IN SUPPORT OF THE IOTC ECOSYSTEM REPORT CARD: THREE ECOSYSTEM INDICATORS TO MONITOR THE ECOLOGICAL IMPACTS OF PURSE SEINE FISHERIES OPERATING IN THE INDIAN OCEAN

Eider Andonegi[1], Maria José Juan-Jordá [2], Hilario Murua[3, 4] , Jon Ruiz[2], Maria Lourdes Ramos[5], José Carlos Baez[5], Philippe S. Sabarros[6], Francisco Abascal[5] and Pascal Bach[7]

SUMMARY

In support of the IOTC ecosystem report card, we estimated several indicators which could be used to measure progress towards monitoring the impacts of IOTC fisheries on and the state of the "Food web/Trophic relationships" ecosystem component. An ecosystem approach requires understanding the ecological effects of removing all animals through fishing. In addition to the monitoring of the total biomass removed, it is also necessary to know the species composition of the total catch and whether they are retained or not, their life history traits and their ecological role in the food web. We used the available fishery statistics and observer data from the EU and Seychelles' purse seine fishery targeting tropical tunas in the western Indian Ocean to examine the potential ecological effects of this fishery on the food web structure and functioning of this ecosystem. We estimated the total biomass removed by the fishery in terms of weight, trophic level and replacement time by purse seine fishing method (sets on floating objects-FOBs and sets on free schools-FSCs) across different areas in the Indian Ocean.

KEYWORDS

Food web, trophic relationships, mean trophic level of the catch, mean replacement time, ecosystem indicators, Indian Ocean

1. Introduction

The WPEB Program of Work (2019-2023) 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

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[1]AZTI, Marine Research Division, Txatxarramendi ugartea z/g, E-48395, Sukarrieta, Bizkaia, SPAIN. Email address of corresponding author: eandonegi@azti.es
[2] Common Oceans ABNJ Tuna Project, FAO Consultant.
[3] AZTI, Marine Research Division, Herrera Kaia, Portualdea z/g E-20110, Pasaia, Gipuzkoa, SPAIN.
[4] International Seafood Sustainability Foundation (ISSF), Washington, DC, USA (current position)
[5] IEO, Centro Oceanográfico de Canarias, Vía Espaldón, dársena pesquera, Parcela 8 38180 Santa Cruz de Tenerife, SPAIN
[6] IRD, MARBEC, Ob7, Avenue Jean Monnet, CS 30171, 34203 Sète, FRANCE
[7] IRD, MARBEC, Ob7, SFA, PO Box 570, Victoria, Mahe, SEYCHELLES

to increase the awareness, communication and reporting of the pressures and the state of the marine ecosystem to the IOTC 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 assessment of the relevant pressures affecting the state of the pelagic ecosystem and provide an assessment of the ecological state of the pelagic ecosystem interacting with IOTC fisheries (Juan-Jordá et al., 2018).

In support of the development of the IOTC ecosystem report card, this paper addresses the "food web/trophic relationships" ecosystem component, focusing on the development of three ecological indicators to examine the potential ecological effects of the EU and Seychelles' purse seine fishery targeting tropical tunas in the western Indian Ocean. To do so, we estimated the total biomass removed by this fishery in terms of weight, trophic level and replacement time of the species removed. We also compared these indicators among the different sampling areas and by purse seine fishing strategy (sets on floating objects-FOBs and sets on free schools-FSCs).

Understanding the state of the "food web/trophic relationships" component requires to monitor the ecological effects of removing all animals through fishing (Gerrodette et al., 2012). 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 (Figure 1). The degree a fishery can affect the structure and function of marine ecosystems not only depends on the total biomass removed, but also depends on the species composition of the catch, their life history and ecological role in the food web of all the species captured (Gerrodette et al., 2012). Therefore, the species composition and their ecological role in the ecosystem of the whole catch, whether they are retained or discarded, should be monitored. Additionally, it is also required to monitor the fate of the discarded catch, whether discarded dead or released alive and their survival.

We used the available fishery and observer data from the European and Seychellois tropical tuna purse seine fishery in the western Indian Ocean, to examine the potential ecological effects of this fleet on the food web structure and functioning on the ecosystem. In this study we examined the entire catch (all fish removed, whether retained or discarded) of both targeted and non-targeted species. Monitoring the entire catch is a standard way of measuring the total removals by fisheries. However, these catch metrics do not account for the ecological effects of removing animals with different trophic levels and different life histories. Therefore, we also estimated the mean trophic level of the catch (MTL_c) and the mean replacement time, aiming at monitoring the ecological effects of removing animals with different trophic levels and reproductive rates. The MTLc reflects how the trophic level, being defined as the position of an organisms in the food chain, of the actual catches is changing over time. The mean replacement time informs about the time necessary to replace a unit of biomass removed by the fishery (Gerrodette et al., 2012). Purse seine fishing in this area uses two different fishing methods (sets on free schools of tunas – FSCs, and sets on floating objects – FOBs) that differ in the amount of biomass removed and the species composition of their catches. Therefore, these ecological indicators were also examined considering the two distinct fishing methods and sampling areas within the Indian Ocean.

2. Methods

2.1 Data

We used detailed fishery statistics and observer data from the purse seine fishery (composed by the Spanish, French and Seychellois fleets) operating in the western Indian Ocean as available. This fishery targets three tropical tunas, skipjack (*Katsuwonus pelamis*-SKJ), yellowfin (*Thunnus albacares*-YFT) and bigeye (*Thunnus obesus*-BET). First, we extracted the total landings of the purse seine fishery operating in the Indian Ocean as reported to IOTC (Nominal Catch by Species and Gear - https://www.iotc.org/data/datasets/latest/NC). This data set provides annual landings from the 1980's, the beginning of the fishery, for the purse seine fishery including the retained catch of the targeted tropical tunas and the retained catch of some of the non-targeted fish species such as small tunas, other bony fish, sharks, rays, etc. In order to monitor the total biomass removed by the fishery, we also estimated total bycatch of the purse seine fishery operating in the western Indian Ocean from 2008 to 2017, using the data collected by observers onboard. In this study, the term bycatch refers to the catch of non-targeted species (whatever the fate is), plus the discards of target tunas, as defined by Amandé et al. (2008). In other words, the bycatch can be divided into two components (Figure 1): 1) the non-targeted retained component that is kept by the fleet to be sold in 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 have low commercial value, or have non-retention measures in place. For the purse seine fishery, the discard component can include discards of the target tunas and also discards of the non-targeted species (usually other bony fishes, sharks, rays, sea turtles, marine mammals) (Ruiz et al., 2018).

