BYCATCH OF THE EUROPEAN, AND ASSOCATED FLAG, PURSE-SEINE TUNA FISHERY IN THE INDIAN OCEAN FOR THE PERIOD 2008-2017

Jon Ruiz [1]*, Francisco J. Abascal[2], Pascal Bach[3], José C. Baez[2], Pascal Cauquil[4], Maitane Grande[1], Iñigo Krug[5], Juliette Lucas[6], Hilario Murua[1], María L. Ramos Alonso[2], Philippe S. Sabarros[4]

SUMMARY

This paper presents an update for the period 2008-2017 of the bycatch estimations for the European and Seychelles tuna purse seine fishery operating in the Indian Ocean. Bycatch data were collected by observers onboard. Given the situation of piracy in the area, the coverage of observers decreases progressively during the first part of the series, until 2010 when the observer program was completely suspended. As of 2011, sampling was resumed, and observation coverage progressively increased; mainly thanks to the implementation of a volunteer program by the fleet. Bycatch data, as collected by the observers, were stratified by quarter, ET sampling area and fishing mode (free school and floating object sets). The total landings of the target species (skipjack, bigeye, yellowfin and albacore tunas) in each stratum was then used as raising factor. The average of the annual total bycatch estimated for the studied period was 9,188 t. However, there are differences throughout the series. More than 90% of the weight of this bycatch occurred in FOB sets. Regarding species groups, discards of target tunas represented the major part of the bycatch during the first years of the series (64% and 46% of the total bycatch in 2008 and 2009 respectively). While in the last years, the group of other bony fishes represented the majority of the bycatch (around 50%), followed by sharks (around 15%), billfishes, rays and turtles.

KEYWORDS: Bycatch, purse seining, Indian Ocean

1. Introduction

All fishing methods aim to extract wild species from the aquatic environment. When fishing, other accessory species, also known as "bycatch”, are caught in addition to the target species. The bycatch varies according to various factors, like fishing techniques, or market factors (Kelleher, 2005). Moreover, the dynamics of populations, such as seasonal migrations, high recruit’s concentrations in certain areas or spawning in certain zones and times, can change the amount of bycatch seasonally and geographically (Lart *et al*., 2002). Obtaining quantitative and qualitative information (composition by species) and its trend over time is fundamental for a better management of resources (Lart *et al.*, 2002), not only from the management of commercial stocks point of view of but also from the ecosystem management perspective.

Regarding the tropical tuna purse seine fishery, several studies provide in the past information on bycatches and discards (Peatman *et al*., 2017; Hall and Roman, 2013; Amandè *et al*., 2010; Amandè *et al*., 2011), some of them referring specifically to the European purse seine fishery operating in the Indian Ocean (Amandè *et al*., 2008; Gonzalez *et al.*, 2007).

[1] AZTI, Sukarrieta (Spain)
[2] IEO, Tenerife (Spain)
[3] IRD, Mahe (Seychelles)
[4] IRD, Sete (France)
[5] AZTI, Mahe (Seychelles)
[6] SFA, Mahe (Seychelles)

The main objective of this paper is to present an update on the bycatch estimations for the tuna purse seine fishery operating in the Indian Ocean, with the aim of understanding better the impact of the fisheries on the environment. European and Seychelles fleets data have been used. Bycatch was defined as the discard of target species (skipjack, yellowfin, albacore and bigeye tuna) plus the catch of non-target species (including neritic tunas, sharks, billfish, and other bony fishes) whatever the fate is.

2. Method

2.1. Data

The data collected by independent observers during fishing operations are commonly used to complement other data, such as those from port sampling or skippers' logbooks. For some types of data, such as bycatch and discards, observer programs can be the most reliable, and sometimes the only source of information available. Observer programs are becoming an increasingly important tool to monitor tropical tuna fisheries. In this context, under the IOTC Resolution 11/04, there is a recommendation of 5% coverage for large fishing vessels (IOTC, 2011).

European framework for the collection and management of fisheries data was established in 2000, and then reformed in 2008 resulting in the Data Collection Framework (DCF) (Council Regulation (EC) No 199/2008; Commission Implementing Decision (EU)2016/1251). Under this framework, France and Spain started in 2003 sampling, with observers onboard, the tropical purse seine fleet operating in the Indian Ocean. This sampling has been conducted in a coordinated manner since the beginning, with the collaboration of the three organisms in charge of managing observers; IRD (France), IEO (Spain) and AZTI (Spain). However, both Spain and France stopped their observer programs in 2009 due to the piracy in the area and safety reasons. No sampling was conducted during 2010, and later, EU resumed its observer program progressively in 2011. Out from the EU-DCF, observer coverage increased significantly since 2014 through private contracts between industry and scientific institutes; French fleet under the OCUP (Observateurs Communs Uniques et Permanents) program (Goujon et al., 2017) and Spanish and Seychellois fleets under the “Best practices Monitoring Program” (Lopez, et al., 2017). Observers that embark under these private monitoring programs belong mostly to SFA, but some specific trips observed by coastal countries should be added. In addition to this observer sampling coverage, an increasingly important number of trips is being covered through EMS (electronic monitoring system) since 2016. This way, total expected monitoring coverage would be close to 100%. Data for the analyses has been collected under all these different monitoring programs; however, trips observed by coastal countries and under EMS programs are excluded from this analysis, as for now these data have not been added to the human observers’ database.

