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

Maria José Juan-Jordá[1], Eider Andonegi [2], Hilario Murua[3], Jon Ruiz[2], Maria Lourdes Ramos[4], Philippe S. Sabarros[5], Francisco Abascal[4] and Pascal Bach[6]

SUMMARY

In support of the development of the IOTC ecosystem report card, this paper addresses the "food web/trophic relationships" ecosystem component and specifically it contributes towards developing the following elements: (1) We describe the importance of this ecosystem component and explain the potential risks of not monitoring it, and make a proposal of a conceptual and an operational objective to measure progress towards monitoring the impacts of IOTC fisheries on and the state of this ecosystem component. (2) We present candidate ecological indicators that could be estimated to capture and describe changes in multiple ecosystem attributes of the marine ecosystem derived from the impacts of fisheries, and discuss main challenges in indicator development. (3) We also present three preliminary ecological indicators, which examine the potential ecological effects of the European and Seychelles purse seine fishery targeting tropical tunas in the western Indian Ocean, to monitor this ecosystem component. The three indicators describe the total biomass removed by this fishery in terms of weight, trophic level and replacement time of the species. (4) Finally, we draft a work plan to guide our future work. We invite the IOTC community and others to contribute towards the development of the IOTC ecosystem report card. If interested, contact the corresponding authors to find out how you can contribute to this initiative.

KEYWORDS

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

1. Introduction

The WPEB Program of Work (2019-2013) includes the development of an indicator-based ecosystem report card for the IOTC region (IOTC WPEB14, 2018). The main purpose of the IOTC ecosystem report card is to provide stronger links between ecosystem science and fisheries management to support the implementation of ecosystem-based fisheries management (EBFM) in the IOTC region. Potentially, it could be an effective communication tool to increase the awareness, communication and reporting of the 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. Ultimately the ecosystem report card aims to provide an integrated assessment of the relevant *pressures* affecting the state of IOTC species and associated ecosystems (Juan-Jordá et al. 2018).

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 IOTC community. As a first step, the WPEB14 drafted a workplan to support the development of the indicator-based ecosystem report card for the IOTC region (IOTC WPEB14, 2018). The workplan included a reporting framework to monitor the full range of interactions between IOTC fisheries and the different components of the pelagic ecosystem with assigned scientists to develop ecosystem indicators and indicator-based assessments to inform the IOTC ecosystem report card.

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[1] Common Oceans ABNJ Tuna Project, FAO Consultant, Madrid, SPAIN. Email address of corresponding author: mjuanjorda@gmail.com
[2] AZTI, Marine Research Division, Txatxarramendi ugartea z/g, E-48395, Sukarrieta, Bizkaia, SPAIN
3 ISSF, International Seafood Sustainability Foundation, Washington, DC, USA (current affiliation)
[4] IEO, Centro Oceanográfico de Canarias, Vía Espaldón, dársena pesquera, Parcela 8 38180 Santa Cruz de Tenerife, SPAIN
[5] IRD, MARBEC, Ob7, Avenue Jean Monnet, CS 30171, 34203 Sète, FRANCE
[6] IRD, MARBEC, Ob7, SFA, PO Box 570, Victoria, Mahe, SEYCHELLES

In support of the development of the IOTC ecosystem report card, this paper addresses the "food web/trophic relationships" ecosystem component and specifically it contributes towards developing the following elements:

1. We describe and highlight the importance of this ecosystem component and explain the potential risks of not monitoring it. We also provide a conceptual and an operational objective to monitor the impacts of IOTC fisheries on and the state of this ecosystem component, which can be used to measure progress towards management of this component.
2. We present a candidate list of ecological indicators to monitor this ecosystem component.
3. We discuss main challenges in monitoring this ecosystem component.
4. We present several preliminary indicators, describe their trends and briefly describe their relevance towards monitoring this ecosystem component.
5. Finally, we draft a work plan to guide our future work.

2. The "foodweb/trophic relationship" component and objectives to measure progress

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. 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 foodweb. 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, and no documented changes in the marine system in response of tuna fisheries. While alternative ecosystem states have not been document 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.