Since 2003, Spain and France have implemented observer programs as part of the Spanish and French National Programs for the Data Collection in the Fisheries sector established according to the European Regulations (Council Regulation (EC) No. 199/2008; Commission Implementing Decision (EU) 2016/1251). No sampling was conducted in 2010 due to the piracy problem in the area (Figure 3). Coverage values have changed significantly among years, from very low values in the beginning of the series, up to values close to 27-28% in total production terms for the most recent years (Table 1; Ruiz et al., 2018). Out from the EU Data Collection Framework, observer coverage also increased significantly in the last years (since 2014 mostly) through private contracts between industry and scientific institutes (see more detailed information in Ruiz et al., 2018). Using the observed sets, we estimated total annual bycatch between 2008 and 2017 assuming that bycatch is proportional to total production (Amandé et al., 2008). This method allowed to raise the observed bycatch in weight to total bycatch in weight using the total production as the ratio estimator. The extrapolation was stratified by year, season, sampling area (Figure 2) and fishing mode (FSC and FOB- Figure 3) following the work of Amandé et al. (2008) and Ruiz et al. (2018).

2.2. Indicators analyses

Total removal indicator

We summarized the total biomass removed (retained and discarded catch) by year, fishing method (FSC and FOBs) and functional groups. The functional groups included the three targeted tuna species (skipjack, yellowfin and bigeye), billfishes, sharks, rays, small tunas and mackerels, and other bony fish groups containing a variety of species with similar ecological characteristics (Table 2). Given the lack of food web and/or ecosystem modelling approaches in the study area, functional groups were defined based on the information provided by a food web model developed in the Atlantic Tropical Area by Forrestal (2016) and other information derived from IOTC and observer databases. Taxonomic groups of conservation concern also caught by purse seiners such as sea turtles and marine mammals were removed from the bycatch analysis. The low observation rate made the bycatch estimates for sea turtles and marine mammals too imprecise, due to the high variability in the capture rate of these taxa, to be included in the indicator analyses.

Mean trophic level of catches (MTLc) and mean replacement time (Biomass/Production) indicators

We also described the total biomass removed (retained and non-retained catches) by mean trophic level and mean replacement time. These metrics account for the ecological effects of removing animals from different trophic levels and different life histories. We estimated the mean trophic level of the catches (MTLc) for the retained and non-retained component of the catches. The MTLc indicator is widely used to assess the effects of fishing on marine ecosystems. It describes how the trophic level of the actual catch changes over time, being the trophic level defined as the position of an organism in the food chain. The catch-based MTL is the primary marine index chosen by the Convention on Biological Diversity to measure changes in global marine biodiversity and it is widely applied to report on the state of the marine environment (CBD 2004). Estimates of the trophic level of each species, or functional groups, were taken from the recent food web model using Ecopath with Ecosim (EwE) developed for the eastern tropical Atlantic (Forrestal, 2016), since this model was the closest to tuna-like species found in the literature. The MTLc was calculated as the mean trophic level weighted by the total catches of each functional group and fishery type:

$$MTLc = {\sum_{i=1}^{n} TotC_n * TL_n} \Big/ {\sum TotC}$$

where $\boldsymbol{TotC}$ refers to total catch and $\boldsymbol{TL_n}$ is the trophic level of each functional group $\boldsymbol{n}$.

We also estimated the mean replacement time (Gerrodette et al., 2012), which describes the time necessary to replace a unit of biomass removed by the fishery (Biomass/Production – B/P hereafter). This indicator provides insights on how quickly a unit of biomass removed from the fishery can replace itself. In other words, this is an estimate of the biomass per production of each species, or functional group, in the food web, which is the inverse of the Production per Biomass (P/B) ratio, being P the total production rate and B the total biomass of a species or functional group. P/B is related to the turnover rate of a species or functional group and is equal to the total mortality of a species (P/B=Z) (Allen, 1971). Estimates of the B/P ratio of each species or functional groups were obtained by calculating the inverse of the P/B values provided by the Ecopath model available in eastern tropical Atlantic (Forrestal, 2016), following the rationale described above. The B/P values obtained for each species or functional group were weighted by the total catches of each functional group and fishery type.

3. Results and discussion

Given the importance of the European and Seychellois purse seine fishery targeting tropical tunas in the western Indian Ocean in terms of total catches, we suggest that the three indicators (total biomass removed in terms of weight, mean trophic level and replacement time) presented in this study could be used to monitor the ecological effects of purse seine fishing in this area (Figure 2). 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 5). 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, comprised largely of small tunas and other bony fishes, contributes to 0.9% (Figure 4a). Fishing on floating objects shows the highest catch ratios (Figure 4a) in the last years and sampling area 1, 6,7, 8, and 9 seem to be the most exploited, subjected to the highest fishing pressure (Figure 4b).

The estimated total bycatch using the data collected by observer programs has also provided additional information on the total removals of these fishery in the study area. We disaggregated the estimated total bycatch into two components (Figure 5): 1) the estimated retained catch of non-targeted species, which is made of species that are kept and sold usually to local markets (mainly small tunas, other bony fishes and billfishes), and 2) the estimated discards which are the unwanted fish that are thrown back to the sea (dead or alive; usually damaged target tunas, in addition to other bony fishes, sharks and rays). Overall, the estimated retained catch of non-targeted fish has fluctuated significantly among years, with a value over 5,000 tonnes in the last two years of the series. Contrastingly, the estimated discards have decreased from 19,500 tonnes in 2008 to 5,000 tonnes in 2017 (Figure 4). These changes in the last part of the series might be caused by the implementation of the discard ban for target species in 2016. Between 2008 and 2017, the total discards in weight contributed to 2% on average of the total biomass removed (retained and non-retained catches).

Monitoring the amount and the species composition of both retained catches and non-retained catches (discards) of the purse seine fishery (Figure 6) provides information in the ecological effects of fishing on marine ecosystems. Overall, the mean total catch of the purse fishery was 260,000 tonnes per year between 2008 and 2017 (Figure 5&6a). The three target species were 99.09% of the retained catch (Figure 6b1). Furthermore, between 2008 and 2017 the remaining non-targeted catch retained was made mostly of small tunas and mackerels (0.65% of the total retained fish) and Coryphaena species (0.18% of the total retained fish) (Figure 6b). For the non-retained catch, the three target species made 41.5% by weight (Figure 6b1) while the remaining of the non-retained and non-targeted catch was made of small tunas and mackerels (15.4% of the total non-retained fish), sharks (11.7%) and other bony fishes, maily Balistidae and Carangidae species (9.67% and 9.29% respectively). The relatively high amount of the discarded target tunas is driven by the high estimates at the beginning of the observer program when the observer coverage was very low. Differences between sampling areas were also found (Figures 6b2 and 6b3).

