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PRELIMINARY REVIEW OF ICCAT AND IATTC PROGRESS IN APPLYING AN ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

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SUMMARY

There are increasing expectations for RFMOs to implement an ecosystem approach to fisheries management. We constructed an idealized Driver-Pressure-State-Ecosystem Services-Response conceptual ecological model for a role model tuna RFMO and used it to assess the progress of ICCAT and IATTC in applying an ecosystem approach to fisheries management. Both RFMOs have taken steps, yet the extent of their ecosystem-related research activities and programs differed markedly and occurred under different fundamental institutional structures. Both tuna RFMOs have a long list of management measures to mitigate the effects of fishing on target and by-catch 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 reduce bycatch 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 progress of the five tuna RFMOs in applying an ecosystem approach to fisheries to find examples of good practices that can be transferred across them.

RÉSUMÉ

Des attentes croissantes pèsent sur les ORGP de les voir mettre en œuvre une approche de gestion des pêcheries basée sur l'écosystème. Nous avons élaboré un modèle écologique conceptuel idéalisé dénommé « forces motrices – pression – état - écosystèmes - réponse » pour une ORGP thonière à titre d'exemple afin d'évaluer les progrès de l'ICCAT et l'IATTC dans l'application d'une approche écosystémique de la gestion des pêcheries. Les deux ORGP ont toutes deux pris des dispositions dans ce sens ; or, l'étendue de leurs activités et de leurs programmes de recherche en rapport avec l'écosystème diffère grandement et ceux-ci ont lieu au sein de différentes structures institutionnelles et de recherche fondamentale. Les deux ORGP thonières ont établi une longue liste de mesures de gestion visant à atténuer les effets de la pêche sur les espèces cibles et accessoires et ne disposent d'aucune mesure qui tienne compte des impacts de la pêche sur la structure de la chaîne alimentaire et les relations trophiques, ainsi que de la protection des habitats sensibles. Les mesures de gestion en vigueur pour réduire les prises accessoires n'ont en aucun cas été liées à des objectifs opérationnels préconvenus ni à des indicateurs associés, et elles ne sont pas activées lorsqu'un seuil prédéfini est dépassé. À l'avenir, nous avons l'intention d'évaluer les progrès des cinq ORGP thonières dans l'application d'une approche écosystémique aux pêcheries afin de rechercher des exemples de bonnes pratiques qui peuvent être transposés entre elles.

RESUMEN

Las relaciones medio ambiente-reclutamiento pueden ser difíciles de establecer con los modelos estadísticos tradicionales. Se usan técnicas de reconstrucción estado-espacio, que son no paramétricas y no hacen supuestos acerca de relaciones funcionales para solucionar la cuestión de si las influencias medioambientales en las primeras etapas de vida pueden usarse para prever el posterior reclutamiento. Se halló que la temperatura de la superficie del mar (SST), que se había asociado con el crecimiento de larvas y las tasas de supervivencia, puede utilizarse para mejorar las previsiones de futuro de un año del reclutamiento de atún rojo. Este resultado se halló en el archipiélago balear (stock del Mediterráneo), en el golfo de México, en zonas al este

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de Taipei Chino y dentro del mar de Japón (stock del Pacífico septentrional). Nuestro análisis no niega la importancia de las funciones stock-reclutamiento para la ordenación pesquera, en su lugar, identifica la posibilidad de utilizar herramientas alternativas para la previsión del reclutamiento. En particular, se prevé que la reconstrucción estado-espacio sea útil cuando se dispone de una estimación mediocre del reclutamiento mediante los métodos tradicionales, lo que incluye los casos en los que las cohortes no han entrado todavía en la pesquería.

KEYWORDS

Ecosystem, By-catch, Trophic interactions, Habitat, Indicators, Thresholds, Management

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 alternating species interactions and food web dynamics is poorly known (Kitchell *et al.* 2006, Hunsicker 2012, IATTC 2014).

2. Ecosystem based management of fisheries 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, Regional Fisheries Management Organizations (RFMOs) provide a framework for states to cooperate on the management and conservation of fisheries and associated ecosystems within their area of jurisdiction. Thus, RFMOs provide an opportunity for sustainable fishing operations and for the implementation of ecosystem based management to maximize and sustain a suite of ecosystem services important to human well-being delivered by healthy fish populations and associated ecosystems (Gilman *et al.* 2014). There are five Regional Fisheries Management Organizations (RFMOs) in charge of the management and conservation of tuna and tuna-like species and associated ecosystems covering most of the high seas ecosystems. The five tuna RFMOs are 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).