In order to measure progress towards monitoring the impacts of IOTC fisheries on and the state of this ecosystem component of the IOTC ecosystem report card, we proposed the following conceptual and operational objective:

Conceptual objective: "Ensure that IOTC fisheries do not cause adverse impacts on the structure and function of marine ecosystems"

Operational objective: "Ensure trophic interactions and dependencies involving species that are affected by IOTC fisheries are maintained in order to avoid crossing thresholds that might rapidly move the ecosystem into a new unknown state"

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

Multiple ecosystem 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).

We plan to develop and test a set of complementing ecological indicators to monitor the impacts of IOTC fisheries on and 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. 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 last 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 IOTC 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. In the open ocean where most tuna fisheries operate there are not independent fisheries data obtained from biological surveys that can be used to support the development of ecological indicators. In the open-ocean ecosystems, fisheries dependent data, such as the fishery statistics derived from log-books and observer programs, is more readily available to support the developing and testing of ecosystem indicators. Ecosystem models can also provide an alternative tool to study the system and derive model-derived ecosystem indicators to understand the properties of the ecosystem and its responses to fishing pressure (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.

None of the community- and ecosystem-level indicators presented in Table 1 are routinely estimated and monitored by IOTC in any of its fisheries or collectively in the Indian 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, and will be updated as needed.

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

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 fisheries 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, a portion of the fisheries may also carry observers. From these, 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. CPUE indicators 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 monitor what it is actually landed versus what it is actually caught in total. 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 groups	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-level 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 fisheries 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 fisheries 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 fisheries 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 fisheries 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.

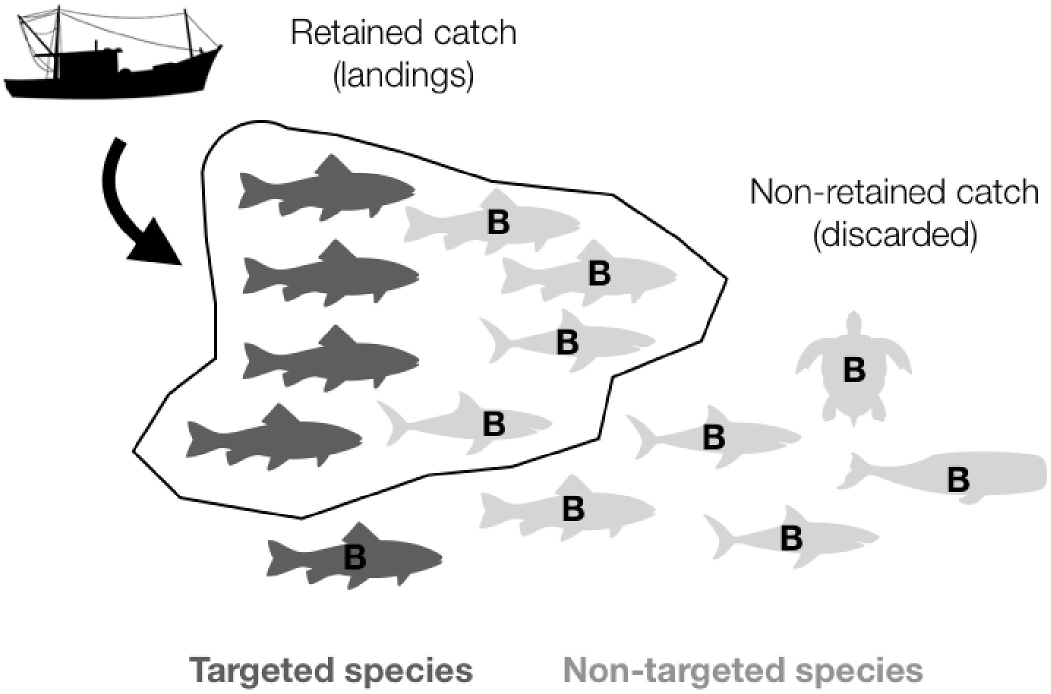
4. Main challenges in monitoring this ecosystem component

IOTC is not currently addressing, from an integrated perspective, the indirect impacts of fishing on marine food webs. The impacts of IOTC fisheries on the broader structure and function of the marine pelagic ecosystem remains poorly evaluated and monitored. 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). 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 Indian 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.