To provide a broader picture of the impacts of purse seine fishing on the ecosystem, it is important to monitor the proportion of catches made by species with different ecological roles in the ecosystem and also differentiate by the type of purse seine fishing (FSC and FOB) (Figure 7). We found the mean trophic levels removed by the two types of fishing methods was different (5.2 for FSCs and 4.9 for FOBs) for the retained component of the catch (Figure 7a1). The higher trophic level of the catch in the free school sets is because these method captures higher proportion of yellowfin and bigeye tuna which have higher trophic level than skipjack which is mostly caught by sets on FOBs. However, the sets on FOBs 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. Additionally, we also observe a slight decrease in the mean trophic level of the catches made in the sets on FOBs since 2011. This decrease in the trophic level of the catches is driven by the big increase in catches of skyjack which have lower trophic level than the other target 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) (Figure 8). For the non-retained component of the catch, the mean trophic levels removed by the two types of fishing methods was the same (4.69 for both, FSC and FOB), with a slightly decreasing trend in FOBs, mainly caused by the decrease in the discards of species with higher trophic levels (YFT, BET, SKJ) and an increasing tendency in discarding albacore, small tunas and mackerels and Carangidae species (Figure 8). With regards to the mean trophic level of FSC, there is more variability, with a significant increase after 2012, that might be caused by an increase on shark catches, and a huge drop at the final year (Figure 7a1). This final drop is completely driven by the drop in the MTLc of the fishery operating in sampling area 6-

‘Seychelles north-west’ (Figure 7a2 - due mainly to a decrease in billfishes and sharks catches) which is the area with higher catches on free schools (see Figure 2).

Mean replacement time was lowest for the retained component of the catches and similar for both types of fishing (mean of 0.67 years for FOB and mean 0.78 years for FSCs) (Figure 7 b1). 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), that could be driven by the low reproductive rate of ray species (Figure 8). There was also a positive and variable temporal trend in mean replacement time for the non-retained component of catches, mainly in FSC and specially for the last year of the time series, also driven by the increasing proportion of rays discards and decreasing proportions of discards of species with high reproductive rate (see Table 2). This last increase seems to be driven by the huge increase in mean replacement time of FSC on sampling area 6 (Figure 7b2), which again could be related to the increase of ray catches that occur in this area (Figure 9).

In summary, we examined the effects of the purse seine fishery targeting tunas on the tropical ecosystem using a set of ecosystem metrics based on the total removal by the fishery (retained and non-retained catches) and the ecological role of the species being removed. The total removal indicator describing total catches in weight is a standard indicator used to monitor impacts on the ecosystem. However, it can be misleading when comparing individuals with different trophic levels and different growth and reproductive rates. In these cases, the mean trophic levels and replacement time indicators can provide additional information about the ecological roles of the species in the catch, since they indicate energy or mass flow through communities (Gerrodette et al., 2012).

By global standards, the quantity of discards in weight in the purse seine tuna fisheries targeting tropical tunas is relatively low (less than 3% on average between 2008 and 2017) compared to the discards of other gears, 7.5% for tuna long liners and 30% for tuna midwater trawls (Kelleher, 2005). Despite the moderate amounts of discards, since 2012 the purse fishery has established a program of best practices aimed to reduce the number interactions of the fishery with sensitive bycatch species by using non-entangling FADs and implementing safe-release good practices to increase the survival of discarded individuals (sharks, rays, etc..) (Goñi et al., 2016). However, despite the moderate amount of discards of this fishery, the fishery needs to continue improving the survival rates of the sensitive species that are released at sea, and it also remains to be understood the impacts of the total removal by the fishery on the ecosystem with regards to the total biomass removed, its size composition and the trophic levels and life history of the species (Gerrodette et al., 2012). Future analysis should also examine the relative contributions of the total removals of the purse seine fishery compared to the removals by other gears operating in the same region. Assessment of the effects of fisheries on the ecosystem should evolve towards understanding the cumulative effects of all the gears (or at least the most important) operating in the same ecosystem.

4. Future work to support the development of ecosystem assessments and ecosystem report cards in the IOTC area

By examining the temporal trends of several ecosystem indicators based on the total removals by the fishery and the trophic level and life history of the species removed, we support the on-going initiative in IOTC to develop ecosystem status assessments and ecosystem report cards to monitor the effects of fisheries and climate in the pelagic ecosystem of the Indian Ocean. This study estimated three ecosystem indicators, using data from the monitored purse seine fishery catching tropical tunas in the western Indian Ocean, to examine the potential ecological effects of purse seine fishing on the food web structure and functioning in the tropical ecosystem. Although this work remains preliminary and we plan to further develop it, we envision these indicators, applied to all gears, could potentially be used to monitor the pressures on and the state of the “food web/trophic relationships” component of the IOTC ecosystem report card.

In addition, other ecosystem indicators could also be potentially estimated and examined to monitor the pressures on and the state of the “food web/trophic relationships” component in order to quantify the broad and cumulative impacts of fisheries on marine ecosystem (Juan-Jordá et al., 2019).

5. References

Allen, K. R. 1971. Relation between production and biomass. J Fish Res Board Can 28:1573-1581.

Amandè, J. M., Ariz, J., Chassot, E., Chavance, P., Delgado de Molina, A., Gaertner, D., Murua, H., Pianet, R., Ruiz, J. 2008. By-catch and discards of the European purse seine tuna fishery in the Indian Ocean: characteristics and estimation for the 2003-2007 period. IOTC-2008-WPEB-12. 23 pp.

CBD. 2004. Indicators for assessing progress towards the 2010 target: indicators for immediate testing. Ad hoc technical expert group on indicators for assessing progress towards the 2010 biodiversity target, Montreal, UNEP/CBD/AHTEG-2010-Ind/1/2, 19-22 October 2004.

Forrestal, F. C. 2016. The Impacts of Bycatch from the Atlantic Tropical Tuna Purse Seine Fishery on Ecosystem Structure and Function. Open Access Dissertations. 1572.

Gerrodette, T., R. Olson, S. Reilly, G. Watters, and W. F. Perrin. 2012. Ecological metrics of biomass removed by three methods of purse-seine fishing for tunas in the eastern tropical Pacific Ocean. Conserv Biol 26:248–256.

Goñi, N., Ruiz, J., Murua, H., Santiago, J., Krug, I., Sotillo de Olano, B., González de Zarate, A., Moreno, G. & Murua, J. (2016) System of verification of the code of good practices in Anabac and Opagat tuna fleet - preliminary results for the Atlantic Ocea. *Collect. Vol. Sci. Pap. ICCAT*, 72, 662-673.

IOTC–WPEB14 (2018) Report of the 14th Session of the IOTC Working Party on Ecosystems and Bycatch. Cape Town, South Africa 10 – 14 September 2018 IOTC–2018–WPEB14–R[E]: 106pp.

Juan-Jordá, M.J., Andonegi, E., Murua, H., J, R., Lourdes Ramos, M., Sabarros, P.S., Abascal, F.J. & Bach, P. (2019) In support of the IOTC ecosystem report card: advances in monitoring the impacts on and the state of the “food web and trophics relationship” ecosystem component. To be presented at the IOTC WPEB15 meeting,

Juan-Jordá, M.J., Murua, H. & Andonegi, E. (2018) An indicator-based ecosystem report card for IOTC - An evolving process. IOTC–2018–WPEB14–20

Kelleher, K. 2005. Discards in the world’s marine fisheries: an update. Fisheries technical paper. Food and Agriculture Organization, Rome.

