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IN SUPPORT OF THE ICCAT ECOSYSTEM REPORT CARD: THREE ECOSYSTEM INDICATORS TO MONITOR THE ECOLOGICAL IMPACTS OF PURSE SEINE FISHERIES IN THE TROPICAL ATLANTIC ECOREGION

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SUMMARY

In support of the ICCAT ecosystem report card, we estimated several indicators which could be used to monitor the state of the "Foodweb/Trophic relationships" ecosystem component. An ecosystem approach requires understanding the ecological effects of removing all animals through fishing, not only the bycatch or discards. In addition to the monitoring of the total biomass removed, it is also necessary to know the species composition of the total catch (whether they are retained or not), their life history traits and their ecological role in the foodweb. We used the available data from the European purse seine fishery catching tropical tunas in the eastern tropical Atlantic to examine the potential ecological effects of this fishery, on the foodweb structure and functioning, in the tropical Atlantic ecoregion. We compared the total biomass removed by the fishery in terms of weight, trophic level and replacement time among each purse seine fishing method (sets on floating objects-FOBs and sets on free schools-FSCs).

RÉSUMÉ

Dans le cadre de la fiche informative sur les écosystèmes de l'ICCAT, plusieurs indicateurs pourraient être utilisés pour suivre l'évolution de la composante écosystémique des relations trophiques et de la chaîne alimentaire. Une approche écosystémique nécessite de comprendre les effets écologiques de la capture de tous les animaux par la pêche, et non pas uniquement les prises accessoires ou les rejets. Outre le contrôle de la biomasse totale capturée, il est également nécessaire de connaître la composition spécifique de la prise totale (qu'elle soit conservée ou non), les caractéristiques de son cycle vital et son rôle écologique dans le réseau trophique. Nous avons utilisé les données disponibles de la pêche européenne à la senne capturant des thonidés tropicaux dans l'Atlantique tropical oriental pour examiner les effets écologiques potentiels de cette pêche sur la structure et le fonctionnement du réseau trophique, dans l'écorégion de l'Atlantique tropical. Nous avons comparé la biomasse totale capturée par la pêche en termes de poids, de niveau trophique et de temps de remplacement de chaque méthode de pêche à la senne (opérations sous objets flottants-FOB et opérations sur bancs libres-FSC).

RESUMEN

En apoyo a la tarjeta informativa ICCAT sobre ecosistemas, estimamos varios indicadores que podrían utilizarse para hacer un seguimiento del estado del componente del ecosistema "Red alimentaria/Relaciones Tróficas". Un enfoque basado en el ecosistema requiere la comprensión de los efectos ecológicos de la eliminación de todos los animales mediante la pesca, no sólo la captura fortuita o los descartes. Además del seguimiento de la biomasa total extraída, también es necesario conocer la composición por especies de la captura total (tanto si se retienen como si no), sus rasgos de ciclo vital y su función ecológica en la red alimentaria. Utilizamos los datos disponibles de la pesquería de cerco europea que captura túnidos tropicales en el Atlántico tropical oriental para examinar los posibles efectos ecológicos de esta pesquería en la estructura y el funcionamiento de la red alimentaria, en la ecorregión del Atlántico tropical. Comparamos la biomasa total capturada por la pesquería en términos de peso, nivel trófico y tiempo de reemplazo entre cada método de pesca con red de cerco (lances sobre objetos flotantes-FOB y lances sobre bancos libres-FSC).

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KEYWORDS

Food webs, trophic relationships, mean trophic level of the catch, mean replacement time, ecosystem indicators, ecoregions

1. Introduction

Since 2017 the Sub-Committee on Ecosystems is working on developing an Ecosystem Report Card. This Report Card aims to highlight and monitor 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 on the structure and function of marine ecosystems to the Commission. The Subcommittee on Ecosystems has 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, socio economic, fishing pressure, environment and habitats. In 2018 a series of indicator-based assessments were produced for each of these operational ecosystem components and reviewed by the Sub-Committee on Ecosystems. Each assessment proposed and calculated a series of indicators that could potentially be used to monitor the state of that particular ecosystem component. Based on these indicator-based assessments, the first example of Ecosystem Report Card was produced in 2018. Noting the preliminary nature of the first ecosystem report card and the understanding that multiple iterations are needed to move towards a more scientifically mature based product, the Sub-Committee on Ecosystems recommended to update and review the card in 2019.

Following this recommendation, we estimated and examined several ecosystem indicators relevant to the "Foodweb/Trophic relationships" ecosystem component in view of its predefined goal and operational objectives. The overall goal for this component has been specifically defined by the Sub-Committee on Ecosystems as "Ensuring that ICCAT fisheries will not cause adverse impacts on the structure and function of ecosystems", and its operational objective defined as "trophic interactions and inter dependencies involving species that are affected by fishing are maintained" (ICCAT 2018).

Understanding the state of the "foodweb/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 foodweb of all the species captured (Gerrodette *et al.* 2012). Therefore, this also requires monitoring and assessing the impact of fisheries on their target and non-target species, whether they are retained or discarded, and monitoring the species composition and their ecological role in the ecosystem. Additionally, it might also be required to monitor the fate of the discarded catch, whether thrown dead or alive and their survival.