Additionally, in the open-ocean ecosystems where most of the tuna fisheries operate, ecosystem models are emerging as an effective tool to understand the impacts of multiple gears and multiple harvest strategies on the structure and dynamics of marine ecosystems, and to evaluate and compare the possible outcomes of the different fishery management options (National Research Council 2006, Griffiths et al. 2019). 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 IOTC. In comparative terms very few research studies are presented at the WPEB meetings on the trophic ecology for IOTC species, ecosystem modelling or multispecies models to understand food web dynamics, species interactions and their ecological role in the food web. However, ecosystem models are increasingly being used in other tuna RFMOs to explorea 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 et al. 2015). Therefore, we also 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 IOTC convention area.

5. Preliminary indicators with a description of trends to monitor this component

In light of the predefined conceptual and operational objectives presented for this ecosystem component, we chose to initiate our work by developing three ecological indicators to examine the potential ecological effects of the European and Seychelles purse seine fishery targeting tropical tunas on the structure and functioning of the ecosystem in the western Indian Ocean (Andonegi et al. 2019). We estimated the total biomass removed by this fishery in terms of weight, trophic level and replacement time of the species, and compared them by purse seine fishing strategy (sets on floating objects-FOBs and sets on free schools-FSCs). In this section, we briefly present the indicators and describe their trends, and refer the reader to Andonegi et al 2019 for further details on the methods and interpretations of these indicators. These three indicators, the total biomass removed by the purse seine in terms of weight, trophic level and replacement time, collectively try to understand the ecological effects of removing all animals through fishing, not only the bycatch or discards. By examining the temporal trends of several ecosystem indicators based on the total removals by the fishery and the trophic level and life history traits of the species removed, we aim to understand better the potential ecological effects of the European and Seychelles purse seine fishery on the structure and function of the marine ecosystem in the western tropical Indian Ocean (Figure 1).



Total bycatch (B) = discarded target species + non-targeted species (whether retained or not)

Figure 1. The catch of a fishery refers to all animals captured and removed from the ocean, and these might include species targeted and not targeted by the fishery. Usually a portion of the catch is retained (also referred as landings) and the remaining portion of the catch is non-retained (also referred as discards) which is thrown back to the sea. In this study, the term bycatch (B) refers to the catch of non-targeted species (whatever the fate is), plus the discards of target tunas (Amandé et al. 2010). In other word, the bycatch can be divided into two components: 1) the non-targeted retained component that are kept and sold usually to local markets (usually small tunas, other bony fishes and billfishes) and 2) the discard component which are the unwanted animals that are thrown back to the sea (dead or alive) either because they are damaged, or their low commercial value, or have non-retention measures in place.

We picked the aforementioned indicators and chose to focus on better understanding the impacts of the purse seine fishery targeting tropical tunas in the western Indian Ocean, in part, because the European and Seychelles purse seine fishery catches a large proportion of the tropical tuna catches in this area which makes it a representative fishery to monitor ecosystem changes derived from fisheries.

Indicator 1: Total removals in terms of weight

The total biomass removed by the purse seine fishery has increased since the 1980s, reaching a peak close to 400,000 tonnes in the early 2000s, and increasing again since 2012 up to a level in 2017 of 350,000 tonnes due mainly to the increase in yellowfin and specially skipjack catches (Figure 2). Within the last 10 years, the target species (skipjack, yellowfin and bigeye tuna) have contributed to 99.09% of the total retained catch, while the non-targeted retained component of the catch was comprised largely of small tunas and other bony fishes, and sharks, contributing to 0.9% (Figure 2).Within the last 10 years, the estimated discards (non-retained fish catch including big and small tunas and other bony fishes, sharks, billfishes and rays) using observer data were around 8000 tonnes and showed an overall declining trend. A discard ban for target species which was introduced in 2016 and for non-target species in 2017-2018, might explain the decrease in the discards rates.

