habitat in the development of an ecosystem approach and there are not specific measures strictly for habitat protection in response to pre-agree operational objectives.

Operational objectives: There are no clear objectives to address the importance of habitat in the development of an ecosystem approach.

Indicators: No indicators have been linked to operational objectives.

Thresholds: No thresholds have been linked to associate indicators.

Responses and management measures: There are not specific measures strictly for habitat protection in response to pre-agree operational objectives.

4. Conclusions and future work

The ICCAT and IOTC Convention Agreements objectives are outdated by not making reference to the UN Fish Stock Agreement, the FAO Compliance Agreement, and FAO Code of Conduct on Responsible Fisheries. ICCAT and IOTC Agreements do not make reference to the Precautionary Approach or the ecosystem approach to fisheries, which constitutes an impediment to the application of more holistic management to the management of tuna species, dependent species and associated ecosystems. Nevertheless, while the extent of the ecosystem-related research programs differs markedly among IATTC, ICCAT and IOTC and occur under different fundamental research and institutional structures, the three tuna RFMOS have taken some steps to apply an ecosystem approach to fisheries management.

The IATTC has a relatively long history of research programs and activities, some of them established since the 1980s and 1990s, that are supported by a relative large group of permanent staff in the Secretariat and a large network of permanent collaborations with local research institutions, universities and diverse research entities. The large staff in conjunction with solid external collaborations with local government and academic research institutions has resulted in a richer IATTC ecosystem research program and larger volume of ecosystem-related research outputs in support of an ecosystem approach to fisheries. Instead, the ecosystem-related research programs and activities conduced in ICCAT, specifically the Sub-Committee on Ecosystems, and IOTC, specifically in the Working Party of Ecosystem and Bycatch, have a relatively shorter history. These research activities conduced and coordinated by these groups are supported by a relatively small group of permanent staff at the ICCAT and IOTC Secretariats, an intermittent support of national scientists participating in the annual meetings, and disperse and limited collaborations from external local government and academic research institutions. An exception is the permanent and solid collaborations of the Non-Governmental Organization Birld Life International with IOTC and ICCAT to produce assessments of seabirds interactions with fisheries. These research and institutional structures operating currently in ICCAT and IOTC has led to a relatively small volume of ecosystem-related research and outputs in support an EAFM since the working group on ecosystems in ICCAT and IOTC were established. However, it is worth noting that since the newly created 2005 ICCAT Sub-Committee of Ecosystems and 2007 IOTC Working Party on Ecosystems and Bycatch, the number of initiatives and volume of ecosystem-related research work have been substantially increasing and gaining momentum in support of an EAFM. Both the ICCAT Sub-Committee on Ecosystem, and the IOTC Working Party on Ecosystems and Bycatch would benefit substantially by increasing its efforts to seek permanent support and solid collaborations from local government and academic research institutions to support its research programs and ecosystem related research activities. Moreover, both the ICCAT Sub-Committee on Ecosystemd and IOTC WPEB have noted the large increase in scientific workload and tasks on bycatch and ecosystem issues requested from the Commission over the last five years. Both working groups are discussing different possibilities to manage the workload, from splitting the groups into smaller groups in order to focus the effort of scientists on the different aspects of an ecosystem approach to fisheries, to recommending the increase the number of permanent staff at the Secretariat in support of the scientific progress of the groups.

The current practices under each of the four main ecological elements (target species, bycatch, trophic relationships and habitats) to address and apply the ecosystem approach to fisheries management vary greatly among ICCAT, IOTC and IATTC. For the ecological element of target species, the three tuna RFMOs have done much progress in assessing the exploitation status for the large majority of target species relative to common fisheries reference points. Yet the large majority of target marlins, sharks and small tunas remain unassessed. Interim limit and target reference points associated with the stock current biomass and fishing mortality rates have now been adopted only for the major principal market tuna stocks in IOTC and IATTC, but not in ICCAT. ICCAT has proposed limit reference points and harvest control rules for the north Atlantic albacore and swordfish stocks, but have not been adopted yet.