Ruiz, J., Abascal, F.J, Bach, P., Baez, J.C., Cauquil, P., Grande, M., Krug, I., Lucas, J., Murua, H., Ramos- Alonso, M. L., Sabarros, P. 2018. Bycatch of the European, and associated flag, purse-seine tuna fishery in the Indian ocean for the period 2008-2017. IOTC-2018-WPEB14-15.

Table 1. Temporal trend in observer coverage by fishing mode from 2008 to 2017

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
FOB	5%	2%	0%	1%	2%	2%	9%	44%	28%	29%
FSC	4%	4%	0%	1%	1%	2%	17%	46%	33%	23%
Total	5%	2%	0%	1%	2%	2%	10%	45%	29%	28%

Table 2. Functional groups defined for the IOTC Convention Area. Trophic Levels (TL) and Biomass per production (B/P) values are provided for each functional group, along with the list of species and families grouped by each of them. Trophic levels and biomass per production values were extracted and informed by the food web model of the tropical Atlantic developed by Forrestal et al 2016.

Ecological group	Functional group	TL	B/P	Species and families included
Tunas	Albacore tuna	4.404	1.818	*Thunnus alalunga*
Tunas	Bigeye tuna	5.125	1.538	*Thunnus obesus*
Tunas	Skipjack tuna	4.655	0.532	*Katsuwonus pelamis*
Tunas	Yellowfin tuna	5.336	0.714	*Thunnus albacares*
Billfishes	Billfishes	5.446	1.190	*Istiophoridae,, Istiophorus platypterus, Makaira indica, Makaira mazara, Makaira nigricans, Tetrapturus albidus, Tetrapturus angustirostris, Tetrapturus audax, , Xiphias gladius*
Sharks	Sharks	5.407	1.754	*Aetobatus narinari, Alopias sp. Alopias superciliosus Alopias vulpinus, Carcharhinidae sp., Carcharhinus falciformis, Carcharhinus leucas, Carcharhinus longimanus, Galeocerdo Cuvier, Isurus oxyrinchus, Lamna nasus, Prionace glauca, Rhincodon typus, Sphyrna lewini, Sphyrna zygaena, Sphyrnidae*
Rays	Rays	3.192	4.000	*Dasyatidae, Dasyatys (Pteroplatytrygon) violácea, Manta alfredi, Manta birostris, Manta sp., Mobula japanica, Mobula mobular, Mobula sp., Mobula tarapacana, Rajiformes*
Tuna nei	Small tunas and mackerels	4.322	0.704	*Acanthocybium solandri, Auxis rochei, Auxis sp., Auxis thazard, Euthynnus affinis, Euthynnus alletteratus, Scomber japonicus, Scombridae*
Other bony fishes	Balistidae	4.274	0.909	*Abalistes stellaris, Abalistes stellatus, Balistidae, Canthidermis maculata*
	Carangidae	4.163	0.606	*Carangidae, Carangoides ortogrammus, Caranx ignobilis, Caranx lugubris, Caranx sexfasciatus, Decapterus macarellus, Elagatis bipinnulata, Naucrates ductor, Seriola rivoliana, Uraspis sp., Uraspis helvola, Uraspis secunda, Uraspis uraspis*
	Coryphaenidae	4.766	0.645	*Coryphaena equiselis, Coryphaena hippurus, Coryphaenidae*
	Epipelagic I	4.205	0.654	*Ablennes hians, Belonidae, Brama brama, Bramidae, Lobotes surinamensis, Sphyraena barracuda, Sphyraenidae, Trichiuridae, Tylosurus crocodilus, Ruvettus pretiosus*
	Epipelagic II	3.507	0.133	*Diodon eydouxii, Diodon hystrix, Diodontidae, Ephippidae, Exocoetidae, Lactoria Cornuta, Masturus lanceolatus, Mola mola, Molidae, Platax sp., Platax teira, Serranidae*
	Epipelagic III	2.817	2.000	*Abudefduf saxatilis, Aluterus monoceros, Aluterus scriptus, Echeneidae, Echeneis naucrates, Kyphosus sp., Kyphosus cinerascens, Kyphosus vaigiensis, Lagocephalus lagocephalus, Monacanthidae, Phtheirichthys lineatus, Ranzania laevis,, Remora remora, Remorina albescens, Tetraodontidae*

