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IN SUPPORT OF THE ICCAT ECOSYSTEM REPORT CARD: ADVANCES IN MONITORING THE IMPACTS ON AND THE STATE OF THE "FOODWEB AND TROPHIC RELATIONSHIPS" ECOSYSTEM COMPONENT

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SUMMARY

In support of the development of the ICCAT Ecosystem Report Card, this paper addresses the "foodweb/trophic relationships" ecosystem component. Specifically, it contributes towards developing the following elements: (1) we describe what this component means in the context of ICCAT species and fisheries and the importance of monitoring it; (2) we describe the role of ecological indicators and ecosystem models in monitoring this ecosystem component; (3) we present a list of candidate ecological indicators that could be estimated to monitor this component; (4) we discuss the main challenges in monitoring this ecosystem component and indicator development; and finally (5), we draft a work plan to guide our future work. We invite the ICCAT community and others to contribute towards the development of ecological indicators and ecosystem models to monitor this ecosystem component. If interested, contact the corresponding authors to find out how you can contribute to this initiative.

RÉSUMÉ

En soutien au développement de la fiche informative sur les écosystèmes de l'ICCAT, ce document aborde la composante "relations alimentaires/trophiques" de l'écosystème. Plus précisément, elle contribue à développer les éléments suivants : (1) nous décrivons ce que cette composante signifie dans le contexte des espèces et des pêcheries de l'ICCAT et l'importance de son suivi ; (2) nous décrivons le rôle des indicateurs écologiques et des modèles d'écosystème dans le suivi de cette composante ; (3) nous présentons une liste de possibles indicateurs écologiques qui pourraient être estimés pour le suivi de cette composante ; (4) nous discutons des principaux défis du suivi de cette composante de l'écosystème et du développement d'indicateurs ; et enfin (5) nous rédigeons un plan de travail pour guider nos travaux futurs. Nous invitons la communauté de l'ICCAT et d'autres à contribuer à l'élaboration d'indicateurs écologiques et de modèles d'écosystème pour surveiller cette composante de l'écosystème. Si vous êtes intéressé, contactez les auteurs correspondants pour savoir comment vous pouvez contribuer à cette initiative.

RESUMEN

En apoyo del desarrollo de la ficha informativa sobre ecosistemas de ICCAT, este documento aborda el componente del ecosistema «red alimentaria/relaciones tróficas». De manera específica, contribuye al desarrollo de los siguientes elementos: (1) describimos lo que significa este componente en el contexto de las especies y pesquerías de ICCAT y la importancia de hacer un seguimiento de él, (2) describimos el papel de los indicadores ecológicos y los modelos ecosistémicos en el seguimiento de este componente del ecosistema, (3) presentamos una lista de posibles indicadores ecológicos que podrían estimarse para hacer un seguimiento de este componente, (4) discutimos los principales problemas a la hora de hacer un seguimiento de este componente y del desarrollo del indicador y, por último, (5) redactamos un plan de trabajo para guiar nuestro trabajo futuro. Invitamos a la comunidad de ICCAT y a otros a contribuir al

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desarrollo de indicadores ecológicos y modelos ecosistémicos para hacer un seguimiento de este componente del ecosistema. Si están interesados, contactar con los autores correspondientes para averiguar cómo pueden contribuir a esta iniciativa.

KEYWORDS

Ecosystem report card, indicators, ecosystem structure, ecosystem function, ecosystem changes, ecosystem attributes, ecosystem thresholds

1. Introduction

Since 2017 the Sub-Committee on Ecosystems (SC-ECO) is working on developing an Ecosystem Report Card. The main purpose of the ICCAT Ecosystem Report Card is to provide stronger links between the ecosystem science presented in ICCAT and the fisheries management advice produced to support the implementation of ecosystem-based fisheries management (EBFM) in the ICCAT region. The Ecosystem Report Card aims to highlight and monitor the main pressures on and the state of several components of the ecosystem impacted by, or important to, the operation of ICCAT fisheries. The Ecosystem Report Card intents to be used as a tool to report on the sustainability of species and stocks under ICCAT management responsibilities and the impact of their fisheries and changes in the environment on the structure and function of marine ecosystems to the Commission. (Juan-Jorda *et al*. 2017). Potentially, it could be an effective communication tool to increase the awareness, communication and reporting of the main pressures on and the state of the marine ecosystem to the Commission, since it can be used to synthesize large and often complex amount of information into a concise and visual product.