Figure 1 shows the total number of sets sampled by year and school type (free school sets and sets on floating objects), and **Figure 2** shows its spatial distribution. **Figure 3** shows the number of observed trips and days by vessel flag. Overall, 29 trips were observed in 2008. The coverage progressively decreased until 2010 (when sampling was not carried out), and progressively increased again from 2011. In 2015 the coverage reaches the maximum of the series, with 193 trips and 4,769 fishing sets observed. During the last years of the series, the number of trips and sets analyzed was at around 135 and 3,500 respectively. Thus, the coverage of data varies significantly between the first years of the series, where only the DCF sampling existed, and the last ones where, through the different observer programs, the number of observed fishing operations was above 3,000. In terms of production, observed coverage is between 2-5% in the first years of the study period, and between 10-45% in the most recent years **(table 1).**

2.2. Analysis and raising

Based on Amandè *et al*., (2010) bycatch was assumed to be linearly correlated with production; understood as the total landings of target tuna species (skipjack, yellowfin, bigeye and albacore). Thus, the total production of the purse seine fleet (EU_FRA, EU_SPA & SEY) was used as the ratio estimator for the raising of the total bycatch in weight. In the specific case of turtles and cetaceans, data were not raised to the fleet level, and only the number of interactions observed is presented. Extrapolated bycatch estimates are presented on a yearly basis, but raising was conducted stratified by; quarter, ET area (**Figure 1**) (Pallares & Hallier, 1997) and fishing mode (sets on floating objects (FOB) and free school sets (FSC)).

Then, let b_s be the mean bycatch on observed sets on stratum s, let p_s be the sample mean total production and let P_s be the stratum total production. The sample ratio (rs) is then

$$rs = \frac{bs}{ps}$$

Bycatch in the stratum (Bs) are estimated to be

$$Bs = Ps * rs$$

And total bycatch, $B\ (tot\ )$, across strata

$$B\ (tot) = \sum_{s} Bs$$

Then

$$Var\ (Bs) = \left(\left(1 - \frac{n_s}{N_s}\right) N_s^2 \frac{\tau_s^2}{n_s}\right.$$

Where ns and Ns are the number of samples in each stratum and all stratum, respectively.

The Variance of $B\ (tot)$ is then

$$Var\ (B\ (tot)) = \sum_{s} Var\ (Bs)$$

3. Results

The average of the annual total bycatch estimated for the studied period was 9,188 t. However, there are differences throughout the series. The average of the first two years is 17,948 t, while in the last three years it is 5,766 t. **(table 2; figure 4)**. **Figure 5** shows the same estimates by ET sampling area. In relation to the fishing mode, most of the bycatch occurs in FOB sets, representing more than 85% of the total annual bycatch in the whole period, and reaching 98% in 2008 and 2009 (**table 4**). Regarding species groups, while discards of target tunas represent the major part of the bycatch during the first years of the series (64% and 46% of the total bycatch in 2008 and 2009 respectively), in the last years the group of other bony fishes represents the majority of the bycatch (around 50%), followed by sharks (around 15%). **Table 3** shows the same values relative to 1000 t of production; an average of 43t /1000t and 7t/1000t. for FSC and FOB respectively.

3.1. Tunas

Tunas constitute an important portion of the bycatch, mainly in FOB sets. This group include both discards of target tunas and neritic or minor tunas. In both cases there are significant differences along the time series; the target tuna discard average rate of the first two years of the series was 58 t per 1000t of production, while the average from 2011 onwards was 5.9t per 1000t of production, decreasing from 2016 to below of 3 t/1000t of production (**table 3**). Similarly, average by-catch rate of neritic tunas decreased from 18.3 t per 1000t during the first two years to an average of 1.7 t/1000t for 2011-2017 (**figure 6**).

3.2. Fin-fish

Together with tunas, “other bony fish” is the group that most contribute to the total bycatch, mainly due to FOB sets (**table 3**). In terms of species composition, the number of fin fish species present within the observed fishing operations, exceeds 51 species in FOB sets and 33 species in FSC sets. However, there are a few predominant species in both cases (**figure 7**). 4 species; *Coryphaena hippurus, Elagatis bipinnulata, Canthidermis maculata and Acanthocybium solandri* are the main caught species, accounting for more than 90% of the bony fish’ total bycatch in weight, in both FSC and FOB sets.

3.3. Shark

24 whale sharks (*Rhyncodon typus*) catch events were reported by observers during the whole studied period (**table 6**); 1 caught every 585 sets. These events where particularly reported in the "Seychelles North-West" area. All whale sharks, except one, escaped from the net or were release alive almost always before the retrieval of the net. Subsequently shark group bycatch estimation did not include whale sharks.

In total terms, the estimated shark bycatch quantity is higher in FOB sets, and the annual average bycatch for the study period is around 3.82 t per 1000 t of production. On the other hand, annual average bycatch in FSC sets is 0.93 t per 1000 t of production. **(table 3**). In terms of the species composition, *Carcharhinus falciformis* is the main species, larger than 80% in weight both in FSC and FOB sets, followed by *Carcharhinus longimanus* (**Figure 8**).

3.4. Rays

Bycatches of rays are well below 1 t per 1000t of production in most of the years, both in FOB and FSC sets. However, some punctual years catches are above this value, notably in 2017, where the bycatch estimates reach a value of 7.84t /1000t production in FSC sets (**table3**). These peaks are due to punctual sets with a higher number of individuals in the catches than normal. In terms of species composition, devil rays (*Mobula spp*) are predominant (**figure 9**).

3.5. Billfish

Billfish catches accounted for around 2-3% of the total bycatch in weight in FOB sets, and 0.2-0.3 % in FSC sets (**table 4**). This supposes less than one ton of bycatch per 1000t of production in both cases (table 3). In terms of species composition, *Makaira indica and Makaira nigricans* are the predominant species (**figure 10**).

3.6. Turtles

140 turtles catch events were reported by observers during the whole studied period, 124 in FOB sets and 16 in FSC sets (**table 7**). 96.4% were released alive. In terms of species composition, olive Ridley turtle *(Lepidochelys olivacea)*, loggerhead turtle *(Caretta caretta) and* hawksbill sea turtle (*Eretmochelys imbricata)* were the main bycaught species, accounting for 29.29%, 23.57% and 22.86% of the events respectively, followed by green turtle (*Chelonia mydas) and leatherback turtle (Dermochelys coriacea)*. Regarding spatial distribution, most of the interactions were observed in Somalia (33.6% and 12.9% Somalia South and Somalia North respectively) and Seychelles (29.3% and 16.4% of the events in Seychelles North and Seychelles South respectively) (**figure 11**). The increase in the number of interactions with turtles in the most recent years is due to the increase in the observation coverage.