There has been a proposal to divide the ICCAT convention area into seven ecological regions to guide ecosystem planning and ecosystem assessments (**Figure 2**). The proposed ecoregions have been defined based on three pillars of information; (1) the biogeography and oceanographic characteristics of the pelagic waters in the Atlantic Ocean, (2) the spatial distributions of tuna and tuna-like fish species in the Atlantic Ocean, (3) and the spatial patterns of the main fishing fleets targeting them (Juan-Jordá *et al.* 2019). We used the available data from the European tropical tuna purse seine fishery in the eastern tropical Atlantic Ocean, to examine the potential ecological effects of this fleet on the foodweb structure and functioning in the tropical Atlantic ecoregion (**Figure 2**). In this study, first, we examined the ecological information on the entire catch (all fishes 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, to monitor the ecological effect of removing animals with different trophic levels and reproductive rates. The MTLc reflects how the trophic level of the actual catches is changing over time, being defined as the position of an organisms in the food chain. 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 the tropical Atlantic 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 in their catches. Therefore, these ecological indicators were also examined among the two distinct fishing methods.

2. Methods

2.1 Data

We used detailed catch data from the EU purse seine fishery (composed by the Spanish and French fleets) operating in the eastern tropical Atlantic as available (**Figure 2**). First, we extracted the total landings of the EU purse seine fishery operating in the eastern Atlantic Ocean as reported to ICCAT (Task I data set). This data set provides annual landings from the 1950s for the EU 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. The European purse seine fishery targets three tropical tunas, skipjack (*Katsuwonus pelamis*-SKJ), yellowfin (*Thunnus albacares*-YFT) and bigeye (*Thunnus obesus*-BET). In order to monitor the total biomass removed by the fishery, we also estimated total bycatch of EU purse seine fishery operating in the eastern tropical Atlantic from 2007 to 2016 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 (Amandé *et al.* 2010). In other word, the bycatch can be divided into two components (**Figure 1**): 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-retantion measures in place. For the EU purse 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.* 2017).

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 (Commission Regulation (EC) No. 665/2008) (Ruiz *et al.* 2017). The observer coverage has been increasing progressively from 181 sets in 2006 to 4042 sets in 2016, yet the coverage of data varies significantly between years (**Figure 3**). In terms of total production (understood as landings of the three target tuna species), the observed coverage was between 8-9% in the first years of the program, and around 50-60% in the most recent years (Ruiz *et al.* 2017). Using the observed sets, we estimated total annual bycatch between 2007 and 2016 assuming to be proportional to total production (Amandé *et al.* 2010). 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 and fishing mode (FSC and FOB) following the work of Amande *et al.* (2010) and Ruiz *et al.* (2017).

2.2. Indicators analyses

Total removals 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 1**). The functional groups were defined based on the foodweb model of (Forrestal 2016) and other information derived from ICCAT 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 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 obtained from the recent food web model using Ecopath with Ecosim developed for the eastern tropical Atlantic (Forrestal 2016). The MTLc was calculated as the mean trophic level weighted by the total catches of each functional group and fishery type.

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). 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 that importance of the European purse seine fishery targeting tropical tunas in the eastern tropical Atlantic in terms of total catches and the high degree of overlap of the fishery with the Tropical Ecoregion (**Figure 1**), 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 the tropical ecoregion.

The total biomass removed by the EU purse seine fishery has increased since the 1960s, reaching a peak of over 200,000 tonnes in the early 1990s, and currently being over 100,000 tonnes annually (**Figure 4**). Within the last 10 years, the target species (skipjack, yellowfin and bigeye tuna) have contributed to 93.5% of the total retained catch (reported to ICCAT in Task 1), while the non-targeted retained component of the catch, comprised largely of small tunas, contributes to 6.5% (reported to ICCAT in Task 1) **(Figure 4)**. The non-target retained component of the catch has increased its importance in the landings over time due to the emergence of the “faux-poisson” local market (Chavance P. *et al.* 2015) . However, it has not been historically well monitored nor reported and should be interpreted with caution. In the most recent years, this component is more precisely estimated due to the larger coverage of observer program in the EU fleet.

The estimated total bycatch using the data collected by EU observer programs has also provided additional information on the total removals of these fishery in the Tropical region. We disaggregated the estimated total bycatch into two components (**Figure 4**): 1) the estimated retained catch of non-targeted species, which is made of species that are kept and sold usually to local African 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 increased from 900 tonnes in 2007 to 5000 tonnes in 2016, while the estimated discards have decreased from 8000 tonnes in 2007 to 4500 tonnes in 2016 (**Figure 4**). Between 2007 and 2016, the total discards in weight contributed to 6% 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 EU purse seine fishery provides information in the ecological effects of fishing on marine ecosystems (**Figure 5**). Overall, the mean total catch of the EU purse fishery was 105000 tonnes per year between 2007 and 2016 (**Figure 5a**). The three target species were 96.7% of the retained catch and 38.7% of the non-retained catch (or discards) by weight (**Figure 4b**). The relatively high amount of the discarded target tunas is driven by the high estimates at the begging of the observer program when the observer coverage was very low. Furthermore, between 2007 and 2016 the remaining non-targeted catch retained was made mostly of small tunas and mackerels (2.1% of the total retained fish) and Carangidae species (0.4% of the total retained fish) (**Figure 5b**). The remaining of the non-retained and non-targeted catch was made of small tunas and mackerels (40.7% of the total non-retained fish), sharks and rays (12%) and Carangidae species (5%).