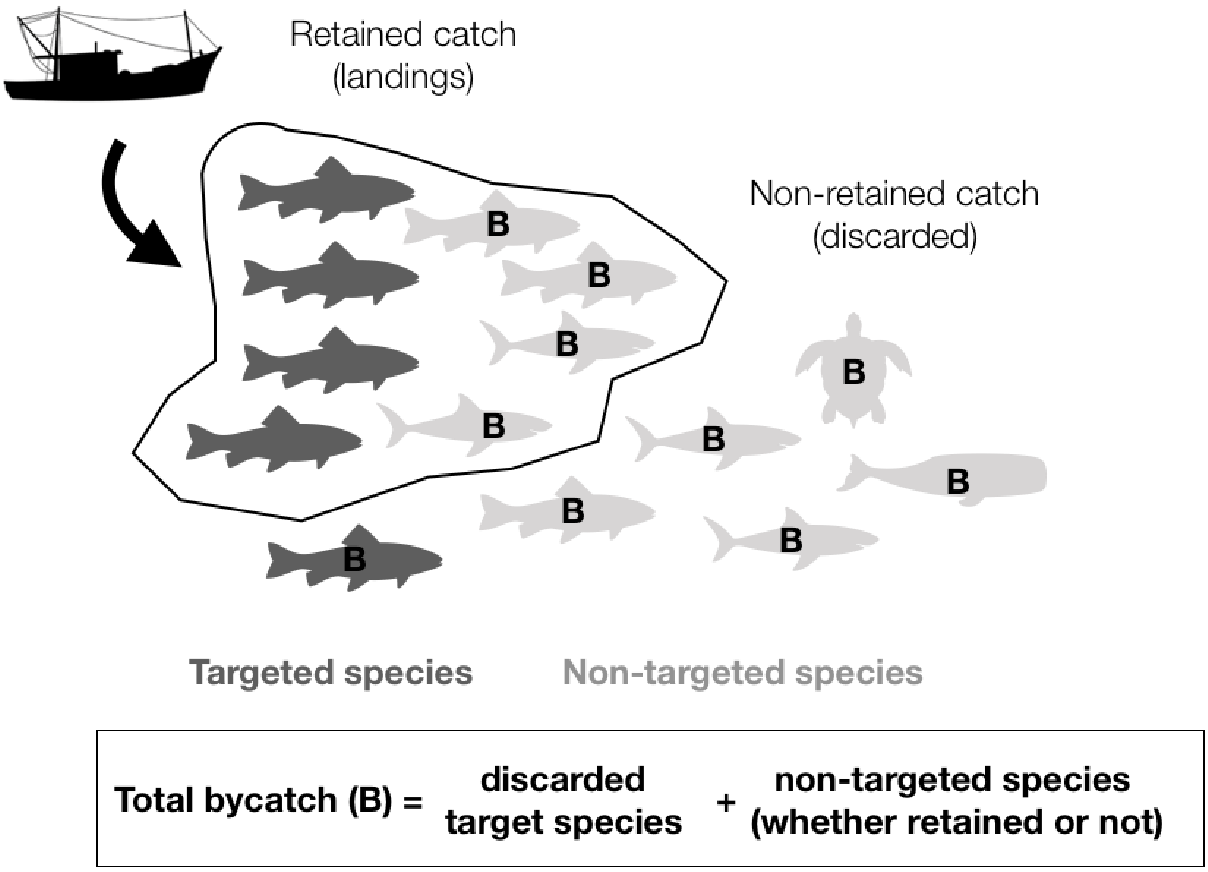


Figure 1. The catch of a fishery refers to all animals captured and removed from the ocean, and these might include species targeted and not targeted by the fishery. Usually a portion of the catch is retained (also referred as landings) and the remaining portion of the catch is non-retained (also referred 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., 2008; Ruiz et al., 2018). 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 African 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.

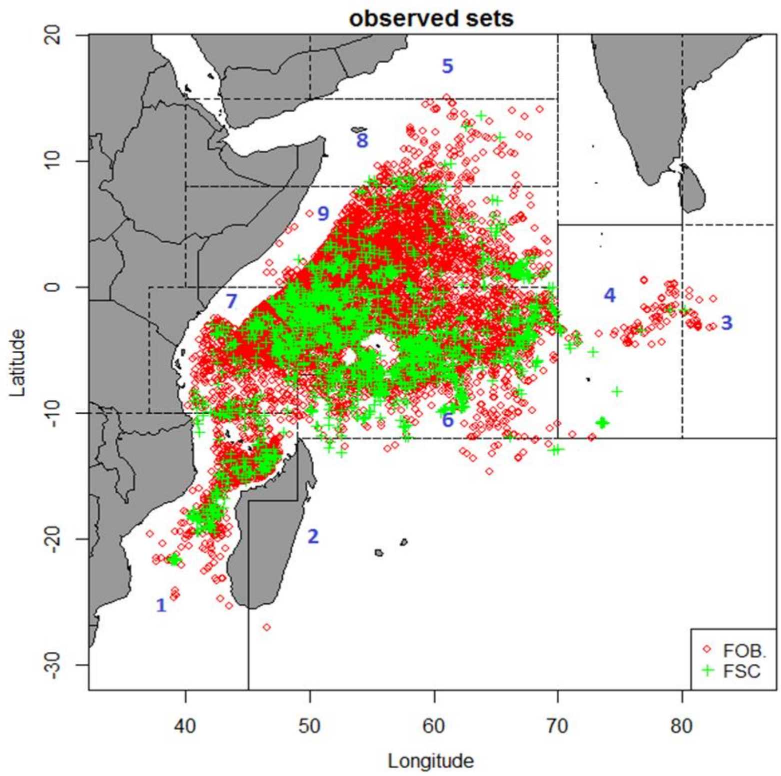


Figure 2. Location of the observed sets of the purse seine fishery between 2008 and 2017 by ET sampling area: 1-Mozanbique_Channel, 2-South_India, 3-Indonesia_west, 4-Maldives_Chagos, 5-Arabian_Sea, 6-Seychelles_north-west, 7- Seychelles_south-east, 8- Somalia_north and 9- Somalia_south. (from Ruiz et al., 2018).

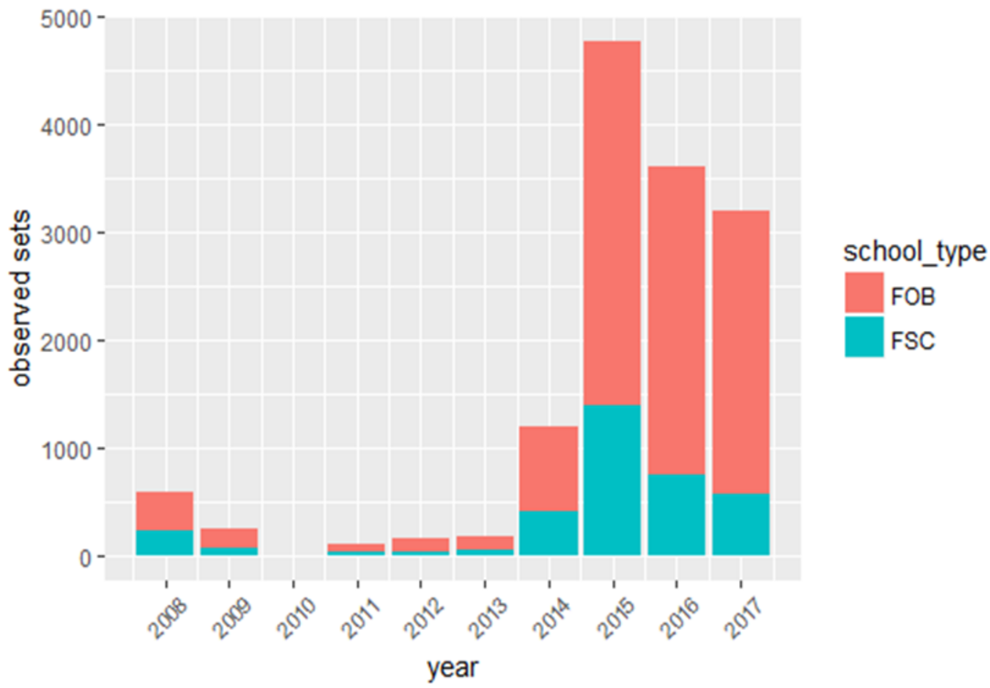


Figure 3. Number of sets observed by fishing mode (FOB: sets on floating object; FSC: sets on free school).