The development of the indicator-based Ecosystem Report Card requires of a long-term strategy to build ecosystem knowledge and increase capacity and collaborations in the ICCAT community. As a first step, the SC-ECO defined broad operational components of the ecosystem to be highlighted and monitored in the Ecosystem Report Card. These include:

- retained species,
- non-retained species including seabirds, marine turtles, marine mammals and sharks,
- food-webs/trophic relationships,
- habitats
- socio economic,
- fishing pressure,
- environmental pressure.

In 2018 and 2019 a series of indicator-based assessments were produced for each of these operational ecosystem components, which were reviewed by the SC-ECO. Based on these indicator-based assessments, the second pilot Ecosystem Report Card was produced in 2019. The indicator-based assessments for each ecosystem component are at different stages of development, from the initial stage of proposing a candidate list of indicators that could potentially be used to monitor that particular ecosystem component, to the stage of presenting the indicators for formal adoption by the SC-ECO. Noting the preliminary nature of the second pilot ICCAT Ecosystem Report Card and the understanding that multiple iterations are needed to move towards a more scientifically mature based product, the SC-ECO recommended to update and review the Ecosystem Report Card in 2020.

In support of the development of the ICCAT Ecosystem Report Card, this paper addresses the “foodweb/trophic relationships” ecosystem component and specifically it contributes towards developing the following elements:

1. Describe what the “foodweb/trophic relationships” component means in the context of ICCAT species and fisheries and highlight the potential risks of not monitoring it.
2. Describe the role of ecological indicators and ecosystem models to monitor this component.
3. Presents a candidate list of ecological indicators to monitor this ecosystem component.
4. Presents main challenges foreseen in monitoring this ecosystem component.
5. Present a work plan to guide future work.

2. The "foodweb/trophic relationships" ecosystem component and underlying objectives to measure progress

The Sub-Committee of Ecosystems has adopted an "overall goal" and "operational goal" to guide the monitoring of the "foodweb/trophic relationships" component, in order to track progress towards achieving these goals (ICCAT 2018).

Overall goal: "Ensuring that ICCAT fisheries will not cause adverse impacts on the structure and function of ecosystems",

Operational objective: "Trophic interactions and inter dependencies involving species that are affected by fishing are maintained"

Here we propose a slight modification to both, the overall goal and the operational objective, in order to provide a more realistic framework, adding natural stressors (e.g. environmental and climate change) and other anthropogenic pressures (e.g. marine debris) that naturally affect the status of the "foodweb/trophic relationships" component. The resulting definitions are detailed below:

Modified Overall goal: "Ensuring that ICCAT fisheries, together with other anthropogenic and natural pressures (marine debris and environmental variability and climate change respectively) will not cause adverse impacts on the structure and function of ecosystems",

Modified Operational objective: "Trophic interactions and inter dependencies involving species that are affected by fishing and other pressures are monitored and when possible maintained"

In view of its predefined goal and operational objectives, we describe below what the "foodweb/trophic relationships" ecosystem component of the ICCAT Ecosystem Report Card will attempt to monitor, and also highlight the potential risks for not doing it.

There is increasing evidence that the abundance and composition of the targeted and the non-targeted species incidentally caught is changing as a result of fishing (Gerrodette *et al*. 2012). Fishing by removing large amounts of biomass and reducing the abundance of multiple species in the foodweb can alter a wide range of biological interactions. These alterations can cause changes in the predatory-prey interactions and cascading effects in the foodwebs (Scheffer *et al*. 2005). Cascading effects are often unforeseen, which might result in unexpected results when implementing a management actions at the species level, especially if the focus species in the management action is playing a critical role in the ecosystem (National Research Council 2006).

There are few documented cases in the marine system where fishing has led to alternative ecosystem states, a state with different species composition or productivity relative to the pre-fishing condition. A classic example of large-scale system changes is the overexploitation and depletion of cod as well as other high trophic levels species in the Northwest Atlantic, which has led to a drastic restructuring of the entire food web, attributed in part to trophic cascades by the removal of top predators (Frank *et al*. 2005).

In open ocean ecosystems where most tuna fisheries operate, there is a poor understanding of how fishing has altered the species composition and productivity of the system relative to the pre-fishing conditions. While alternative ecosystem states have not been documented in the context of tuna fisheries, there is an increasing growing body of literature providing evidence of the impacts of industrial tuna fishing on the structure and function of marine ecosystems (Cox *et al*. 2002, Polovina and Woodworth-Jefcoats 2013, Griffiths *et al*. 2019).