Traditionally tuna RFMOs have focused most of their resources and capacities to manage target tuna stocks to obtain maximum sustainable catches. Only two of the tuna RFMOs conventions (IATTC and WCPFC) 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, numerous law and international agreements such as the United Nation Fish Stock Agreement, FAO Code of Conduct for Responsible Fisheries and ecosystem approach to fisheries among many others have been agreed, and since then, these 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. Ecosystem Based Management of fisheries: Theory and towards practice

3.1 Operational frameworks to implement ecosystem based 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 ecosystem-based management 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 EBM 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 EBM-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 ecosystem-based management, 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 EBM-DPSER (Ecosystem Based Management Driver-Pressure-State-Ecosystem service-Response) 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 ecosystem based management

To our knowledge the IEA framework and the EBM-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 these two approaches. Next we first attempt to build a very general EBM-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 EBM-DPSER model, we pretend 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 and best practices of two tuna RFMOs as case studies, ICCAT and IATTC, to evaluate their progress in applying an ecosystem approach to fisheries management. 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 an EBM-DPSER conceptual ecological model, we constructed what it could be the basis of a “role ecological model” for a 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 produces a change in 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). Although 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 ecosystem approach to fisheries management 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 RFMOs in practice to fully implement an ecosystem approach to fisheries (**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 target fish populations and associated species and ecosystems. Overall, this general idealized DPSER conceptual ecological model illustrates the main pressure affecting the ecosystem by-catch stem state of tunas and associated species and provides an opportunity to evaluate the performance of tuna RFMOs in applying an ecosystem approach to fisheries for each of these elements. Ideally this general EBM-DPSER model could potentially be used to unpack into several sub-models each of the ecological element (e.g. by-catch, trophic interactions, habitats) typically forming part of an ecosystem approach to fisheries.

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

While the new IATTC Antigua convention make 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, the ICCAT convention only make explicit reference to maintain the populations at levels which permit the maximum sustainable yield (de Bruyn *et al.,* 2013). Nevertheless, the two RFMOs have taken steps to apply an ecosystem approach to fisheries management to different extents and under different fundamental research and institutional structures.

IATTC and ICCAT have two different fundamental structures to undertake and integrate ecosystem related research. ICCAT was established in 1969 and 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. The SCRS rely on the research conducted by several Species Working Groups, the Sub-Committee on Statistics, and the Sub-Committee on Ecosystems. In 2005, the Sub-committee on Ecosystems was created for the purpose of integrating ecosystem-related monitoring, research, modeling and advice activities in support of an ecosystem approach to fisheries in ICCAT. Previous to 2005, there existed two separate Working Groups, one dealing with by-catch 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 by-catch 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 by-catch issues and progress of implementing an ecosystem based approach to fisheries management.

On the other side, IATTC established in 1949 has four main research programs including a Stock Assessment Program, the Biology and Ecosystem Programme, the combined By-catch 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 ecosystem approach to fisheries management. 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, planning, execution, analysis and delivery of products to comply with the convention goals. 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 by-catch 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.

We used the information provided by the annual ICCAT Sub-Committee on Ecosystems Reports and the annual IATTC Ecosystem Consideration Reports, to review the current approaches, research and best practices of IATTC and ICCAT to evaluate their progress in applying the ecosystem approach to fisheries in practice. 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 ecosystem approach to fisheries management (**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 (4) whether there are measures and management responses to ensure that those thresholds are not exceeded.

Ecological element 1 of an EBM approach: 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: All target tuna stocks and some of the target billfish 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 (B_{MSY} and F_{MSY}) 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. F_{MSY} 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 binding and 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 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, and minimum size limits for swordfish and bluefin tunas. Rebuilding plan for bluefin tuna. Management strategy evaluation is increasingly being considered to inform decision-making.

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: All target tuna stocks and only some of the target billfish 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 (B_{MSY} and F_{MSY}) 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: Limit reference points associated with the biomass and fishing mortality rate indicators have not been defined for any of the target stocks. F_{MSY} is used implicitly as a target reference point. A Working Group has been established to suggest preliminary limit and target reference of points and currently several reference points are being considered.