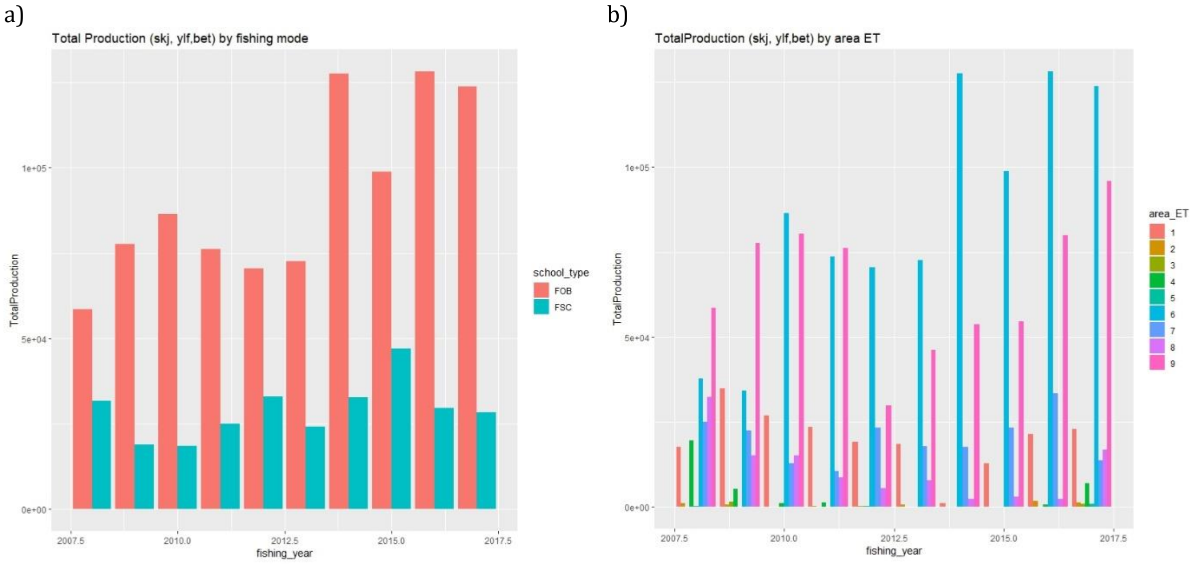


Figure 4. Total production by (a) fishing type – FOB and FSC- and (b) ET sampling area (as defined in Figure 2)

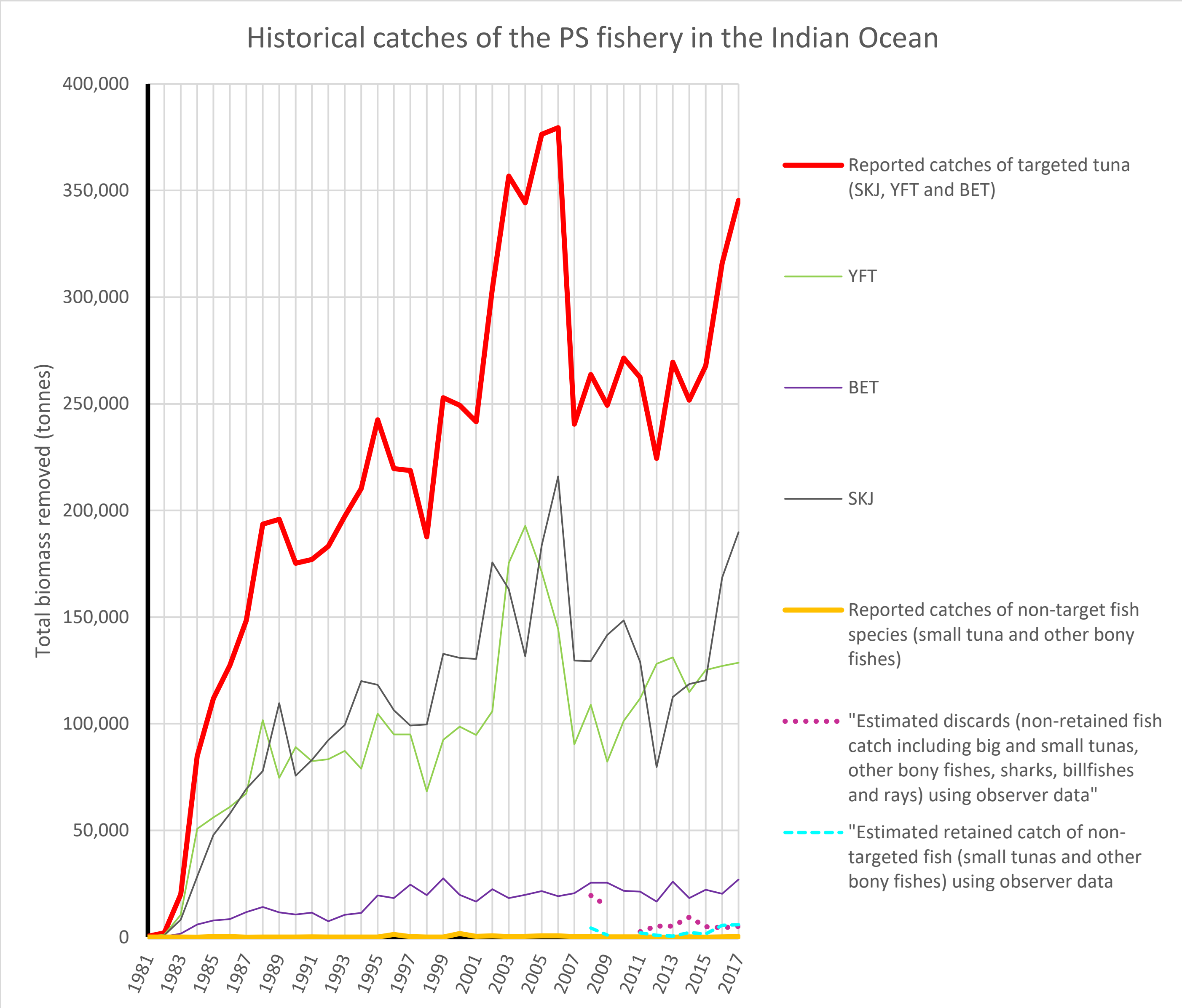


Figure 5. Total biomass removed (retained and non-retained catches) by the EU and Seychellois purse seine tuna fishery in the Indian Ocean (red line). Green, purple and grey lines show the total removals of YFT, BET and SKJ respectively. Reported catches of non-targeted fish species (small tunas and 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.