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 6**). We find the mean trophic levels removed by the two types of fishing methods was different (5.2 for FSCs and 4.8 for FOBs) for the retained component of the catch (**Figure 6a**). 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 average catch of these species 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 weak decrease in the mean trophic level of the catches made in the sets on FSCs. This slight decrease in the trophic level of the catches is driven by the decreasing proportion in catches of species with high trophic levels (billfishes) and increasing proportions in catches in species with lower trophic levels (small tunas and mackerels, and the epipelagic I and Carangidae functional group) (**Figure 7**). For the non-retained component of the catch, the mean trophic levels removed by the two types of fishing methods was similar (4.7 for FSC and 4.6 for FOB), and it increased slightly over time, particularly in the sets of FSCs (**Figure 6a**). The slight increase in the trophic level of the non-retained catches is driven by the increase in the discards of high trophic level species such as sharks, and a decrease in the discards of species with lower trophic levels (skipjack, small tunas and mackerels) (**Figure 7**).

Mean replacement time was lowest for the retained component of the catches and similar for both types of fishing (mean of 0.7 years for FOB and mean 0.75 years for FSCs) (**Figure 6 b**). There were no 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 0.78 years) and highest for the FSC sets (mean of 1.15 years), driven by the low reproductive rate of shark species (**Figure 7**). There was also a positive and variable temporal trend in mean replacement time for the non-retained component of catches, also driven by the increasing proportion of shark discards and decreasing proportions of small tuna discards. Shark species have relatively high B/P values (**Table 1**).

In summary, we examined the effects of the EU 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 animals 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 (6% on average between 2007 and 2016) compared to the discards of other gears, 7.5% for tuna longliners and 30% for tuna midwater trawls (Kelleher 2005). Despite the moderate amounts of discards, since 2012 the EU 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 sl 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 discarded, 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 EU purse seine fishery compared to the removals by other purse seine fisheries and other gears also 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 ICCAT 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 would like to support the on-going initiative in ICCAT to develop ecosystem status assessments and ecosystem report cards to monitor the effects of fisheries and climate in the Atlantic pelagic ecosystem. This study estimated three ecosystem indicators, using data from the well-monitored European purse seine fishery catching tropical tunas in the eastern tropical Atlantic, to examine the potential ecological effects of purse seine fishing on the foodweb structure and functioning in the tropical ecosystem. Although this work remains preliminary and we plan to continue expanding on it, we envision these indicators could potentially be used to monitor the state of the “foodweb/trophic relationships” component in the ICCAT ecosystem report card.

In addition, other ecosystem indicators could also be potentially estimated and examined to monitor state of the "foodweb/trophic relationships" component in order to quantify the broad and cumulative impacts of fisheries on marine ecosystem (**Table 2**). A recent EU project, focused on enhancing EAF implementation, identified and proposed candidate indicators to monitor multiple components of the ecosystem and the interaction between them (Juan-Jordá *et al.* 2019). **Table 2** shows candidate indicators to monitor the "foodweb/trophic interactions" ecosystem component. The proposed indicators are divided into three categories depending on the on-going work in ICCAT and data availability to estimate them: (1) Indicators currently estimated and/or monitored in ICCAT; (2) Indicators for which data is potentially available (or partially available), but are not currently estimated and/or monitored by ICCAT; (3) Indicators for which data is not currently and readily available for their estimation, but are included to guide future data collection and research efforts. We plan to continue examining these list of candidate indicators to better monitor the state of the "foodweb/trophic relationships" component.