For the ecological element of bycatch, the three tuna RFMOs have adopted management measures to mitigate the effects of fishing on by-catch species including sensitive species. Yet, these management measures have not been generally linked to pre-agreed operational objectives and associated indicators, and are not activated when predefined thresholds are exceeded. The only exception is the IATTC management measure that limits the incidental mortality rates of dolphins in large purse-seine tuna fisheries. Most of the management measures adopted by the three tuna RFMOs focus in applying the precautionary approach to minimize fishing impacts on non-target species and focus less in strictly applying an EAFM. In the three tuna RFMOs the status of non-target species is in most cases unknown or relatively poorly known compared with target species, and very few quantitative stock assessments exist for non-target species. In all the cases, the paucity of basic information on fisheries statistics and on the biology of the non-target species hinders many of the efforts to comprehensively evaluate the impact of fisheries on by-catch species. In the three tuna RFMOs, the development of qualitative and quantitative Ecological Risk Assessments for incidentally caught species of sharks, birds, turtles, marine mammals and other teleost fishes have been critical to set priorities and take management action following the precautionary approach in the absence of quality stock assessments for bycatch species. In ICCAT and IOTC, the delay on applying an EAFM is mostly due to the absence of quality standardized bycatch datasets, reliable indicators to track the impacts of tuna fisheries on bycatch species and absence of quality assessments to quantify the extent of the impacts. In addition, the dedication of Sub-Committee on Ecosystems in ICCAT and the Working Party on Ecosystem and Bycatch in IOTC depends on the priorities set by the Commissions, which until now has focused more on bycatch mitigation (eg birds and sharks) than in establishing methods and a management strategies to link by-catch objectives and bycatch indicators to the management of target species and protection of associated ecosystems. IOTC presents an additional challenge in respect to the other two tuna RFMOs, since artisanal fisheries take 50% of total catch in the IOTC convention area, which increases the difficulty of evaluating the impact of fisheries on bycatch species. IATTC has a strong bycatch research and monitoring program in place which produces annually a series of single species and multi-species aggregate indicators to track the impacts of fisheries on bycatch species in support an ecosystem approach to fisheries management, yet IATTC has been unsuccessful in defining and adopting bycatch thresholds associated to pre-established indicators for any bycatch species and link it to management actions, with the exception of the incidental mortality limits established for dolphin species.

The three tuna RFMOs recognize the value of research activities on food web interactions, diet analysis, ecosystem modeling, and development of indicators to track ecosystem change or impacts of fishing on ecosystems. Nevertheless, these research activities are relatively scarce and have a shorter history in the ICCAT and IOTC than IATTC. No formal mechanisms exist to accommodate food web interactions and ecosystem modeling into the current management of ICCAT, IOTC or IATTC species and associated ecosystems. There are no clear objectives in place in either tuna RFMO to maintain the structure and functioning of marine food webs and ecosystem health, neither ecosystem indicators and associated thresholds and management responses have been liked to pre-established operational objectives. A good practice in the IATTC consist in the preparation of an annual Ecosystem Consideration Report which includes pertinent information on major ecosystem components including forage organisms, trophic interactions, ecosystem modeling, aggregate ecosystem indicators to track impacts of fishing on different component of the eastern pelagic ecosystem. A simple practice such as this could maybe be a valuable product that could be established in ICCAT and IOTC with the aim of establishing priorities and direct future work.

Despite the recognition that habitat is central to the productivity and size of populations and biodiversity in ecosystems (Lodge et al. 2007), the development of practices and research activities to address the importance of habitat preferences, together with trophic relationships, have been the most underdeveloped aspects in an ecosystem approach to fisheries in the three tuna RFMOS. Most of the habitat work has focused in using oceanographic information to improve single species stock assessments and understand habitat preferences and habitat utilization for target species. The three tuna RFMOs need to define clear operational objectives to address the importance of habitat utilization and preferences in a multi species context in order to development an ecosystem approach to fisheries management.

Here, we conducted a preliminary review based of the current approaches and practices of three tuna RFMOs as case studies to evaluate their progress in applying an EAFM. In the future, we intend to evaluate the performance and progress in applying each ecological element of an ecosystem approach to fisheries in the five tuna RFMOs. Our work seeks to identify data and methodological needs, useful ecological indicator to assess the ecosystem health in the pelagic realm, limitations in capacities that hinder process, and identify synergies, example of good practices and opportunities that can be transferred across the tuna RFMOS towards applying an EAFM without compromising the function and structure of marine ecosystems and ensure the delivery of ecosystem services for the wellbeing of humanity.