Responses and management measures: Several binding and 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 EBM approach: by-catch and threatened species

ICCAT

An extensive regional by-catch program is not in place to monitor non-target species that are either retained or discarded for any of the fisheries. Instead contracting parties monitor and collect data on by-catch species as part of their national research programs. In many cases the data from these programs are not available at the ICCAT secretariat for use, hindering research activities to assess the overall impact of tuna fisheries on by-catch species in the ICCAT area and, hence their advisory role to the Commission. 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 by-catch species as part of an ecosystem approach to fisheries management.

Operational objectives: There are no clear objectives in place to mitigate the impacts of fisheries on by-catch species.

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 by-catch 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, by-catch 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 by-catch 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 (B_{MSY} and F_{MSY}) 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 by-catch 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 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 by-catch 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.

- ICCAT has taken the initiative to coordinate the tuna RFMO By-catch Joint Technical Working Group in order to develop minimum standards for harmonized longline observer data collection for the tuna RFMOs.

Thresholds: No thresholds have been linked to associate indicators. Limit and target reference points have not been defined or adopted for any of the by-catch 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 and actions 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 by-catch species have been decisive to establish priorities and management action to mitigate the impact of ICCAT tuna fisheries on sensitive by-catch species such as birds, turtles and sharks which generally lack quality data for more quantitative assessments.

We briefly list a series of measures put in place 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 20º south; measure to assess the efficacy of the seabirds by-catch mitigation measures; measure to encourage contracting parties to collect information on shark by-catch; 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, thresher sharks, 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.

IATTC

An extensive regional by-catch program is in place to monitor non-target species that are either retained or discarded. The by-catch 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 by-catch 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 by-catch 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 by-catch rates has been collected to evaluate measures to reduce by-catches, such as closures, effort limits, *etc*.

Operational objectives: The convention objectives request for a reduction of by-catch 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 By-catch Programs have developed a series of indicators to track the impacts of fisheries on by-catch 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 by-catch 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 shark

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 EBM approach: 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 ecosystem approach to fisheries management. 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.

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, flying fishes 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 EBM approach: 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 research program to map a collaborative plan to assess 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, Maunder 2012, 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 target ICCAT target species (Arrizabalaga *et al.*).

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.

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

Both IATTC and ICCAT have taken steps to apply an ecosystem approach to fisheries management, yet the extent of their ecosystem-related research programs differ markedly and occur under different fundamental research and institutional structures. The IATTC have 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 and a large network of solid collaborations with local research institutions, universities and diverse research entities. This 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. The ecosystem-related research programs and activities conduced in ICCAT, and specifically the Sub-Committee on Ecosystems, have a relatively shorter history. These research activities are supported by a relatively small group of permanent staff of the secretariat, and the intermittent support of national scientists and limited input from local research institutions and universities. These research and institutional structures has led to a relatively small volume of ecosystem-related research and outputs in support an ecosystem approach to fisheries since ICCAT was established. However, since the newly created 2005 Sub-Committee of Ecosystems, the number of initiatives and volume of ecosystem-related research work have been substantially increasing and gaining momentum in support of an ecosystem approach to fisheries management. The ICCAT Sub-Committee on Ecosystem would benefit substantially by increasing its efforts to seek permanent support and solid collaborations from local university and research institutions and other RFMOs to support its research programs and ecosystem related research activities.

The current practices under each of the four main ecological elements (target species, by-catch, trophic relationships and habitats) used in IATTC and ICCAT to address and apply the ecosystem approach to fisheries management vary greatly between IATTC and ICCAT. Both IATTC and ICCAT have done much progress in assessing the exploitation status for the large majority of target species relative to common fisheries reference points. Yet, limit and target reference points associated with the stock current biomass and fishing mortality rates have not been adopted for any of the target stocks. Both tuna RMFOs are working towards defining thresholds including target and limits reference points for their target species, and ICCAT, for example, has proposed limit reference points and harvest control rules for the north Atlantic albacore and swordfish stocks.