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Table 1. Functional groups defined for the tropical ecoregion in the ICCAT 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 albicans, Makaira indica, Makaira nigricans, Tetrapturus albidus, Tetrapturus angustirostris, Tetrapturus pfluegeri, Xiphias gladius*
Sharks	Sharks	5.407	1.754	*Alopias pelagicus, Alopias spp, Alopias superciliosus, Alopias vulpinus, Carcharhinidae sp., Carcharhiniformes, Carcharhinus falciformis, Carcharhinus leucas, Carcharhinus longimanus, Carcharodon carcharias, Galeocerdo Cuvier, Isurus oxyrinchus, Isurus spp, Lamna nasus, Lamnidae, Odontaspididae, Orectolobiformes, Prionace glauca, Selachimorpha, Sharks, Sphyrna lewini, Sphyrna mokarran, Sphyrna zygaena, Sphyrnidae, Squaliformes, Rhincodon typus*
Rays	Rays	3.192	4.000	*Ephippidae, Dasyatidae, Manta birostris, Manta sp., Mobula japanica, Mobula mobular, Mobula sp., Mobula tarapacana, Mobula thurstoni, Mobulidae, Myliobatis Aquila, Pteroplatytrygon violácea, Rajiformes, Rhinopteridae sp., Torpedinidae*
Tuna nei	Small tunas and mackerels	4.322	0.704	*Acanthocybium solandri, Sarda sarda, Scomber scombrus, Scomberomorus tritor, Scombridae, Auxis rochei, Auxis sp., Auxis thazard, Euthynnus alletteratus, Thunnus atlanticus, Tunas nei*
Other bony fishes	Balistidae	4.274	0.909	*Balistes carolinensis, Balistes punctatus, Balistidae, Cantherhines macrocerus, Canthidermis maculata, Cantidermis sufflamen*
	Carangidae	4.163	0.606	*Carangidae. Caranx crysos, Caranx lugubris, Caranx sexfasciatus, Decapterus macarellus, Decapterus spp, Elagatis bipinnulata, Naucrates ductor, Selene dorsalis, Seriola rivoliana, Uraspis helvola, Uraspis secunda, Uraspis sp.*
	Coryphaenidae	4.766	0.645	*Coryphaena equiselis, Coryphaena hippurus, Coryphaenidae*
	Epipelagic I	4.205	0.654	*Ablennes hians, Belonidae, Brama brama, Bramidae, Gempylus serpens, Lobotes surinamensis, Sphyraena barracuda, Sphyraenidae, Tylosurus crocodilus, Ruvettus pretiosus*
	Epipelagic II	3.507	0.133	*Cubiceps capensis, Cubiceps spp, Diodon eydouxii, Diodon hystrix, Diodontidae, Euleptorhamphus velox, Exocoetidae, Fistularia spp, Masturus lanceolatus, Mola mola, Molidae, Pomacentridae, Psenes cyanophrys, Serranidae*
	Epipelagic III	2.817	2.000	*Abudefduf saxatilis, Aluterus monoceros, Aluterus scriptus, Echeneidae, Echeneis naucrates, Echeneis naucrates, Kyphosus sectatrix, Kyphosus sp., Kyphosus vaigiensis, Lagocephalus lagocephalus, Monacanthidae, Phtheirichthys lineatus, Ranzania laevis, Remora australis, Remora brachyptera, Remora osteochir, Remora remora, Remorina albescens, Tetraodontidae*

Table 2. Candidate indicators to monitor the "foodweb/trophic relationships" ecosystem component.

Indicators which are currently estimate and/or monitored in ICCAT	*Indicators currently not monitored in ICCAT for which data are available*	*Indicators currently not monitored in ICCAT for which data are not available*
	• **Total biomass removed by fishery** • **Mean Trophic Level Indicators (catch data)** • **Replacement time indicators (catch data)** • Group spawning stock biomass relative to a reference level (e.g. B_{MSY} or proxies) • Biomass indicators (total, guild/community) • Proportion of non-declining exploited species • Recovery in the Population Abundance of Sensitive Species • Group Fishing mortality relative to a reference level (e.g. F_{MSY} or proxies) • Community size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (catch based) • Proportion of predatory fish or "Large Species Indicator" (catch data) • Abundance-Biomass Comparison (ABC) curve • Mean maximum length of community (catch data) • Species diversity indices (Shannon/Simpson/Evenness/Richness) (catch data) for each major gear • Tropicalization index	• Community size-based indicators (mean length, 95th percentile of the length distribution, Proportion of fish larger than the mean size of first sexual maturation) (model based) • Mean Trophic Level Indicators (model derived) • Size spectra (total, by guild/community) (model based) • Mean maximum length of community (model derived) • Species diversity indices (Shannon/Simpson/Evenness/Richness) (model derived) • Proportion of predatory fish or "Large Species Indicator" (model derived)

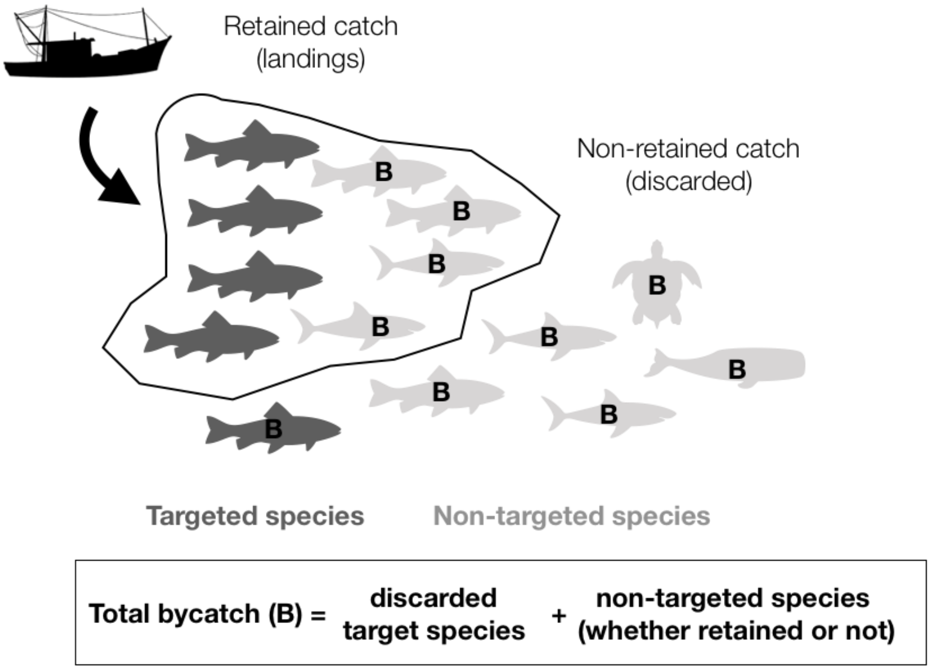


Figure 1. The catch of a fishery refers to all animals captured and removed from the ocean, and these might include species targeted and not targeted by the fishery. Usually a portion of the catch is retained (also referred as landings) and the remaining portion of the catch is non-retained (also referred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