3.7. Cetaceans

15 cetacean catch events were reported by observers during the whole studied period (**table 5**). Most have been reported as baleen whales (*Mysticeti*), without identifying the species. A single specimen was identified as humpback whale (*Megaptera novaeangliae*). As recorded by observers, all of them were released/escaped alive almost always before the retrieval of the net.

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TABLES

Table 1. Observed coverage in terms of production

Production on observed trips										
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
FOB	8,792	2,903		1,761	3,050	2,958	17,791	85,862	75,174	81,215
FSC	3,942	1,631		612	857	1,046	8,210	32,965	14,832	13,066
Total	12,733	4,534	-	2,373	3,907	4,004	26,002	118,827	90,005	94,281
Total production										
	2,008	**2,009**	**2,010**	**2,011**	**2,012**	**2,013**	**2,014**	**2,015**	**2,016**	**2,017**
FOB	163,587	191,141	222,584	192,426	136,810	156,914	202,790	192,962	268,028	283,254
FSC	90,262	45,755	39,181	43,682	59,871	48,611	49,336	70,904	44,785	56,365
Total	253,849	236,896	261,766	236,109	196,681	205,525	252,126	263,867	312,813	339,619
Observed production coverage										
	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. Estimated total bycatch (tones) by species group and fishing mode for the period 2008-2017.

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
FOB	**20190**	**15124**	**-**	**3585**	**4966**	**8836**	**10485**	**4866**	**5169**	**5692**
Billfishes	331	33	-	77	152	164	225	175	247	274
Minor tuna	3025	3461	-	90	95	13	695	91	636	1175
Other bony fishes	2674	3495	-	2437	3272	1539	6305	2952	2794	2350
Rays	19	295	-	0	5	331	26	24	26	56
Sharks	988	865	-	560	362	597	1430	962	798	923
Target tuna (discards)	13153	6974	-	420	1080	2223	1759	660	666	851
To precise	0	0	-		1	3970	43	2	2	64
FSC	**401**	**181**	**-**	**573**	**541**	**332**	**383**	**697**	**138**	**534**
Billfishes	42	12	-	0	52	8	33	30	23	20
Minor tuna	176	3	-	9		1	88	2	7	9
Other bony fishes	17	1	-	69	331	2	119	179	21	18
Rays	27	7	-	1		4	12	27	9	442
Sharks	65	17	-	17	70	121	74	96	39	24
Target tuna (discards)	73	138	-	477	88	196	58	363	30	21
To precise		4	-						7	
Total	**20591**	**15305**	**-**	**4158**	**5506**	**9168**	**10867**	**5563**	**5307**	**6226**

Table3. Bycatch tones per 1000 t of production (BET + YFT + SKJ+ALB landed) by species group and fishing mode, for the period 2008-2017.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
FOB total BYC/1000t	**123**	**79**	**-**	**19**	**36**	**56**	**52**	**25**	**19**	**20**
Billfishes	2.02	0.17	-	0.40	1.11	1.04	1.11	0.91	0.92	0.97
Minor tuna	18.49	18.11	-	0.47	0.70	0.08	3.43	0.47	2.37	4.15
Other bony fishes	16.34	18.28	-	12.67	23.91	9.81	31.09	15.30	10.42	8.30
Rays	0.12	1.54	-	0.00	0.04	2.11	0.13	0.13	0.10	0.20
Sharks	6.04	4.53	-	2.91	2.64	3.81	7.05	4.98	2.98	3.26
Target tuna (discards)	80.41	36.48	-	2.18	7.89	14.16	8.67	3.42	2.48	3.00
To precise	0.00	0.00	-	0.00	0.00	25.30	0.21	0.01	0.01	0.23
FSC total BYC/1000t	**4**	**4**	**-**	**13**	**9**	**7**	**8**	**10**	**3**	**9**
Billfishes	0.46	0.26	-	0.01	0.86	0.16	0.67	0.42	0.52	0.35
Minor tuna	1.95	0.06	-	0.20	0.00	0.03	1.78	0.03	0.17	0.16
Other bony fishes	0.19	0.02	-	1.59	5.53	0.03	2.40	2.52	0.48	0.32
Rays	0.30	0.15	-	0.01	0.00	0.08	0.23	0.38	0.21	7.84
Sharks	0.72	0.37	-	0.39	1.17	2.50	1.51	1.35	0.88	0.43
Target tuna (discards)	0.81	3.03	-	10.91	1.47	4.02	1.17	5.12	0.67	0.37
To precise	0.00	0.09	-	0.00	0.00	0.00	0.00	0.00	0.15	0.00

Table4. Estimated bycatch percentage by fishing mode for the period 2008-2017.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
FOB	0.981	0.988	-	0.862	0.902	0.964	0.965	0.875	0.974	0.914
Billfishes	0.016	0.002	-	0.019	0.028	0.018	0.021	0.032	0.047	0.044
Minor tuna	0.147	0.226	-	0.022	0.017	0.001	0.064	0.016	0.120	0.189
Other bony fishes	0.130	0.228	-	0.586	0.594	0.168	0.580	0.531	0.526	0.377
Rays	0.001	0.019	-	0.000	0.001	0.036	0.002	0.004	0.005	0.009
Sharks	0.048	0.057	-	0.135	0.066	0.065	0.132	0.173	0.150	0.148
Target tuna (discards)	0.639	0.456	-	0.101	0.196	0.242	0.162	0.119	0.125	0.137
To precise	0.000	0.000	-	0.000	0.000	0.433	0.004	0.000	0.000	0.010
FSC	0.019	0.012	-	0.138	0.098	0.036	0.035	0.125	0.026	0.086
Billfishes	0.002	0.001	-	0.000	0.009	0.001	0.003	0.005	0.004	0.003
Minor tuna	0.009	0.000	-	0.002	0.000	0.000	0.008	0.000	0.001	0.001
Other bony fishes	0.001	0.000	-	0.017	0.060	0.000	0.011	0.032	0.004	0.003
Rays	0.001	0.000	-	0.000	0.000	0.000	0.001	0.005	0.002	0.071
Sharks	0.003	0.001	-	0.004	0.013	0.013	0.007	0.017	0.007	0.004
Target tuna (discards)	0.004	0.009	-	0.115	0.016	0.021	0.005	0.065	0.006	0.003
To precise	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Total	1.000	1.000	-	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 5. Number of events with cetaceans observed during the period 2008-2017