Consequently, it is important we strive towards understanding the impacts of the total removals of biomass from the different fisheries and gears operating in a given area, and detecting changes in the relative abundance of species and potential consequences on the structure and function of the marine ecosystem.

Fishing does not take place in isolation, other factors such as changes in environmental conditions and regime shifts might also affect the structure and function of marine ecosystems. Therefore, the impacts of ICCAT fisheries and environmental changes will be examined in combination to understand the current state and predict the future state of the ecosystem.

3. The role of ecological indicators to monitor the "foodweb/trophic relationships" component of the ICCAT ecosystem report card

Ecological indicators have been mostly used in two ways in terms of monitoring and ultimately managing the impacts of different pressures caused by either manageable (i.e. fishing, marine debris) and non-manageable (i.e. climate change) stressors on the structure and function of marine ecosystems. First, indicators have been used to monitor ecosystem changes and track how well the ecosystem-level objectives are met. Second, and most challenging, indicators can be linked to the management system and can be used as part of decision rules to determine if management strategies are addressing those impacts (Fulton *et al*. 2005). We plan to initiate our work by developing ecological indicators to monitor ecosystem changes and responses to fishing and track how well the established objectives are met, yet, we also foresee research that can advance of knowledge and models so that these indicators can be connected to the fisheries management system.

Multiple ecological indicators have been identified, developed and tested to describe and capture changes in multiple attributes of the ecosystem including, biomass, size structure, spatial structure, diversity, trophic level, and energy flows. Attributes are features of the ecosystem that society might be interested to capture and protect and are usually liked to common ecosystem-level objectives such as maintaining ecosystem health, integrity or resilience (Fulton *et al*. 2005, Shin and Shannon 2010, Coll *et al*. 2016).

Ecological indicators can be estimated using three main types of data sources:

(1) fishery-independent data obtained from biological surveys, satellites, echosounders, acoustic surveys, tagging programs,
(2) fishery-dependent data obtained from fishing vessels (logbooks) and fisheries observer programs, and
(3) model-derived when ecosystem models are available.

3.1 Using fishery-independent data to derive ecological indicators

Fishery-independent data obtained from biological surveys, satellite data, acoustic surveys, tagging programs etc., have been widely and successfully used for deriving ecological indicators worldwide (Shin and Shannon 2010, Gerrodette *et al*. 2012, Coll *et al*. 2016). The availability of this type of information from which ecological indicators could be estimated to monitor the status of the different ICCAT Ecosystem Report Card is still very limited. Most of the information comes from coastal areas that could be used to inform different components in certain case studies, but not at a broader scale. However, the possibility of using the existing information at a case study or ecoregion scale to inform about the state of certain ecosystem components and in particular the "foodweb/trophic relationships" one (e.g. primary production from satellite data could help estimating the lower trophic levels of the foodweb) should be explored, and we encourage the SC-ECO to start working on it.

3.2 Using fishery-dependent data to derive ecological indicators

In the open ocean, where most tuna fisheries operate, the paucity or non-existence of fishery-independent biological surveys have been identified as a major impediment to properly analyze the current state of fisheries and ecosystem (National Research Council 2006). In these systems, fishery-dependent data (e.g. fisheries logbooks, FAD logbooks, data from the fisheries observer programs and port sampling) are more readily available to support the developing and testing of ecological indicators. The tuna fisheries observers programmes have already been used to monitor total catches of bycatch species (both retained and discarded fractions) in different tuna RFMOs (Amandé *et al*. 2008, 2010, Ruiz *et al*. 2017, 2018). Since fishery-independent data is lacking, this information could then be used to estimate the effects of the fishing pressure on bycatch species, and, together with the fisheries dependent information regarding the target species, be used to derive different ecological indicators.

3.3 Ecosystem models to support the development of ecological indicators

Ecosystem models can provide an alternative tool to study the system and obtain model-derived ecosystem indicators to understand the properties of the ecosystem and its responses to different types of pressure including fishing and environmental change (Fulton *et al*. 2005). However, it is important to bear in mind that the fishery dependent data complemented with data derived from dedicated research studies (e.g. trophic ecology of species) also remains the main source of data to feed the ecosystem models in the open-ocean.