For the ecological element of by-catch, both tuna RFMOs have a long list of management measures and actions 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 a predefined threshold is 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 IATTC and ICCAT management measures that are in place focus in applying the precautionary approach to minimize fishing impacts on non-target species and focus less in strictly applying an ecosystem based approach to fisheries management. In both tuna RFMOs, the development of qualitative and quantitative Ecological Risk Assessments for incidentally caught species of sharks, birds, 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 assessments for by-catch species. In ICCAT, the delay on applying an ecosystem approach to fisheries management is mostly due to the absence of quality standardized by-catch datasets, reliable indicators to track the impacts of tuna fisheries on by-catch species and absence of quality assessments to quantify the extent of the impacts. In addition, the dedication of Sub-Committee on Ecosystems in ICCAT depends on the priorities set by the Commission, which until now has focused more on by-catch mitigation (e.g. birds and turtles) than in establishing methods and a management strategies to link by-catch objectives and by-catch indicators to the management of target species and protection of associated ecosystems. IATTC have a strong by-catch 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 by-catch species in support an ecosystem approach to fisheries management, yet IATTC has been unsuccessful in defining and adopting by-catch thresholds associated to pre-established indicators for any by-catch species and link it to management actions, with the exception of the incidental mortality limits established for dolphin species.

Both 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 area than in the IATTC area. No formal mechanisms exist to accommodate food web interactions and ecosystem modeling into the current management of ICCAT or IATTC target 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 the Sub-Committee on Ecosystems 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 both 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. Both 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 two tuna RFMOs as case studies to evaluate their progress in applying an ecosystem approach to fisheries management. 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 ecosystem approach to fisheries management 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 EBM-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) measures and management 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)

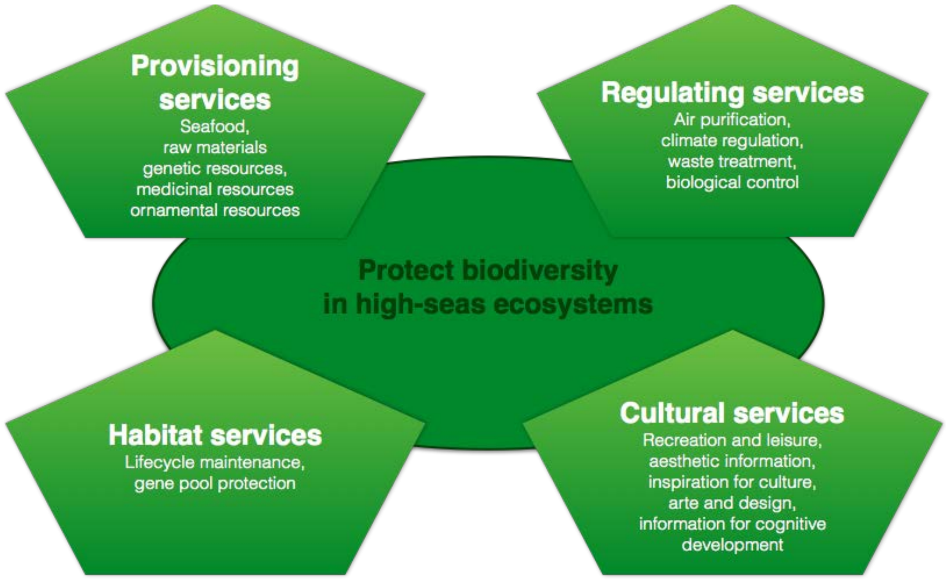

Figure 1. Ecosystems services provided by healthy high seas (based on Rogers *et al.* 2014).