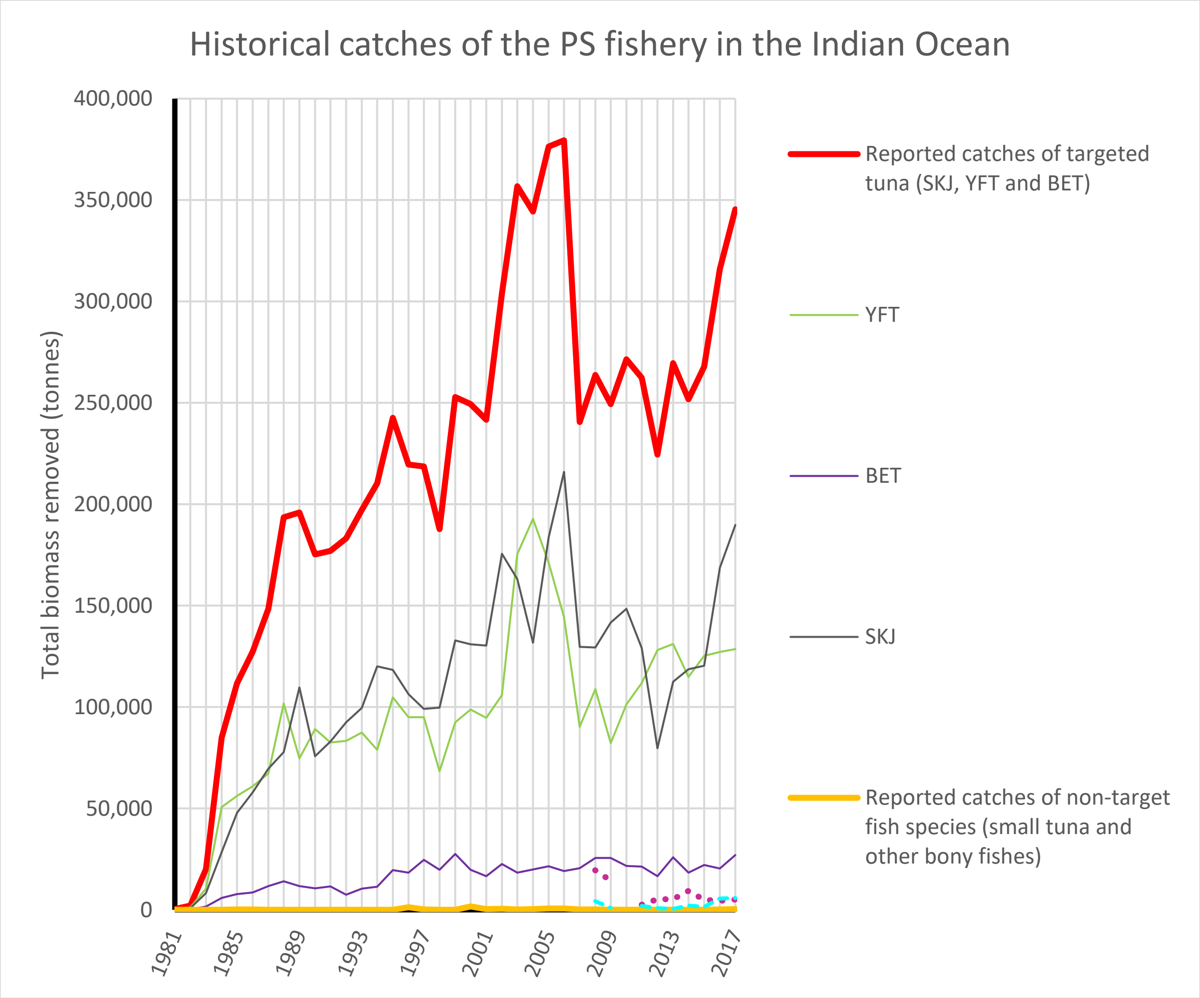


Figure 2. Total biomass removed (retained and non-retained catches) by the European and Seychelles purse seine tuna fishery in the Indian Ocean (red line). Green, purple and grey lines show the total removals of YFT, BET and SKJ respectively. Reported catches of non-targeted fish species (small tunas and other bony fishes) are in yellow Reported catches have been extracted from IOTC databases. Dashed lines show the discarded (dark pink) and retained (cyan) fraction of the catch estimated from EU the purse seine observer data.