	(2008-20012)	2013	2014	2015	2016	2017
FOB	**0**	**0**	**0**	**0**	**0**	**0**
FSC	**0**	**11**	**3**	**1**	**0**	**0**
Megaptera novaeangliae			1			
Mysticeti		11	2	1		
Total	**0**	**11**	**3**	**1**	**0**	**0**

Table 6. Number of whale shark catches observed by ET area during the period 2008-2017

AREA	2008	2009	(2010-2012)	2013	2014	2015	2016	2017	Total
Canal du Mozambique	3						1		**4**
Seychelles Nord-Ouest				1	4	1	3	1	**9**
Seychelles Sud-Est					3		2		**5**
Somalie Sud		1		1			1	2	**5**
Total	**3**	**1**	**0**	**2**	**7**	**1**	**7**	**3**	**24**

Table7. Number of turtle catches observed (not raised) and their fate, by ET area during the period 2008-2017

	2008	2009	2011	2012	2013	2014	2015	2016	2017	Total
FOB										
Discarded alive	**11**	**2**	**1**	**2**	**4**	**11**	**17**	**24**	**47**	**119**
Caretta caretta	5				1	4	3	5	12	30
Chelonia mydas		1			1	2	5	1	8	18
Eretmochelys imbricata	2		1	1		2	4	11	2	23
Lepidochelys olivacea	4				1	2	4	4	24	39
Non identified turtle		1		1	1	1	1	3	1	9
Discarded dead							**1**	**2**	**2**	**5**
Chelonia mydas							1			1
Eretmochelys imbricata								1	2	3
Non identified turtle								1		1
FSC										
Discarded alive	**1**		**1**			**1**	**3**	**5**	**5**	**16**
Caretta caretta						1	1		1	3
Chelonia mydas			1					1	1	3
Dermochelys coriacea							1	1		2
Eretmochelys imbricata							1	3	2	6
Lepidochelys olivacea	1								1	2
Total	**12**	**2**	**2**	**2**	**4**	**12**	**21**	**31**	**54**	**140**

FIGURES

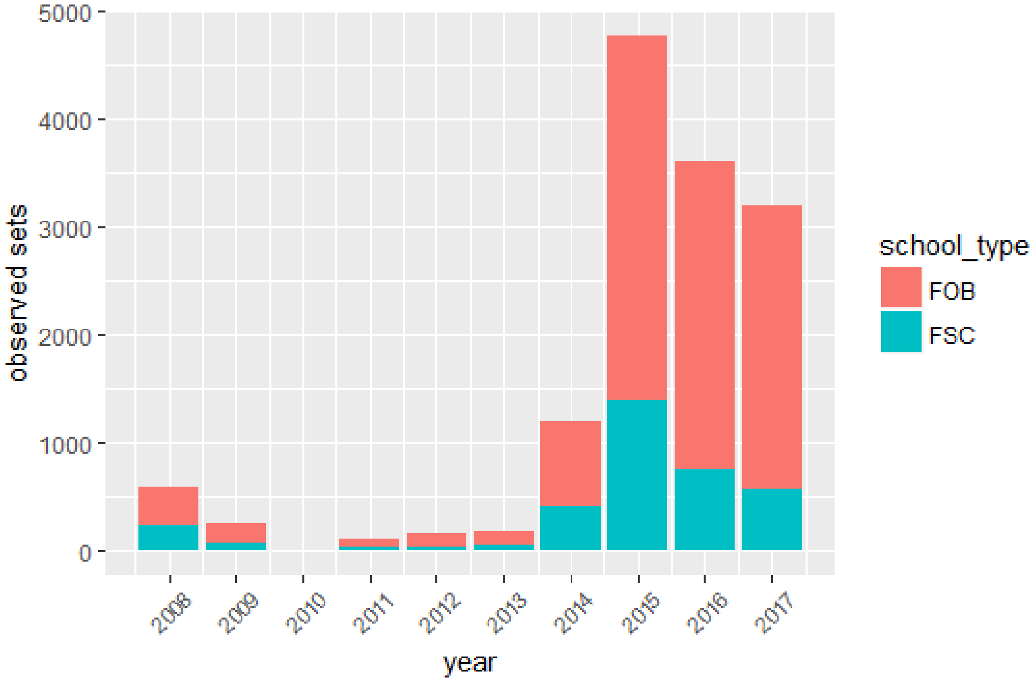

Figure 1. Number of sets observed by fishing mode during the period 2008-2017 (FOB: sets on floating objects; FSC: sets on free schools)