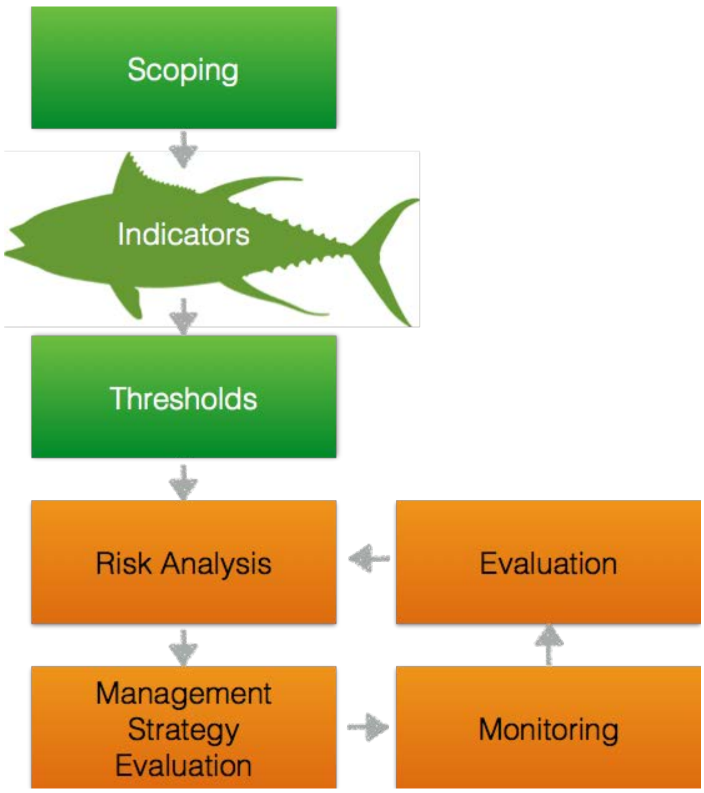

Figure 2. Integrated ecosystem assessment (IEA) framework (based on Levin *et al*. 2009 and Tallis *et al.* 2010).

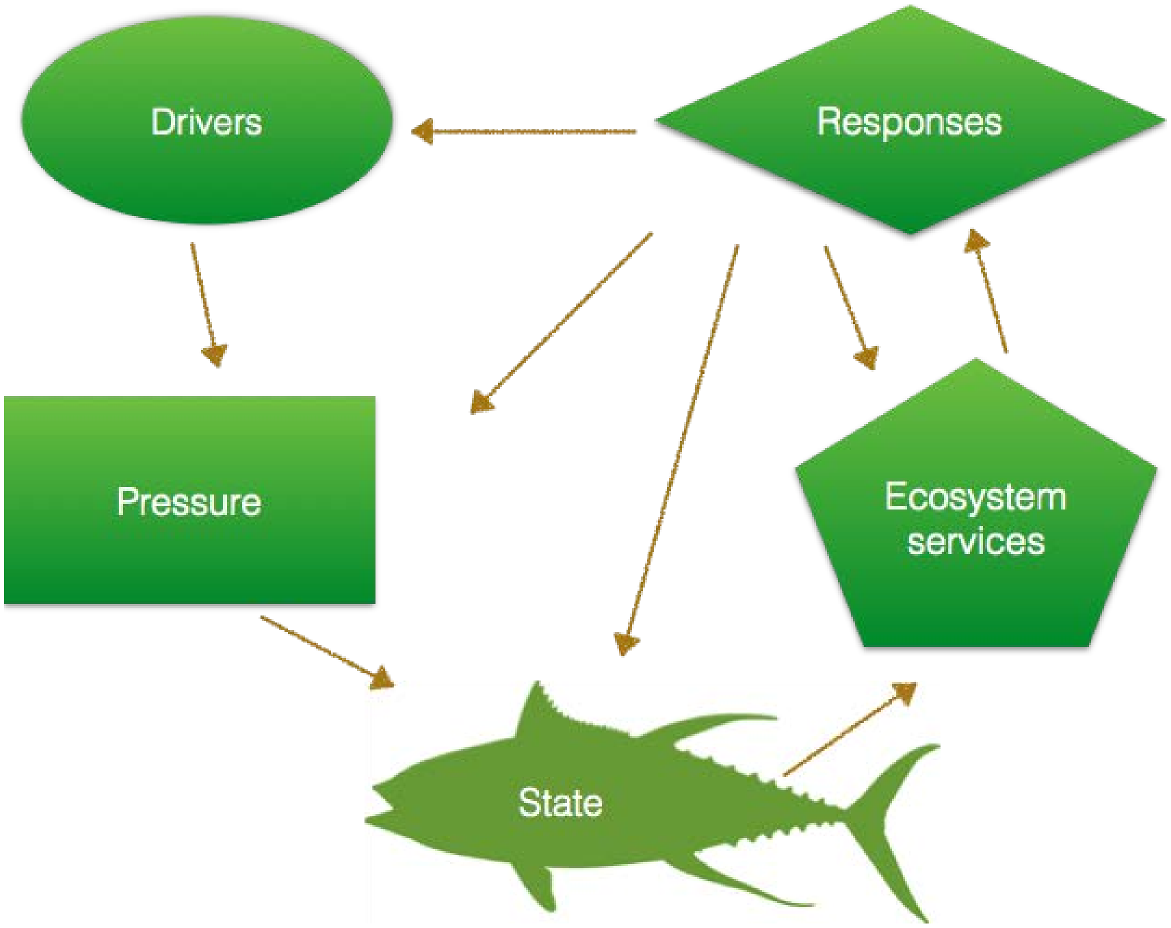

Figure 3. The Drivers, Pressures, State, Ecosystem Services and Response -DPSER- conceptual model (based on Kelble *et al.*, 2013).