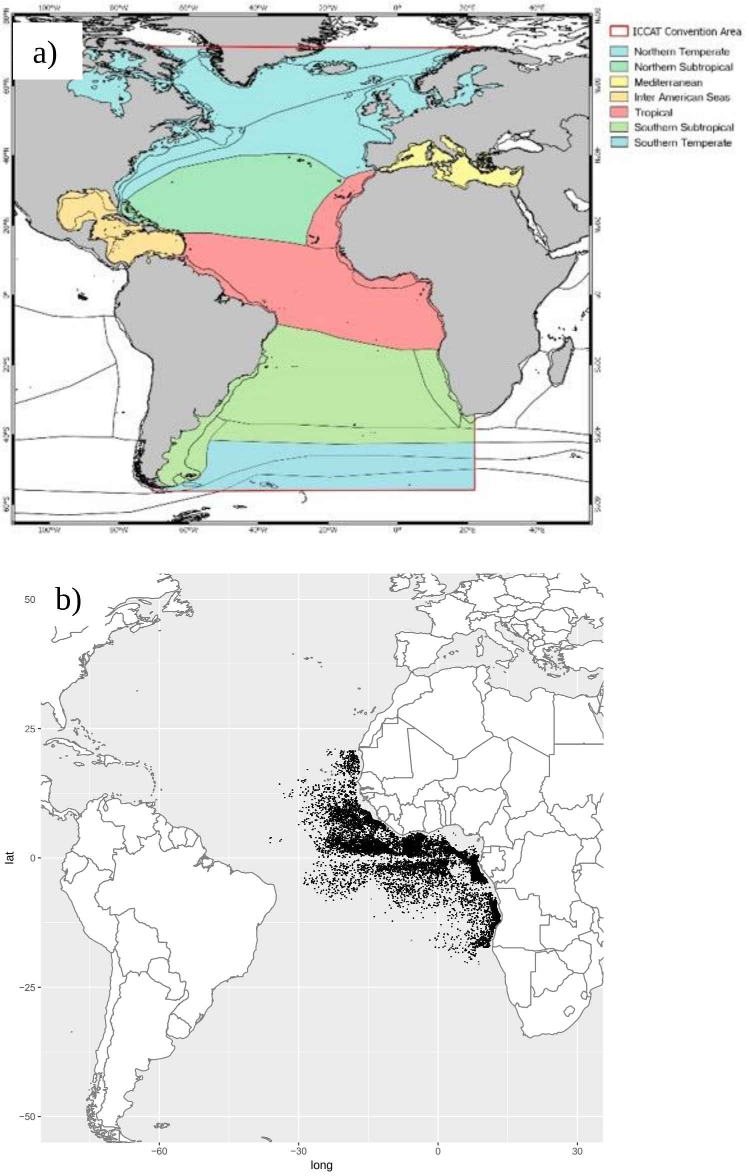


Figure 2. Ecological boundaries to support the development of ecosystem assessments and indicators. (a) Candidate ecoregions to guide ecosystem planning and assessments in support of the operationalization of the EAF in the ICCAT Convention Area (Juan-Jordá *et al.* 2019). (b) Location of the observed sets of EU purse seine fishery between 2007 and 2016.

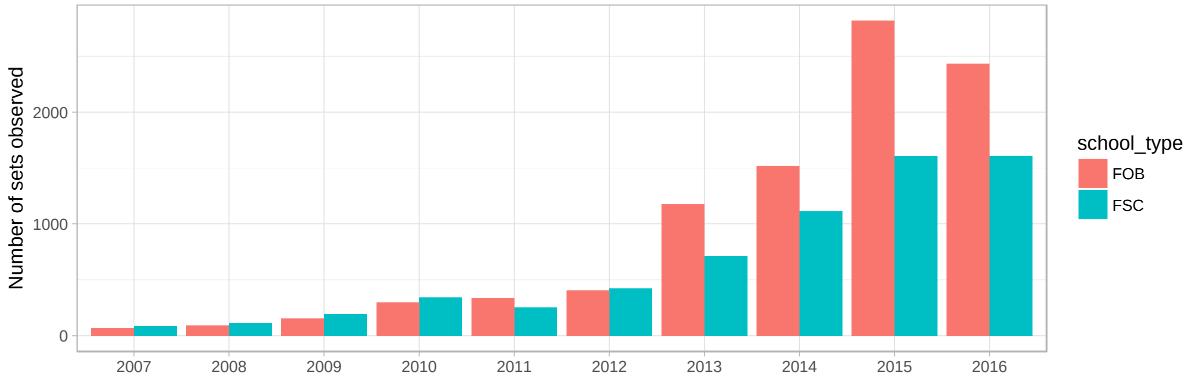


Figure 3. Number of sets observed by fishing mode (FOB: sets on floating object; FSC: sets on free school).