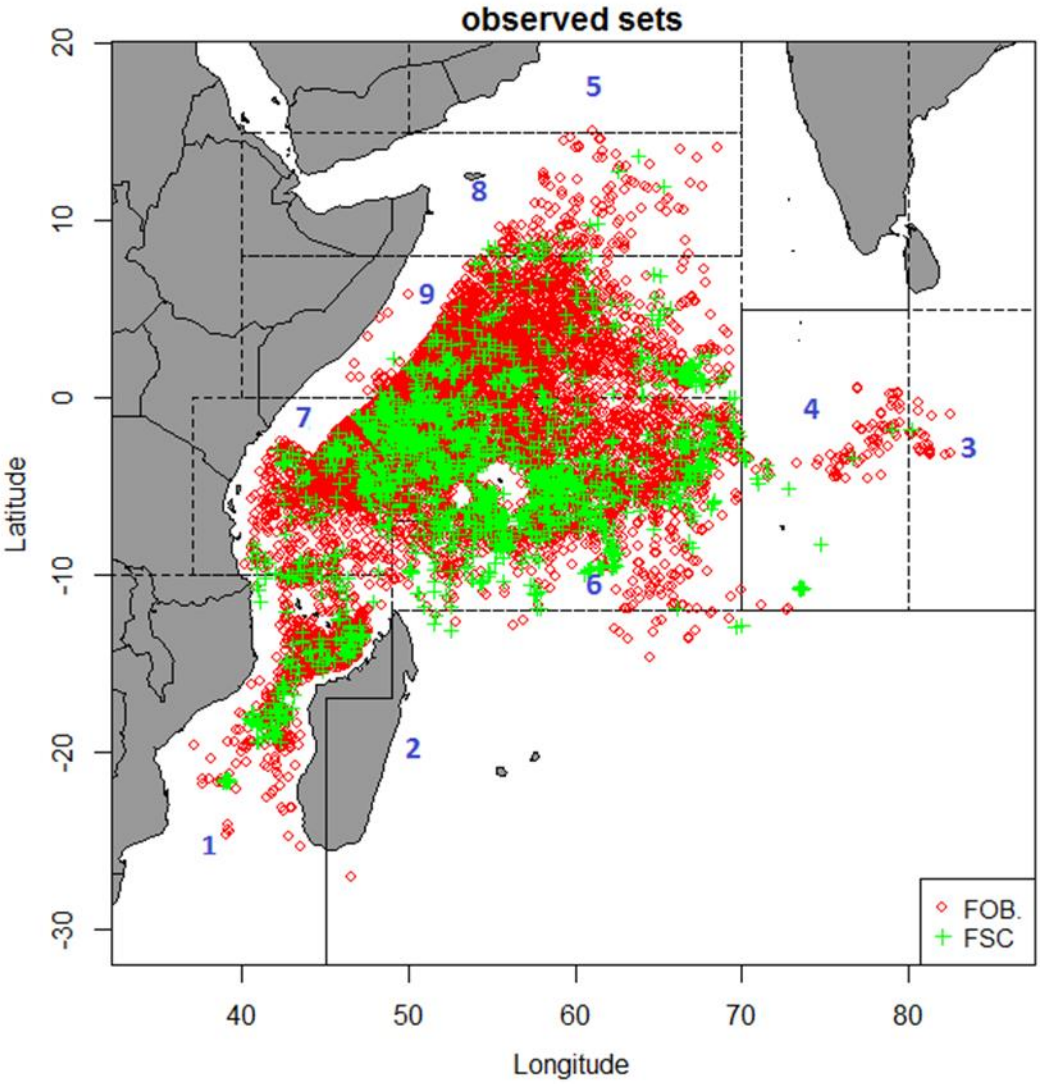

Figure 2. Distribution of the observed sets during the 2018.2017 period by ET sampling area; (1) “Mozanbique_Channel”, (2)"South_India", (3) "Indonesia_west",(4)"Maldives_Chagos", (5) "Arabian_Sea" (6) "Seychelles_north-west", (7) "Seychelles_south-east", (8) "Somalia_north" and (9) "Somalia_south". Sets on floating objects (red) and sets on free schools (green).

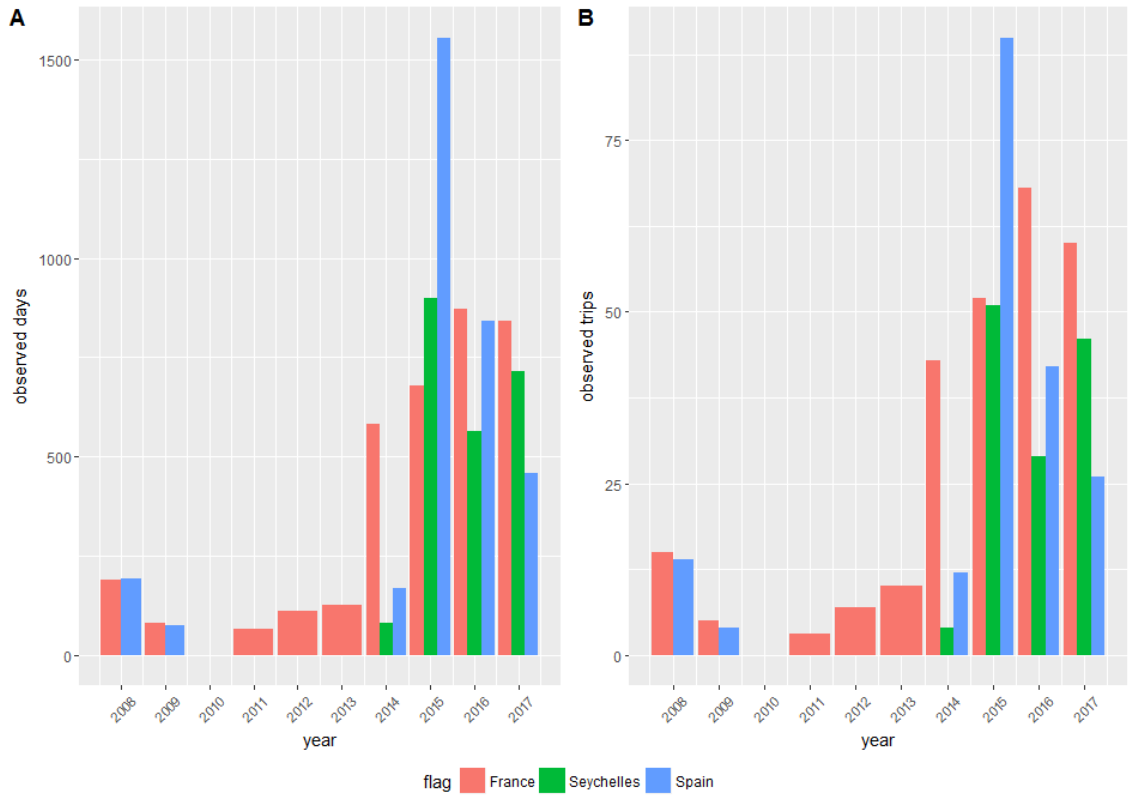

Figure 3. Number of days (A) and trips (B) observed by year and flag during the period 2008-2017.