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Table 1. Towards developing an DPSER conceptual ecological model for a "role model" RFMO. The conceptual model is based on the best conservation and management practices of RFMOs in applying ecosystem based management and the precautionary approach from Lodge et al 2007. The Table describes the modules depicted in the EBM-DPSER model of Figure 4, and includes (1) the overall overarching objective of a "role model" RFMOs, (2) the four ecological elements most used in practices to address ecosystem based management of fisheries and assess the ecological state of target species and associated ecosystem, (3) operational objectives for each ecological element, (4) associated indicators to track the state and trend of each ecological element, (5) thresholds for those indicators and (6) management and conservation measures and responses to ensure that those thresholds are not exceeded (modified from Lodge et al 2007).

Role Model RFMO				
Overarching objective: The main goal of ecosystem based management is to ensure the sustainability of catches without compromising the inherent structure and functioning of marine ecosystems, which deliver ecosystem services for human society (Lodge et al 2007).				
Principal ecological elements of an EBM approach to fisheries	**Operational objectives**	**Associated state indicators**	**Associated thresholds**	**Associated measures and management responses**
(1) Target and commercially retained species	Maximize sustainable harvest of target species applying the precautionary approach	Species level indicators: -Biomass trends relative to Bmsy or Bo -Fishing mortality rate trends relative to Fmsy -Size/age structure trends	-Target and limit reference points are defined for population biomass and fishing mortality * Reference points need to ensure the ecological role of the species is maintained, and to account for the needs of other dependent species *In absence of information apply the PA	-Recovery plans -Capacity-reduction plans -Time-area restrictions
(2) Bycatch species	-Maintain sustainable populations of non-target species populations and ecosystem processes -Mitigate/reduce the bycatch of threatened species	Species-level indicators: -Population size trends -Size/age structure trends -Catch trends -Vulnerability of a species to overfishing Community-level indicators: -Aggregate catch trends -Species composition of the catch -Community size structure -Diversity indices -Trophic spectra of catches, mean trophic level of catches -Relative catch of a species or group Fishery-level indicators: -Bycatch percentage per fishery -Percent coverage of observers per fishery	-TAC allocated to vulnerable species *In absence of information apply the PA	-Risk-based impact assessments of the effects of fishing, followed by measures when risk is presumed. -Bycatch limits or caps for species or groups -Time-area restrictions -Gear modifications and practices to reduce bycatch -Release of capture life animals following protocol
(3) Trophic relationships	Maintain viable trophic interactions and interdependencies involving species that are affected by fishing	Ecosystem-level indicators (mostly model derived): -Total removal (landings and discards) indicators -Size based indicators -Trophic level based indicators -Relative abundance of a species or group of species -Trophic links and biomass flows *Indicators can be empirically based, using total removals (landings and discards) or model-based derived from ecosystem models	-Limit reference point for the impacts of fishing on key stone predators and preys in the ecosystem -In absence of knowledge, precautionary reference point values based on general expectations	- Multispecies management plans (e.g. one bycatch specie limiting the catch of other target species)
(4) Habitat	Maintain productive habitats for target species and associated species	-Habitat size (e.g. O2 minimum zones) -Habitat shifts and range contractions -Habitat suitability index	-Minimum spawning habitats for population viability	-Restriction or limit the impact of fishing and gears on critical and sensitive habitats (e.g spawning habitats)