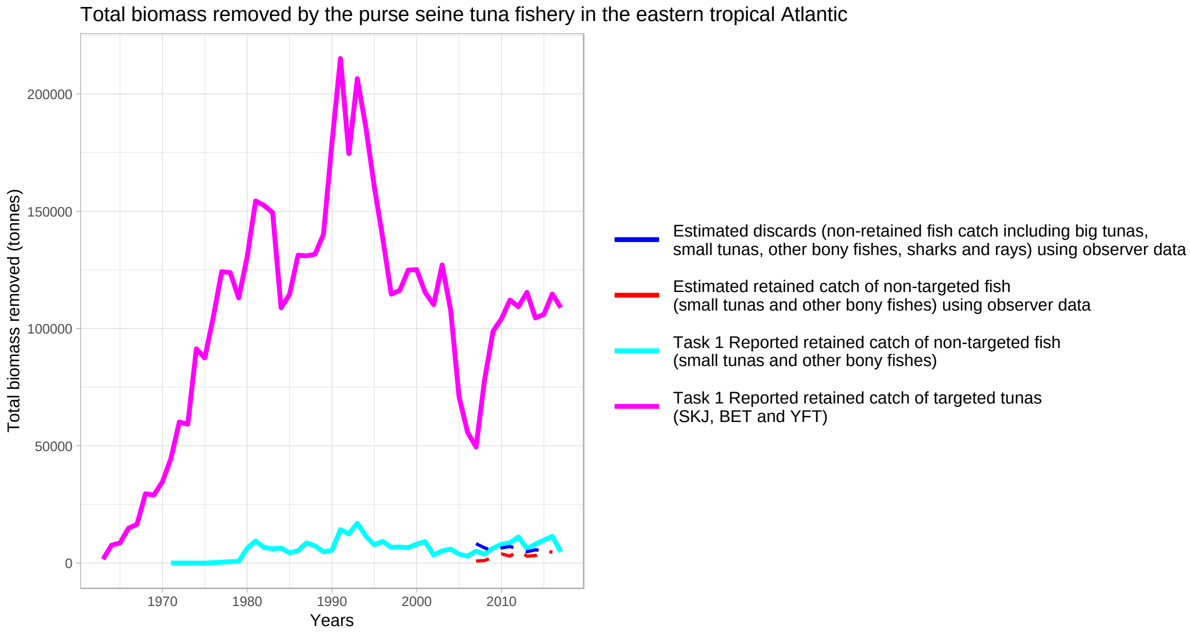


Figure 4. Total biomass removed (retained and non-retained catches) by the EU purse seine tuna fishery in the eastern tropical Atlantic.