Indicator 2: Total removals in terms of trophic level

The mean trophic level of the total removals differed between the two type of fishing strategy (5.2 for FSCs and 4.9 for FOBs) for the retained component of the catch (Figure 3). The higher trophic level of the catch in the free school sets is because these fishing method captures higher proportion of yellowfin and bigeye tunas which have higher trophic level than skipjack tuna which is mostly caught by sets on FOBs. The sets on FOBs also catch on average smaller individuals of yellowfin and bigeye tunas that the sets on FSC. The different species-specific average size of the catch by school type was not accounted when the trophic levels were assigned to these species, which should be accounted in future version of these analysis when the size data is analyzed. The retained component of the catch in the FOB sets also shows a slight decrease in the mean trophic level since 2011. This decrease in the trophic level of the catches is driven by a large increase in catches of skyjack, which have lower trophic level than the other targeted tuna, and also the increasing proportion of species with even lower trophic levels (small tunas and mackerels, and the epipelagic II and III and Balistidae functional group) (Andonegi et al. 2019).

For the non-retained component of the catch, the mean trophic levels did not differ by fishing methods at the beginning of the observed period (4.69 for both, FSC and FOB), and a slightly decreasing trend is observed in FOBs, mainly caused by a decrease in the discards of species with lower trophic levels (YFT, BET, SKJ) and an increasing tendency in discarding albacore, small tunas and mackerels and Carangidae species (Andonegi et al. 2019). With regards to the mean trophic level in the FSC fishing strategy, there is more variability, with a significant increase after 2012 driven by an increase in discards of higher-trophic level species (billfish and sharks), followed a huge drop at the final year driven by a decrease in discards of billfish, shark and yellowfin tuna and a sudden increase in discards of rays with lower trophic level (Andonegi et al. 2019).