Following the approaches of more coastal and spatially well-defined ecosystems, multispecies models and ecosystem models are emerging also in oceanic ecosystems, as effective tools to understand the impacts of multiple gears and multiple harvest strategies on the structure and dynamics of marine ecosystems and to compare the possible outcomes of the different fishery management options (National Research Council 2006, Griffiths *et al*. 2019). Trophic-based and size-based ecosystem models are increasingly being used to explore specific hypothesis because they allow representing the complex ecological interaction and trophic (feeding) relationships or size based relationships across a wide range of species in the ecosystem and their interactions with different fishing gears (and harvest strategies) and other external factors such as major features of the environment and climate change (Polovina and Woodworth-Jefcoats 2013, Allain *et al*. 2015). Therefore, ecosystem models are useful for exploring the consequences of alternative fisheries management scenarios on economically important species, but also to understand how fishing impacts may propagate to other species and through the wider pelagic ecosystem. Ecosystem models also can also derive a suit of model-derived ecosystem indicators to understand the properties of the ecosystem and its responses to fishing (among other) pressure (Fulton *et al*. 2005).

4. Candidate ecological indicators to monitor the "foodweb/trophic relationship" component of the ICCAT ecosystem report card

We plan to develop and test a set of complementing ecological indicators (both empirical and model-based indicators) to monitor the impacts of ICCAT fisheries on the state of the "foodweb/trophic relationship" ecosystem component. It is widely recognized that no single or type of indicators is able to provide a complete picture of the ecosystem state. The natural complexities of marine ecosystem and ecological process demands to use a suite of complementary indicators to provide a complete picture of the impacts of fishing on the ecosystem (Shin *et al*. 2010). At the end, the suite of indicators chosen need to be able to monitor and highlight changes in the ecosystem structure, help to diagnose the causes of those changes in the system, and monitor the recovery of lost properties in the ecosystem (Fulton *et al*. 2005).

We provide a snapshot of candidate ecological indicators (Table 1) that could be estimated to capture and describe changes in multiple ecosystem attributes of the marine ecosystem derived from the impacts of ICCAT fisheries. A brief description is provided for each type of ecosystem indicators with a reference to the type of attribute it tries to capture and describe of the ecosystem. A distinction is also made whether the indicator can be empirically estimated using regularly collected fisheries dependent data, or whether it necessarily needs to be derived from ecosystem models.

None of the ecological indicators presented in **Table 1** are routinely estimated and monitored by ICCAT in any of its fisheries or collectively in the Atlantic Ocean. Furthermore, the proposed list should not be seen as an exhaustive list of ecological indicators. Instead this list aims to guide the ongoing work of the Sub-Committee of Ecosystems, and it will be updated as needed.

5. Main challenges in monitoring the "foodweb/trophic relationships" ecosystem component

ICCAT is not currently addressing, from an integrated perspective, the indirect impacts of fishing and total removals of biomass on marine food webs, nor the potential bottom-up impacts of variations in trophic relationships on the targeted species or their fisheries. The impacts of ICCAT fisheries on the broader structure and function of the marine pelagic ecosystem remains poorly evaluated and monitored (Juan-Jordá *et al*. 2018). This may be in part because the development of the ecosystem indicators proposed in Table 1 to monitor this type of impacts have been mostly developed in the context of coastal fisheries and using fishery independent data (e.g. independent research surveys) (Coll *et al*. 2016). Yet this type of independent fishery data does not exist at the scale needed to estimate these indicators in the context of tuna fisheries and thus, monitoring the impact of tuna fisheries on the wider Atlantic Ocean ecosystem remains elusive. In the context of tuna fisheries, fisheries dependent data from logbooks and observer programs are more readily available to support the developing and testing of ecosystem indicators, and we encourage to examine further the existing fishery statistics from logbooks and observer programs and evaluate their potential usefulness to support the development the indicators listed under table 1 (Juan-Jordá *et al*. 2019).

Similarly, the effects of climate change and environmental variability on the dynamics of marine ecosystems inside the ICCAT convention area are yet poorly understood, with only few studies available in the literature trying to address this issue (Golet *et al*. 2007). Most efforts have been directed to understand the effect of the environmental variability (natural or human induced) on the habitat utilization (Arrizabalaga *et al*. 2015) or the biological processes (Reglero *et al*. 2018) of major ICCAT species. Foodweb research should also consider the bottom-up effects triggered by changes in the environmental variability and productivity on marine foodwebs (Moullec *et al*. 2016). Bottom up effects might, together with the ones caused by the fishing pressure, directly or indirectly affect the productivity of these ecosystems (Hulot *et al*. 2014) and therefore end up affecting the productivity of the target´s species biology (e.g. growth, migration, distribution, and potential yields) and fisheries operating on them (Chassot *et al*. 2007).