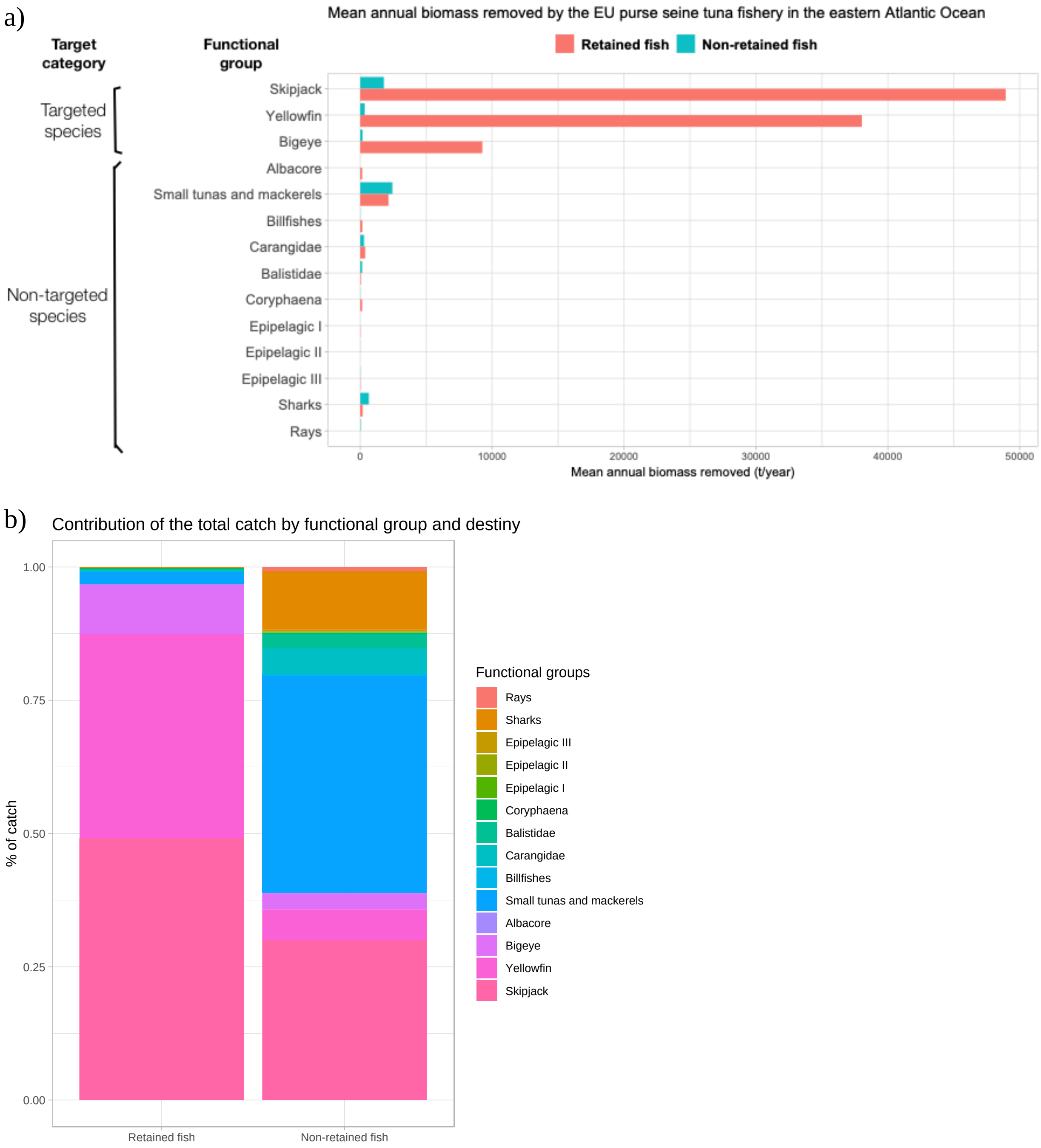
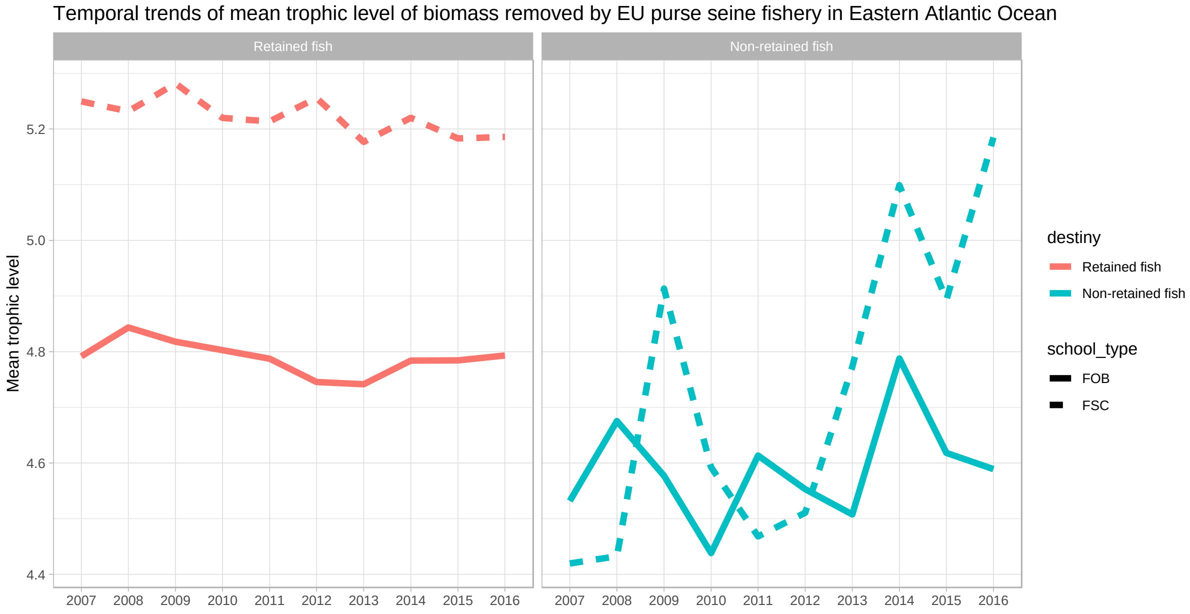


Figure 5. Biomass removed by destiny (retained catch and non-retained catch) and functional groups by the EU Tropical fleet in the eastern Atlantic Ocean. (a) Mean annual biomass removed in tonnes per year between 2007 and 2016, and (b) Relative biomass removed by functional group and destiny.

a)



b)