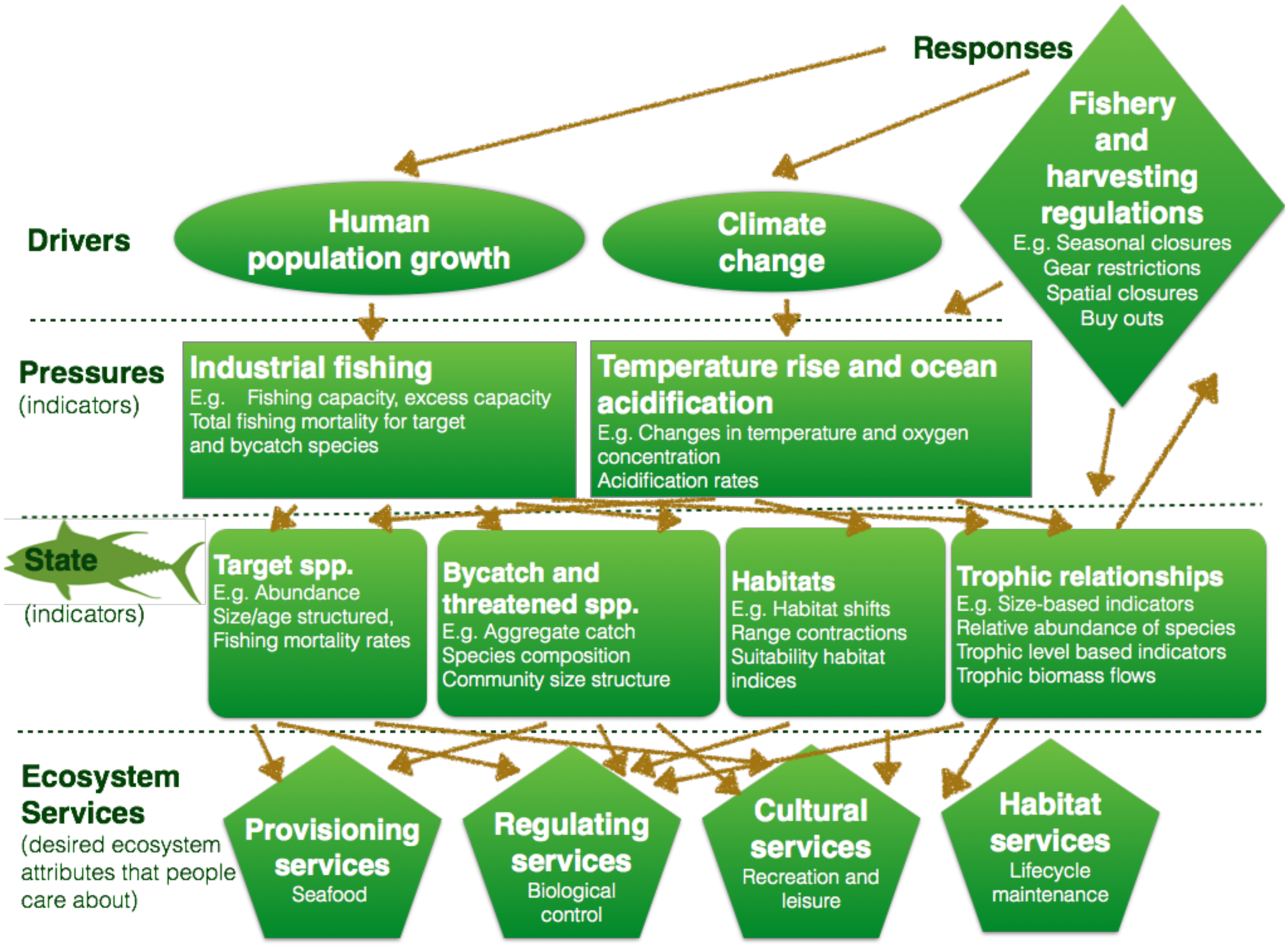

Figure 4. Conceptual Ecological Model for a role model tuna RFMO based on the DPSER framework to monitor the effects of fishing and climate change on tuna species and associated ecosystems.