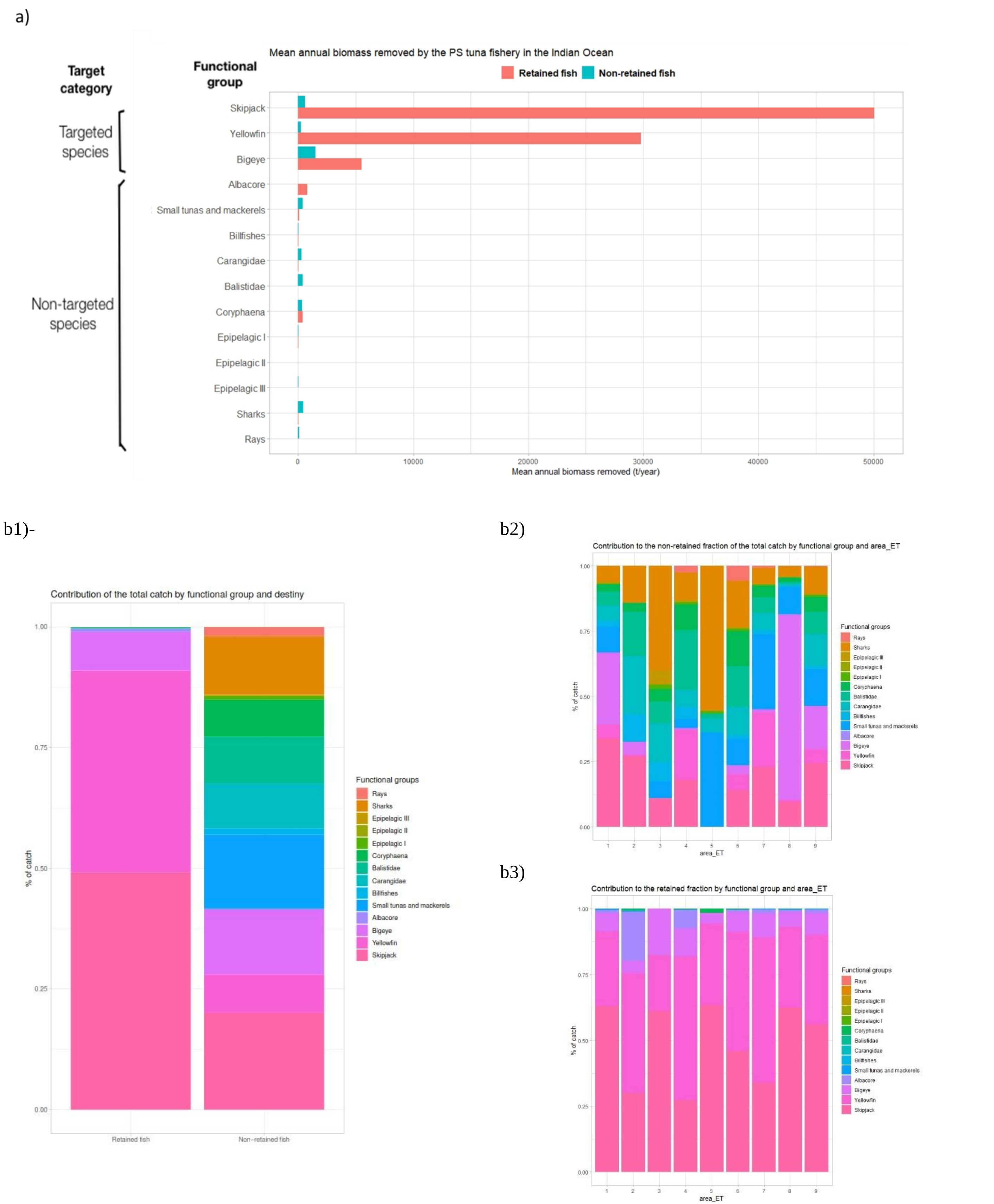
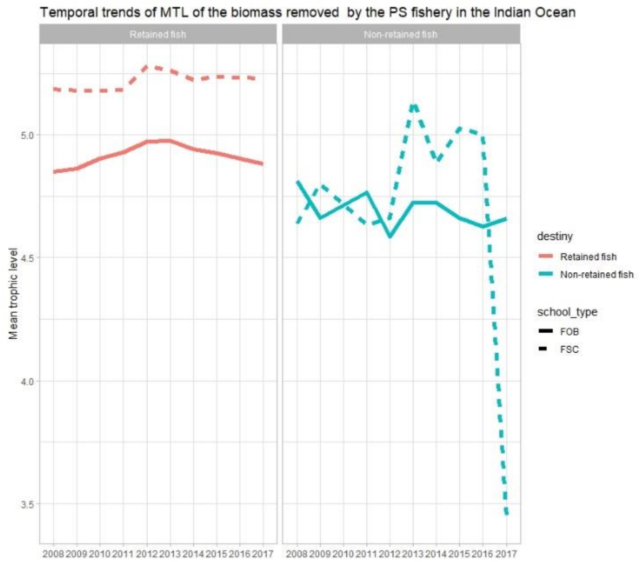


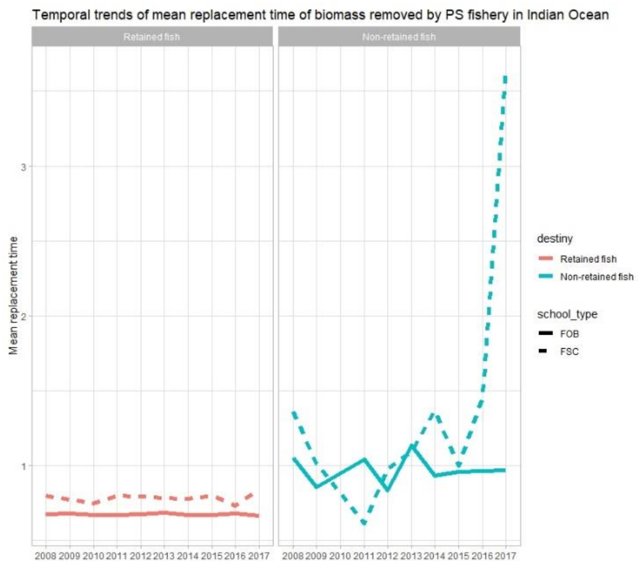
Figure 6. Biomass removed by destiny (retained catch and non-retained catch) and functional groups by the PS fleet in the Indian Ocean. (a) Mean annual biomass removed in tonnes per year between 2008 and 2017, and (b1) Relative biomass removed by functional group and destiny and (b2 & b3) by functional group and sampling area, referring to the non-retained and the retained fraction of the catches respectively.

a1)



a2)

b1)



b2)

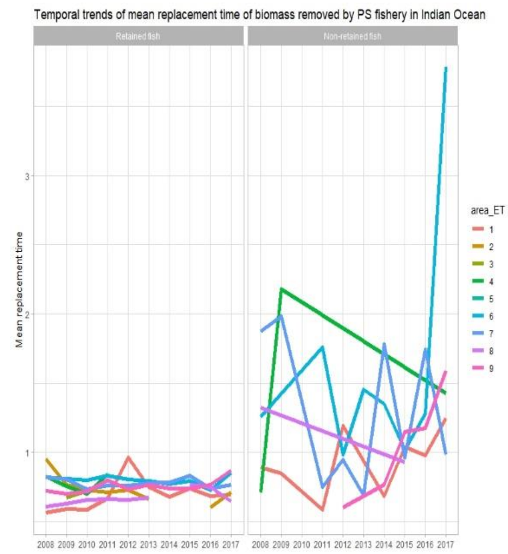


Figure 7. Total biomass removed over time in terms of: (a) mean trophic level and (b) mean replacement time by the purse seine fishery operating in the Indian Ocean. (a1) shows the mean trophic level by fishing mode and (a2), the mean trophic level by sampling area, but focusing only on the FSC fishery. (b1) shows the mean replacement time by fishing mode and (b2) mean replacement time by sampling, again focusing only on the FSC fishery. Total biomass removed has been disaggregated into the retained component of the catches (left panels) and non-retained component of the catches (right panels).