The development and use of ecosystem models as a tool to understand the impacts of multiple gears and multiple harvest strategies on the structure and dynamics of marine ecosystems has also been scarce in ICCAT. Compared with the work developed in the Pacific Ocean in IATTC and the WCPFC, very few research studies have been presented at the Subcommittee of Ecosystems meetings on the trophic ecology for ICCAT species, ecosystem modelling or multispecies models to understand food web dynamics, species interactions and their ecological role in the food web. Ecosystem models are increasingly being used in other tuna RFMOs (e.g. IATTC, WCPFC) to explore wide range of hypothesis because they allow representing the complex ecological interaction and trophic (feeding) relationships or size based relationships across a wide range of species in the ecosystem and their interactions with different fishing gears (and harvest strategies) and other external factors such as major features of the environment and climate change (Polovina and Woodworth-Jefcoats 2013, Allain V. *et al*. 2015).

The few attempts to build ecosystem indicators and models in oceanic ecosystems of the Atlantic Ocean can be explained in part because they require and rely on a large number of fisheries, biological and ecological data, but also in part because until recently ICCAT has focused its vision and work on the conservation and management of species under its mandate (mostly tuna and tuna-like species) and rather from a single species perspective(Juan-Jordá *et al*. 2018). We encourage further studies on fish diet, feeding ecology and food habits to support the development of ecosystem models and better understand trophic interactions and foodweb dynamics in marine ecosystems in the ICCAT convention area.

If robust ecosystem models were to be developed in the wide Atlantic Ocean at relevant spatial scales, they would need to be supported by the combination and the improvement of the following data and research avenues in ICCAT:

(1) high-quality stock assessment model output data for the exploited fish species (the targeted species and, if possible, the most relevant bycatch species);
(2) reliable catch) time series for non-targeted species (retained and non-retained) for each major fishery;
(3) reliable estimates for forage species and lower trophic levels (phyto- and zooplankton);
(4) a comprehensive research program to improve the knowledge on the trophic ecology of key species;

Recognizing that this ideal situation is hard to achieve, and that there is still a lot to do to get in a situation where the knowledge of the dynamics of oceanic systems will be more complete, we recommend the SC-ECO to start exploring the potential of the ecosystem models to inform different ecological indicators and get involved in a ‘learn by doing process’, as done in other marine systems (Link 2010, Link and Browman 2014, Juan-Jordá *et al*. 2018, Griffiths *et al*. 2019). This process could help us better understand the knowledge gaps, the needs and the potential of the use of ecosystem models to inform the implementation of EBFM in ICCAT. Nevertheless, the need of getting robust ecosystem models to be used for management purposes is a reality that should not be neglected. And for this, we would need to have ecosystem models that are feed with good quality data, are very well documented, and have gone through a peer-reviewed process. In this sense, we would encourage establishing a link with the Working Group on Stock Assessment Methods and evaluate how this process should be incorporated in the ICCAT workplans.

6. Work plan

Below we summarize future steps planned to advance our work towards monitoring the “foodweb/trophic relationships” ecosystem component of the ICCAT ecosystem report card, which we plan to update annually at the Sub-Committee on Ecosystems meetings. This is work in progress which requires the collaboration of multiple experts with experience on the ecology of the ICCAT species and dependent species, ecosystem models and fisheries in the ICCAT convention area.

Short-term future steps:

- Continue the work presented in Working Document SCRS/2018/073 to examine the potential ecological effects of the European purse seine fishery (with three complementary empirical-based ecological indicators) on the structure and function of the marine ecosystem in the tropical Atlantic Ocean.
- Identify areas where ecosystem models have already been developed and run for tuna-related research purposes and identify case studies within the ICCAT convention area where the development of ecosystem models could be insightful.
- Start developing static and time-dynamic ecosystem models for different case studies, in collaboration with other tuna RFMOs, based on the existing work and the information available in the literature (including ICCAT scientific volumes) aiming at analyzing the effects of fishing at an ecosystem scale.
- Explore potential links with the work developed in the different Species Working Groups, in order to identify relevant information and examples about any critical change on the ecosystem that could finally affect the dynamics of the ICCAT target species.