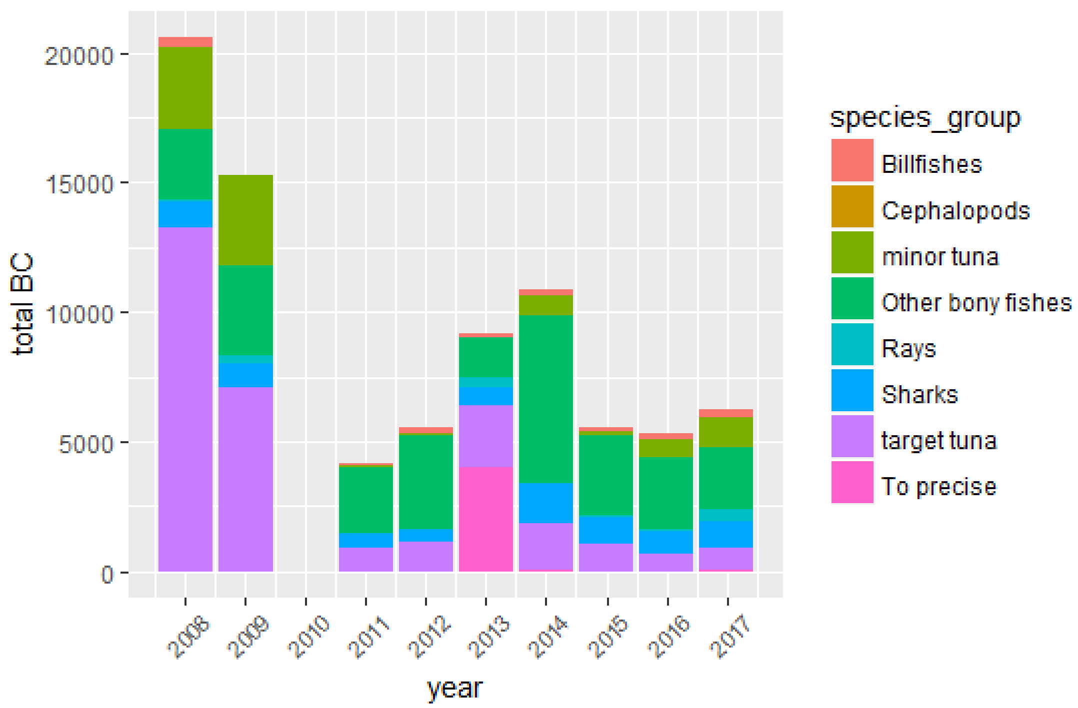

Figure 4. Total estimated bycatch (tons) by species group for the period 2008-2017.

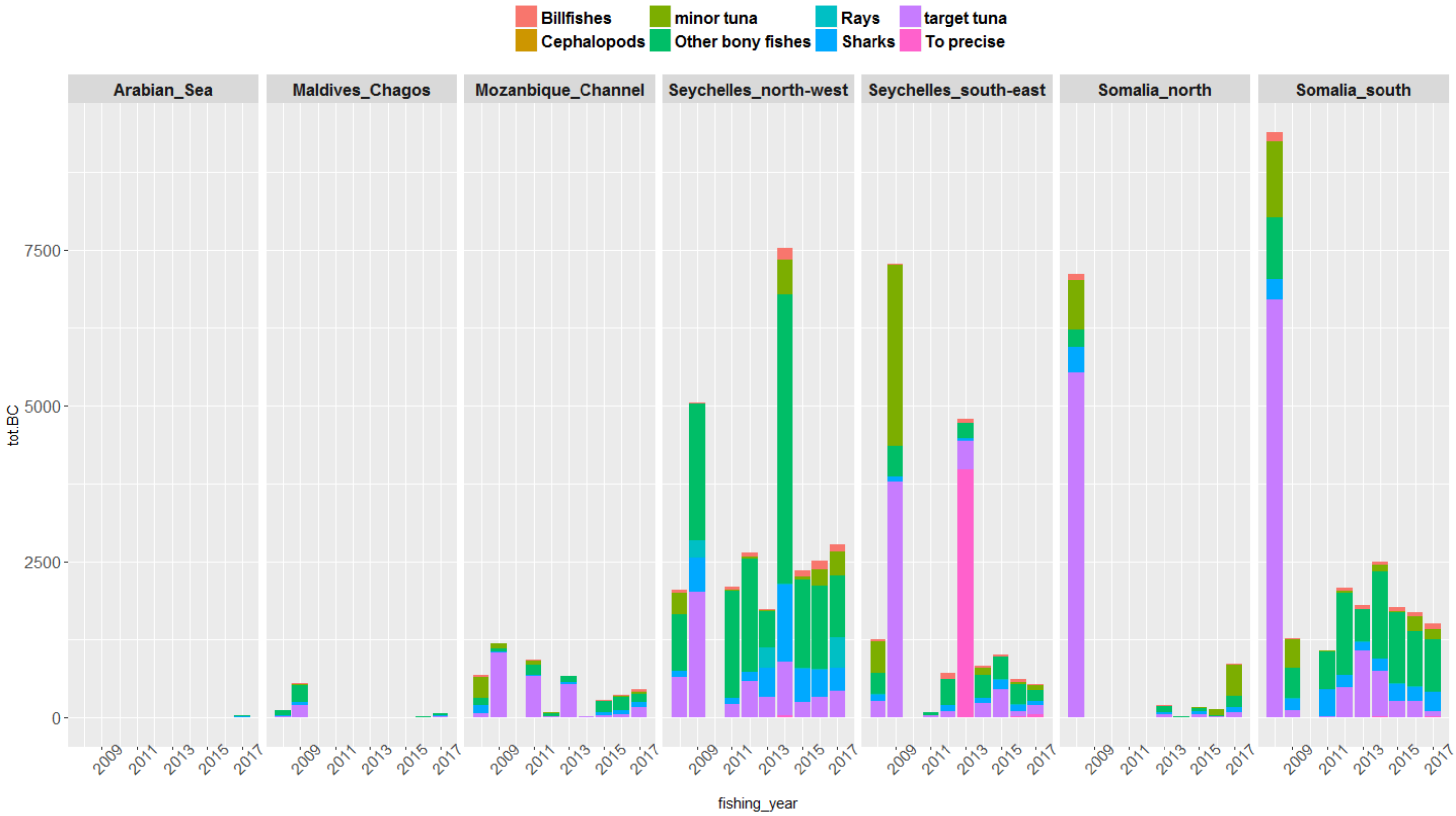

Figure 5. Total estimated bycatch (tons) by species group and ET area, for the period 2008-2017.