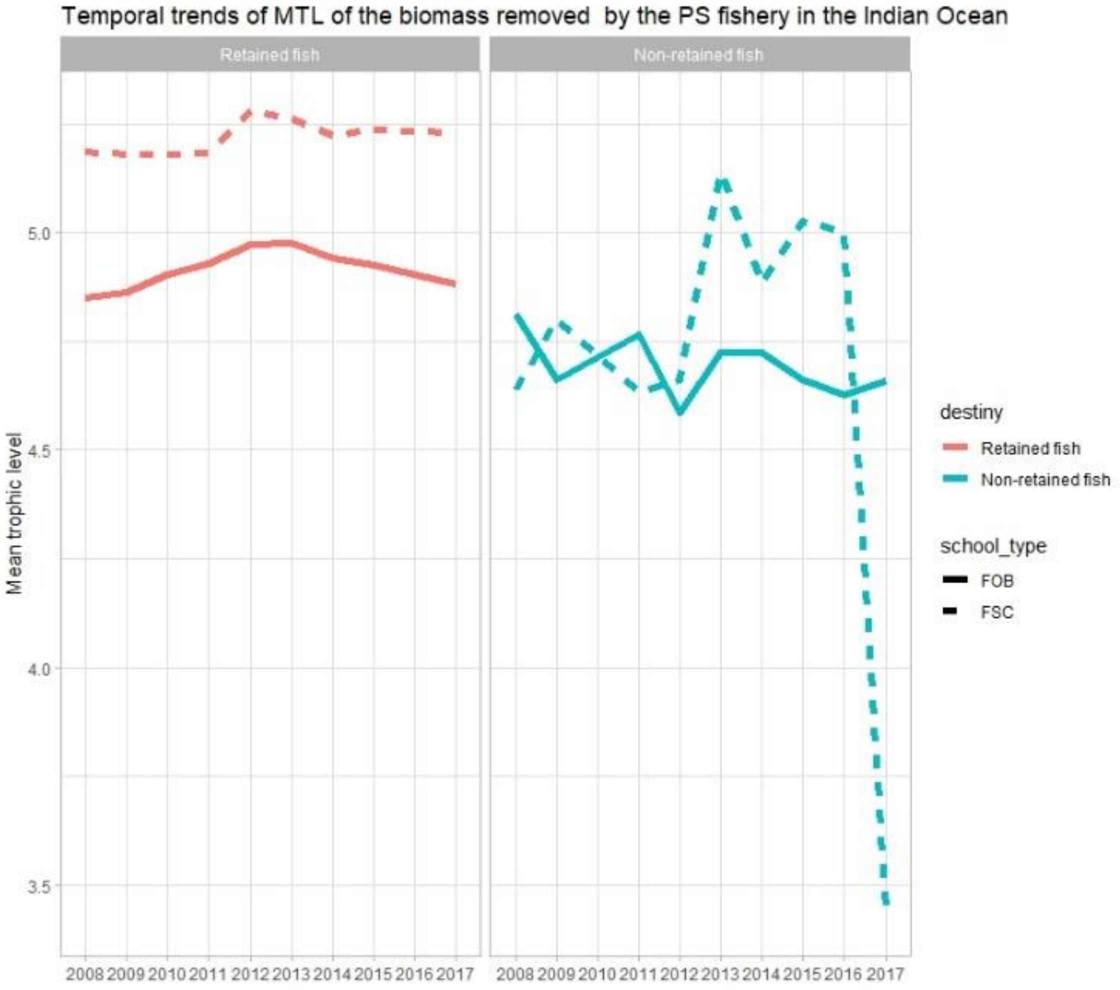


Figure 3. Total biomass removed over time in terms of mean trophic level by the European and Seychelles tropical tuna purse seine fishery in the western Indian Ocean. The mean trophic level of the catches is shown by fishing mode and by destiny (retained fish and non-retained fish).

Indicator 3: Total removals in terms of mean replacement time

Mean replacement time was lowest for the retained component of the catches and similar for both types of fishing strategy (mean of 0.67 years for FOB and mean 0.78 years for FSCs) (Figure 4). There were no clear temporal trends in mean replacement time for the retained component of catches. Instead, the mean replacement time was intermediate for the non-retained component of catches by FOB sets (mean of 0.96 years) and highest for the FSC sets (mean of 1.19 years). The higher replacement time is driven by the higher proportion of sharks found in the non-retained component of the catches which are characterized with low reproductive rate. There was also a positive and variable temporal trend in mean replacement time for the non-retained component of catches, mainly in FSC fishing strategy and specially for the last year of the time series, also driven by the increasing proportion of sharks until 2014 and a sudden increase in rays discards in 2015, and decreasing proportions of discards of species with high reproductive rate.