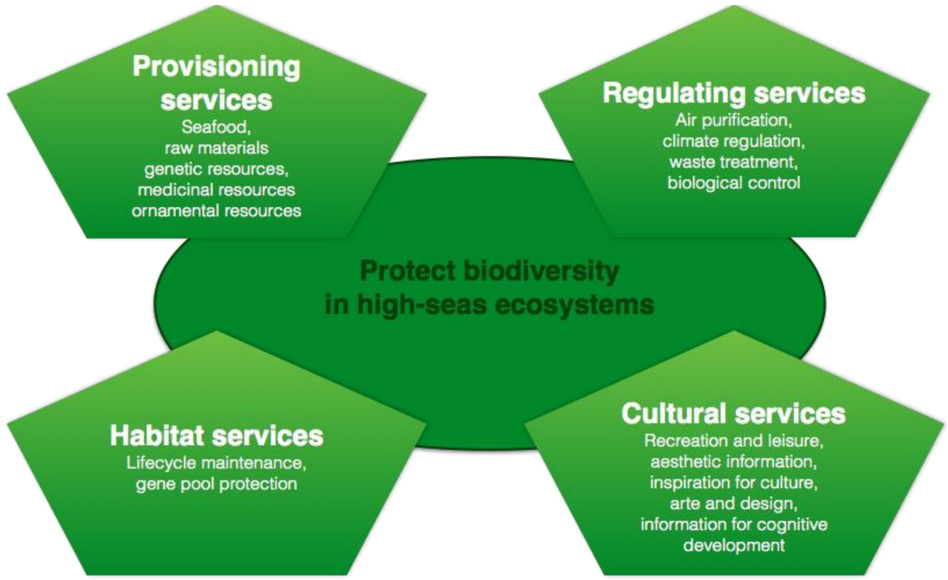

Figure 1. Ecosystems services provided by healthy high seas (based on Rogers et al 2014).

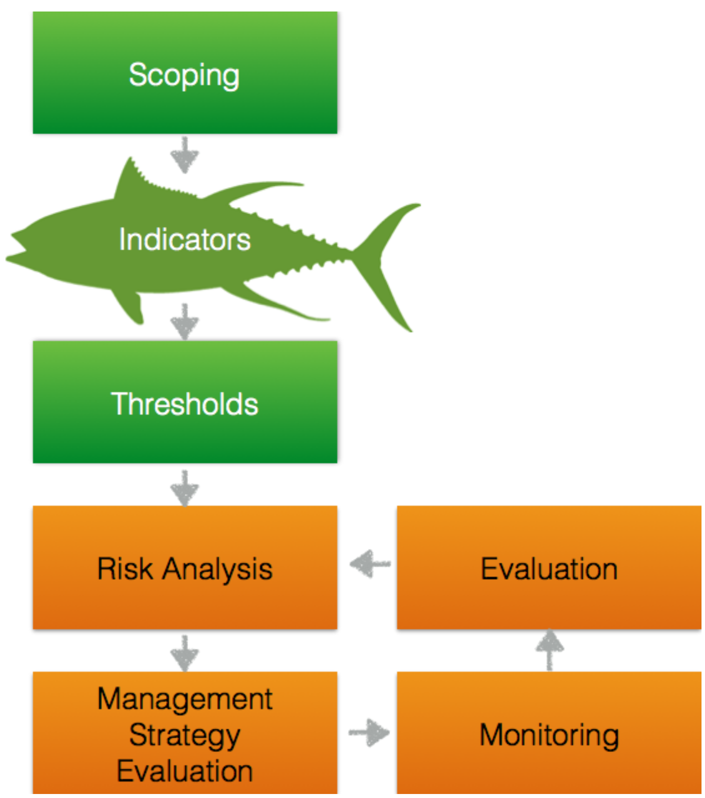

Figure 2. Integrated ecosystem assessment (IEA) framework (based on Levin et al 2009 and Tallis et al 2010).

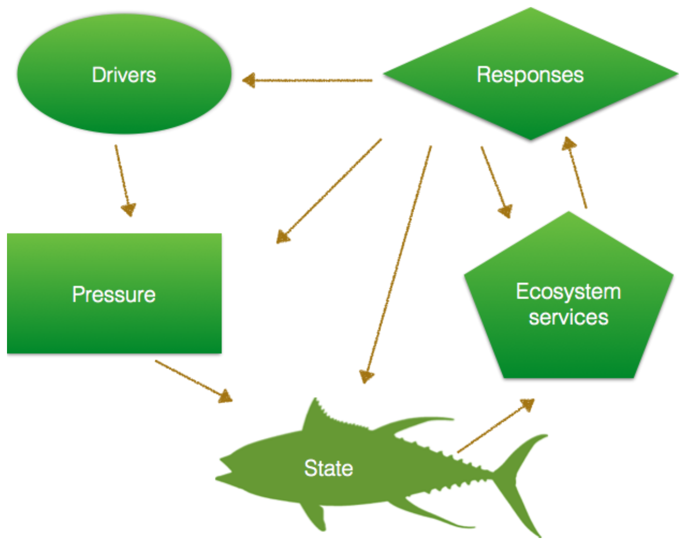

Figure 3. The Drivers, Pressures, State, Ecosystem Services and Response -DPSER- conceptual model (based on Kelble et al 2013)