Medium long-term future steps:

- Continue the development of ecological indicators presented in Table 1 to monitor the “food web/trophic relationships” ecosystem component of the ICCAT report card.
- Examine and evaluate the quantity and quality of fisheries dependent data available from logbooks and observer programs to support the development of ecological indicators presented in Table 1.
- Explore the potential of monitoring other relevant indicators to monitor the effect of external driers (environmental changes, regime shifts, marine debris) on foodwebs.
- Work on the identification of knowledge gaps and data needs in collaboration with the Secretariat.
- Work on spatially explicit ecosystem models that could better explain the dynamics of the highly migratory species.
- Explore the potential of these spatially explicit models to inform other ecosystem component, such as habitats, etc.
- Explore the potential of using these spatially explicit models to investigate the use of time-area closures and different spatial uses to inform marine spatial planning.
- Explore the need for development of new indicators related to effects of bottom-up foodweb/trophic impacts on tunas and their fisheries (e.g. abundance and distributions of prey species for tunas).

We invite the ICCAT community to contribute towards the development of the “foodweb/trophic relationship” component to support the ICCAT ecosystem report card. If interested, contact the corresponding authors to find out how you can contribute to this initiative.

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Table 1. Candidate ecological indicators to capture and describe changes in multiple attributes of the marine ecosystem derived from the impacts of ICCAT fisheries in the Atlantic Ocean.

Indicator type	Indicator examples	Attributes measured	Potential data sources
Community-level pressure indicators.	-Catch rates -Discards rates or proportion of discards in the fishery (discards/landings)	Pressure on the ecosystem, also uses as proxy of community abundance changes	-Empirically estimated using fishery-dependent data -Model-derived

Brief description and rationale

Logbook records with total catches and effort for the commercially valuable species are widely reported in fisheries statistics. In addition, fisheries may also be partially monitored through the use of observers. From these, community-level catch-per-unit-of-effort CPUE over time can be estimated, at least for the most common species, to monitor changes in catch rates over time. Standardized CPUEs are commonly used as an indicator of stock health in single species fisheries assessments, but they can also be used to monitor community-level changes in CPUE rates, yet they are not so easily obtained as it will depend on the quality of the fishery data sets (Fulton *et al*. 2004).

Community and population-level discards rates can be used to estimate the total removals on the ecosystem, since it may differ from the landed quantities, usually available from the traditional sources (e.g., landing slips). It is used to provide insights about the pressures on the entire community exposed to fishing and it is important to estimate them at the fishery levels as each fishery and gear type can have very different discards rate and therefore distinct ecological effects.

These indicators rely on fisheries dependent data, and its interpretation can be masked by a wider range of confounding factors (changes in gear type, targeting and effort) (Fulton *et al*. 2004).

Indicator type	Indicator examples	Attributes measured	Potential data sources
Community level biomass-based indicators.	-Total biomass -Biomass by taxa group	Biomass	Model-derived

Brief description and rationale

Community-level or population level biomass indicators are commonly used to assess the impacts of fisheries on the ecosystem and track the state of key functional groups in the system. Easy to understand but also subject to natural environmental variation. Direct independent measures are not available to derive them, stock assessment and ecosystem models are required to obtain estimates of abundance and biomass.

Indicator type	Indicator examples	Attributes measured	Potential data sources
Community level size-based indicators.	- Mean size of predefined groups from catch data or biomass estimates - 95% percentile (or others) of the size distribution of predefined groups from catch data or biomass estimates -Proportion of large fish (proportion of fish catches or fish biomass larger than a specific size value) - The slope and intercept of the biomass size spectra of the marine community	Size structure	-Empirically estimated using fishery-dependent data -Model-derived

Brief description and rationale

Size data is the most commonly and easily collected type of fishery data. Aside from supporting the fisheries assessments at the population level, it can also serve to assess the changes in size structure at the community and ecosystem level. Fish size generally decreases under fishing pressure as high-value target species are generally lager, fishing gears are also size-selective often designed to target the larger fish, and larger fish also tend to be more vulnerable to fishing because of their life history traits (Shin and Shannon 2010).

These community level size-based indicators can be derived using catch data or biomass estimates from ecosystem models.