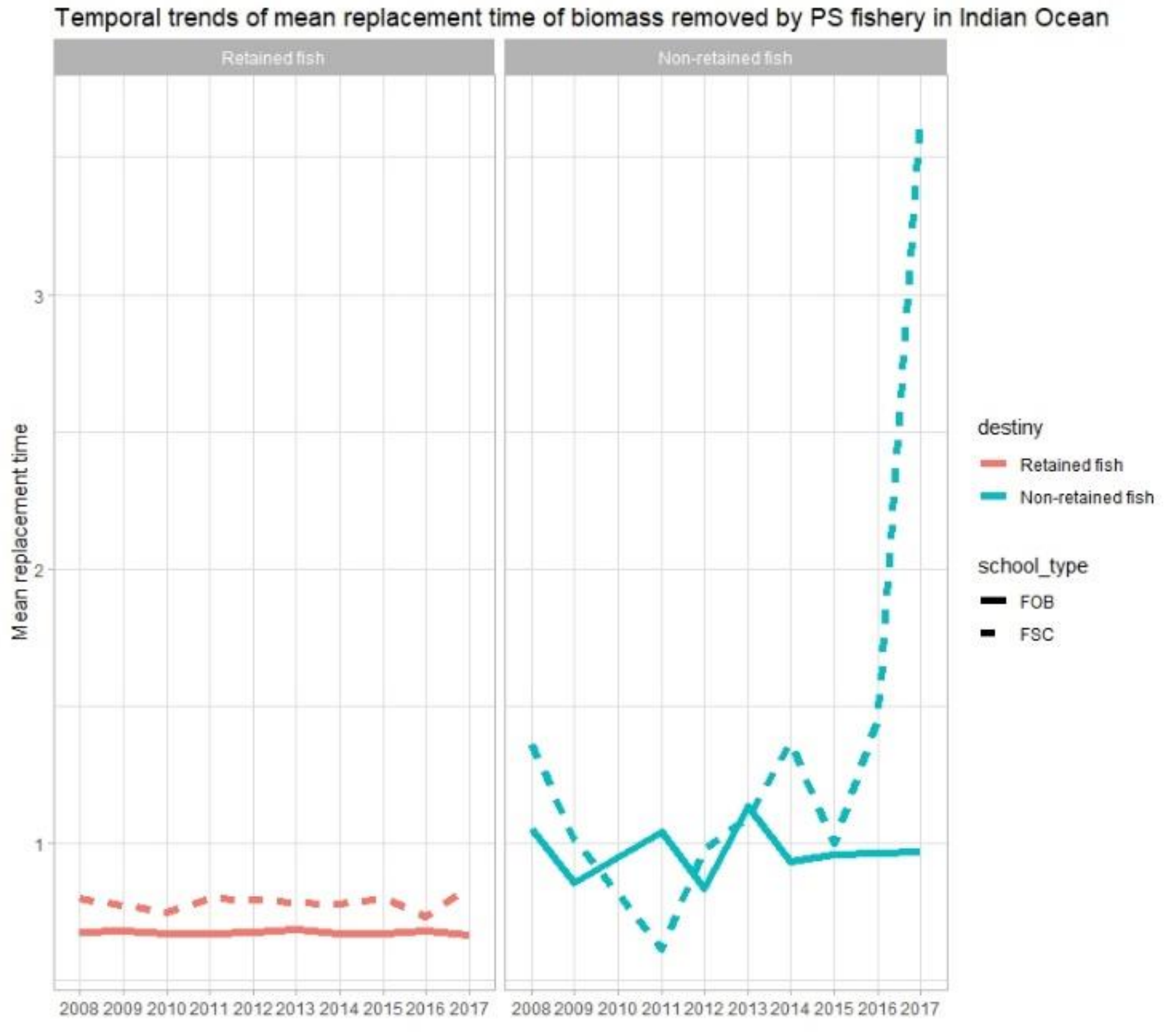


Figure 4. Total biomass removed over time in terms of mean replacement time by the European and Seychelles tropical tuna purse seine fishery in the western Indian Ocean. The mean trophic level of the catches is shown by fishing mode and by destiny (retained fish and non-retained fish).

Finally, we recognized the indicators calculated and presented here are preliminary, therefore, they should be considered work in progress. Furthermore, the purse seine fishery is just one of the many fisheries operating in the western tropical Indian Ocean and therefore we highlight that fishery impacts need to be investigated by major fisheries and gears, not only purse seine fisheries, to evaluate the cumulative impacts of all gears on a regional basis, since cumulative impacts can only provide a true understanding of the extent of the fishing impacts on the structure and function of marine ecosystems.

6. Work plan

Below we summarize some future steps planned to advance our work towards monitoring the “foodweb/trophic relationship” ecosystem component of the IOTC ecosystem report card, which we plan to update annually at the WPEB meetings. This is work in progress which requires the collaboration of multiple experts with experience on feeding ecology of the IOTC species and dependent species, ecosystem models and fisheries in the IOTC convention area. We invite the IOTC community to contribute towards the development of the “foodweb/trophic relationship” component to support the IOTC ecosystem report card. If interested, contact the corresponding authors to find out how you can contribute to this initiative.

Future steps:

- Continue the development of ecological indicators presented in Table 1 to monitor the “food web/trophic relationships” ecosystem component of the IOTC 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
- Continue the work on the three ecological indicators presented above to examine the potential ecological effects of the European and Seychelles purse seine fishery on the structure and function of the marine ecosystem in the western tropical Indian Ocean.

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