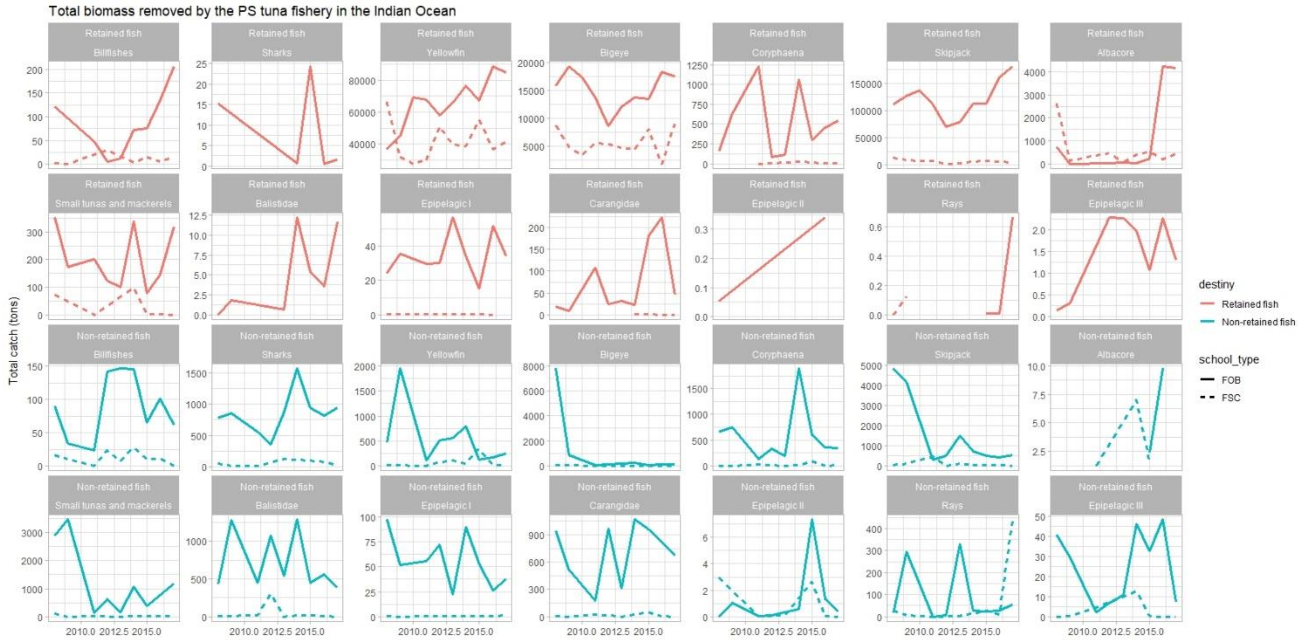


Figure 8. Trends in total removals of biomass of the purse seine fishery by functional group and fishing mode. Total biomass removed has also been disaggregated into the retained component of the catches and non-retained component of the catches. Straight lines refer to sets on FOB whereas dashed lines refer to sets on FSC. The functional groups have been ordered according to their trophic level position in the food web (from highest starting at the left side of the panels).

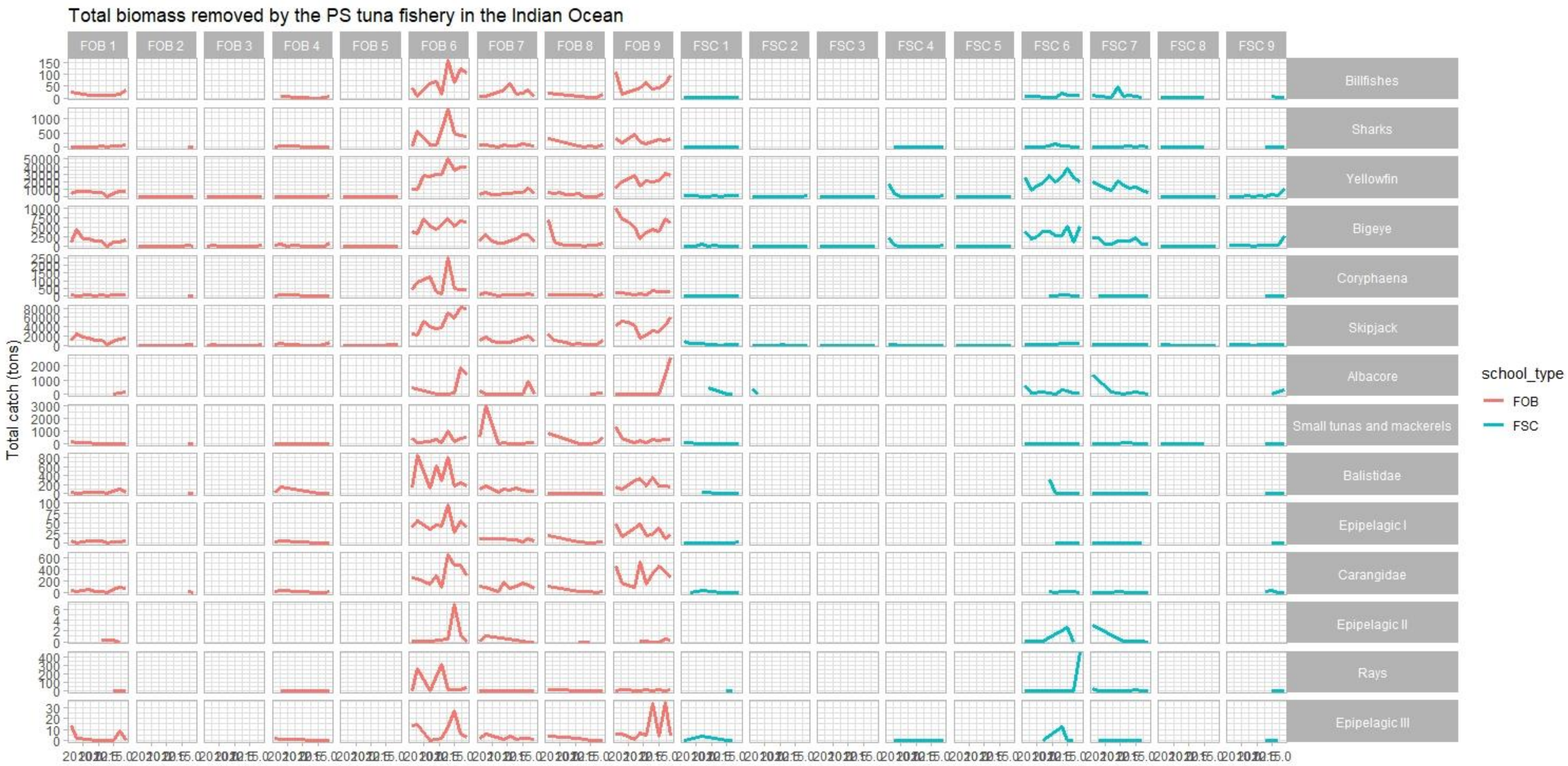


Figure 9. Trends in total removals of biomass of the purse seine fishery by functional group and fishing mode and area combination. Sampling areas coincide with the ones detailed in Figure 2.