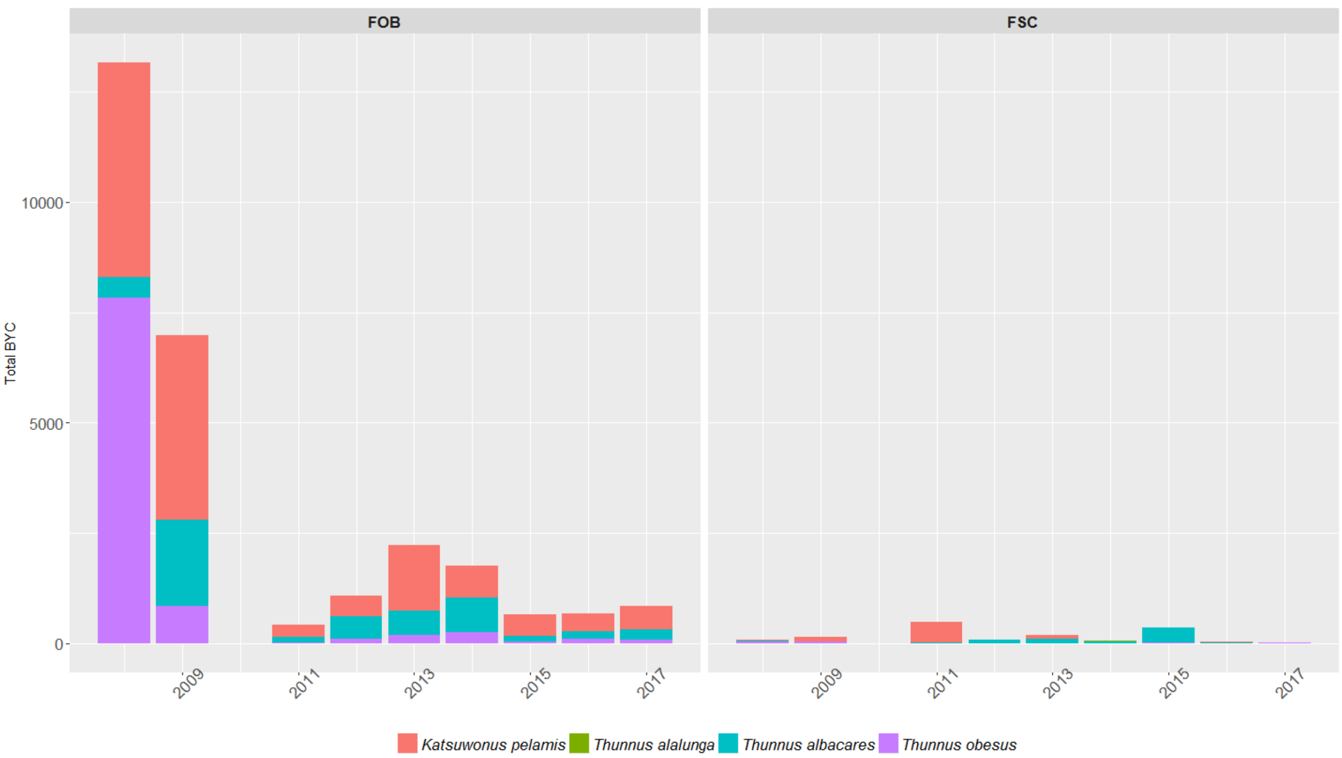

Figure6. Target tuna discards species composition by fishing mode for the period 2008-2017.