In the case of the biomass size spectra, this indicator could be only estimated from size-based ecosystem models (Shin *et al*. 2005). The biomass size spectra indicators while they are also commonly estimated using data from independent-surveys, these data are not available in open-ocean ecosystems.

Indicator type	Indicator examples	Attributes measured	Potential data sources
Community level age-based indicators.	- Average age of predefined groups from catch data or biomass estimates - 95% percentile (or others) of the age distribution of predefined groups from catch data or biomass estimates -Proportion of older fish (proportion of fish catches or fish biomass larger than a specific age value).	Age structure	-Empirically estimated using fishery-dependent data -Model-derived

Brief description and rationale
The increasing reliability of aging techniques has increased the number and use of age-based indicators. The means and tails of age distributions data at the species and community level can be informative about fishing effects as fisheries usually target the larger and older individuals. Yet the collection and estimation of age structure data remains more costly than collecting size data. Aside from supporting the fisheries assessments at the population level, age data can also server to assess the changes in age structure at the community and ecosystem level (Fulton *et al*. 2004).

These indicators can be derived using catch data or biomass estimates from ecosystem models.

Indicator type	Indicator examples	Attributes measured	Potential data sources
Trophic-based indicators	-Mean trophic level of the catch by fisheries -Mean Trophic Index (the same as the mean trophic level of catches but includes only catches of species with trophic levels above 4) -Mean trophic level of the community (derived with biomass estimates from ecosystem models). - Proportion of predatory fishes in the ecosystem -Fishing in Balance (FIB) index. It relates the catches and the average trophic level in a given year to the catches and trophic level of an initial year, and the determines if the change in the mean trophic level is compatible with the trophic efficiency of the region.	Trophodynamics	-Empirically estimated using fishery-dependent data -Model-derived

Brief description and rationale
Trophic-based indicators have been used to identify shifts in community and ecosystem structure. There are multiple forms and variations of these indicators and depending on the way they are estimated (based on catches or based on the estimates of biomass from models) different interpretations and uses can be made. In general terms, they allow monitoring the species composition (in the catch or in the ecosystem) in terms of trophic positioning.

The mean trophic level when derived using catch data from the fisheries (Pauly and Watson 2005) can be a useful metric to monitor ecosystem change. Generally, it is expected to decrease in response to fishing because fisheries tend to target species at higher trophic levels first. But other patterns (increases in the trophic level of catches) have also been observed, and therefore this indicator can also provide information on the changes of fishing and targeting practices in response to changes in fish abundances or market drivers.

The mean trophic level of the community-level biomass can be derived with the biomass estimates from ecosystem models (Shannon *et al*. 2014). This indicator can be used to monitor the mean trophic level of different functional groups in the ecosystem (categorized in different trophic levels ranges, e.g. trophic level 3.0-3.25, 3.25-5, >4), and allows to identify changes in the ecosystem structure after the biomass removals from fisheries. These model-derived indicators across different trophic level groups can be used in combination to detect trophic cascades.

The proportion of predatory fish measured as the estimated biomass of predatory functional groups is also used to monitor the potential effects of fishing on the functioning of marine foodwebs as their depletion can lead to trophic cascades (Shin and Shannon 2010).

The FIB index provides indication whether fisheries are balance in ecological terms and not causing disruption to the functionality of the ecosystem (Pauly *et al*. 2000). When the FIP is constant (equal to zero) provides that a fishery is balanced, which means that all trophic level changes are matched by ecological equivalent changes in the catches.

Indicator type	Indicator examples	Attributes measured	Potential data sources
Diversity based indicators	-Shannon's index -Kempton's Q index adapted for ecosystem models	Diversity	-Empirically estimated using fishery-dependent data -Model-derived

Brief description and rationale

Diversity-based indicators to monitor fishing impacts at the community and ecosystem level might be difficult to be applied as they are highly susceptible to sampling problems. Simple biodiversity indicators are preferred.

For example, the Shannon's index is widely used as a measure of species diversity based on species richness and the relative proportions of species in a community (evenness), generally measures in terms of biomass (Shannon 1948). A decrease in the index indicates a decrease in evenness and richness.

Kempton's Q index adapted for ecosystem models is a diversity-based index for assessing changes in the diversity and biomass of high trophic level species (trophic level >3) (Ainsworth and Pitcher 2006). A decrease in the index indicates a decrease in upper level evenness and richness.