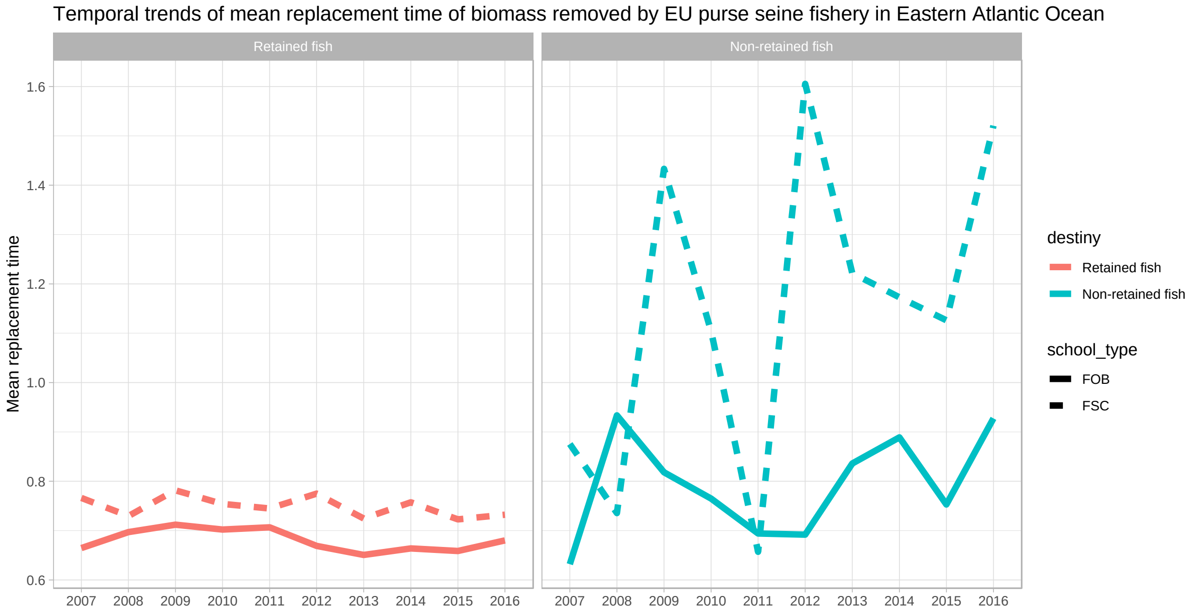


Figure 6. Total biomass removed over time in terms of (a) trophic level and (b) mean replacement time by the EU purse seine fishery in the eastern tropical Atlantic. Total biomass removed has been disaggregated into the retained component of the catches (left panels) and non-retained component of the catches (right panels). Straight lines refer to sets on FOB whereas dashed lines refer to sets on FSC.

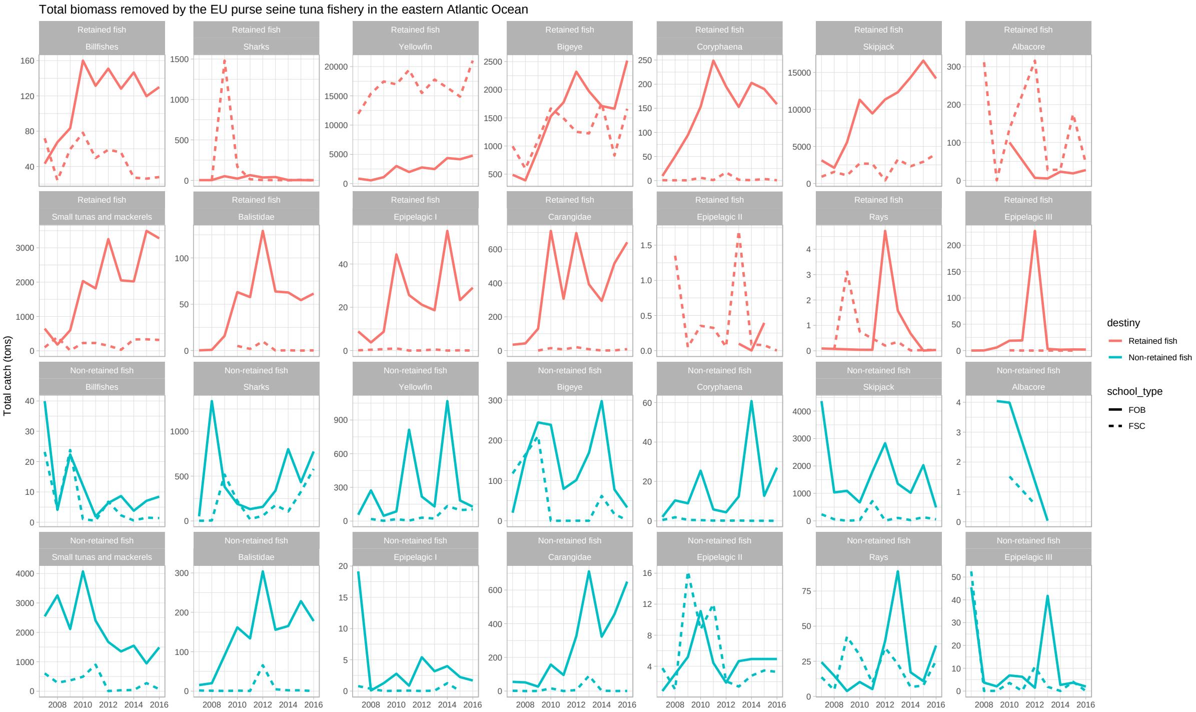


Figure 7. Trends in total removals of biomass of the EU tropical purse seine fishery by functional group and fishing mode. Total biomass removed has also been disaggregated into the retained component of the catches and non-retained component of the catches. Straight lines refer to sets on FOB whereas 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).