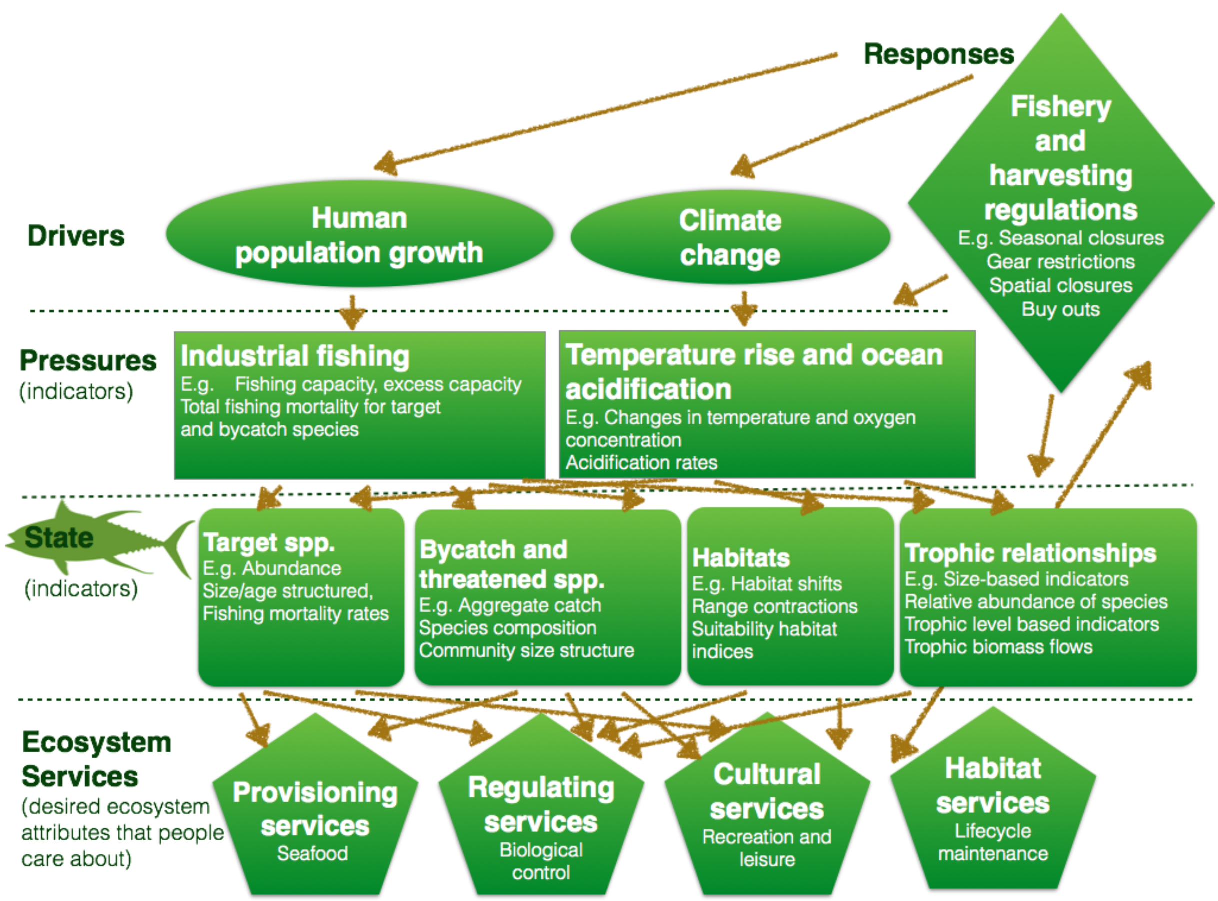

Figure 4. Conceptual Ecological Model for a role model RFMO based on the DPSER framework to monitor the effects of fishing and climate change on tuna species and associated ecosystems.