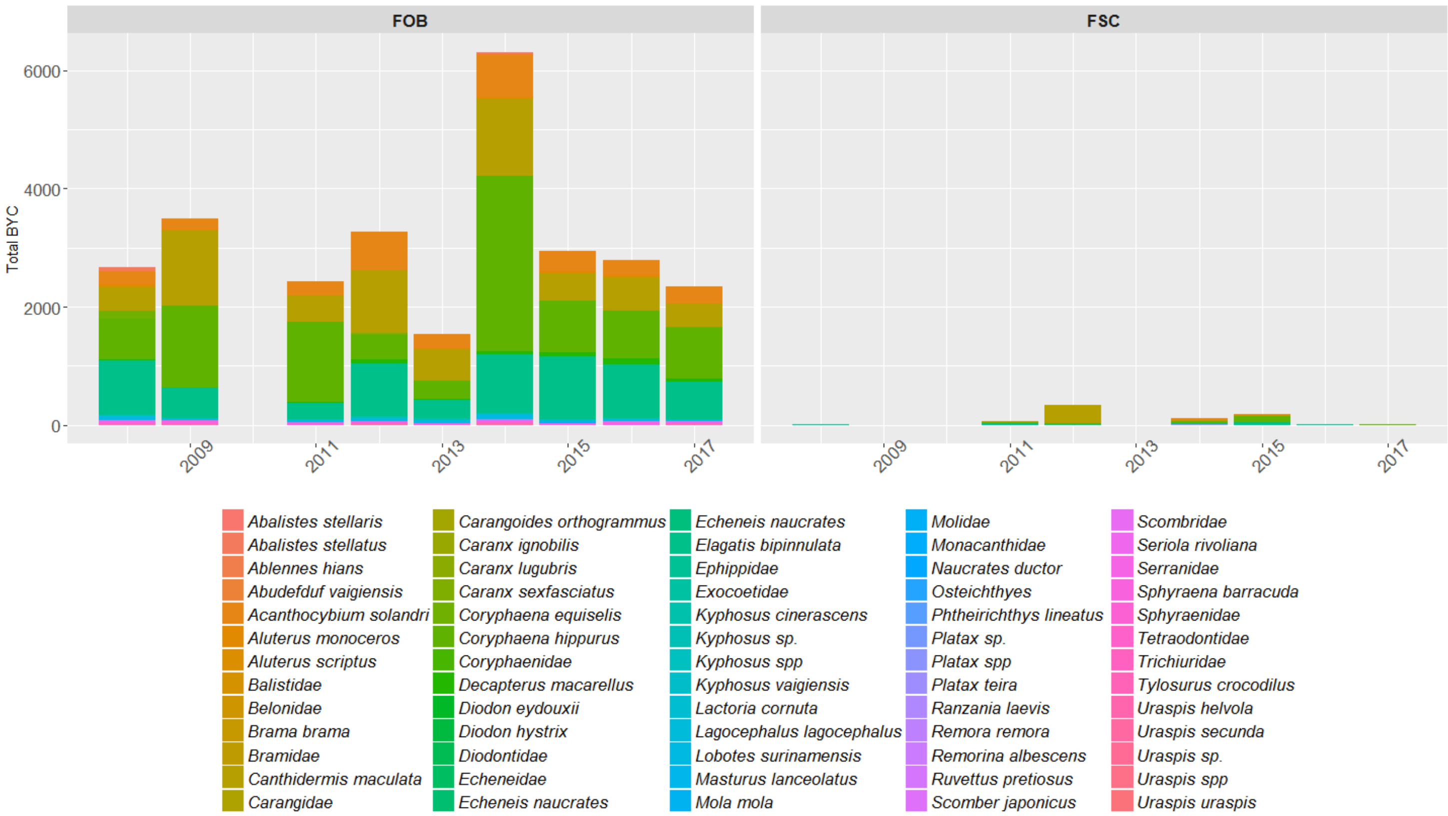

Figure7. Other bony fish species composition by fishing mode for the period 2008-2017.

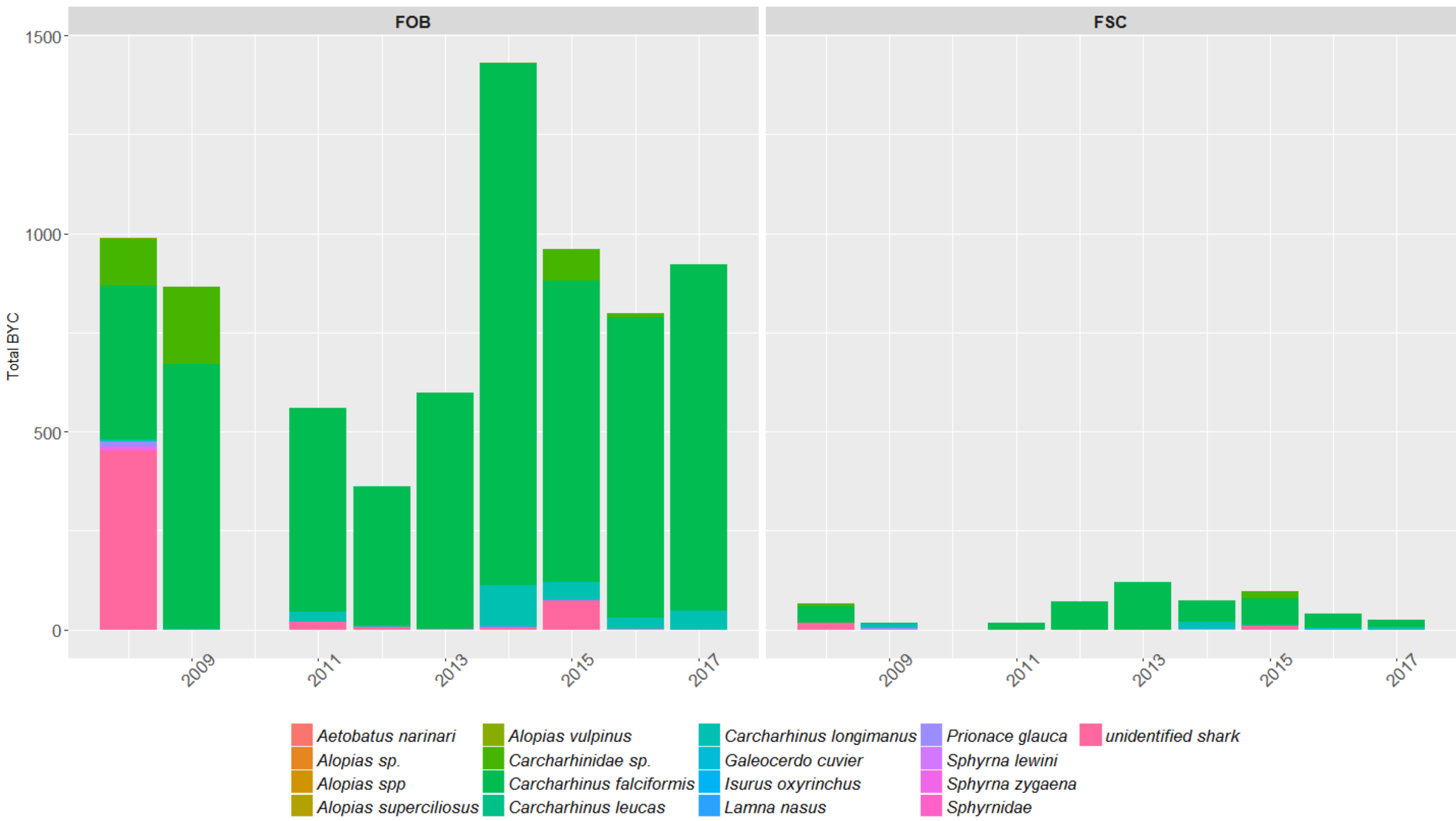

Figure8. Sharks species composition by fishing mode for the period 2008-2017.

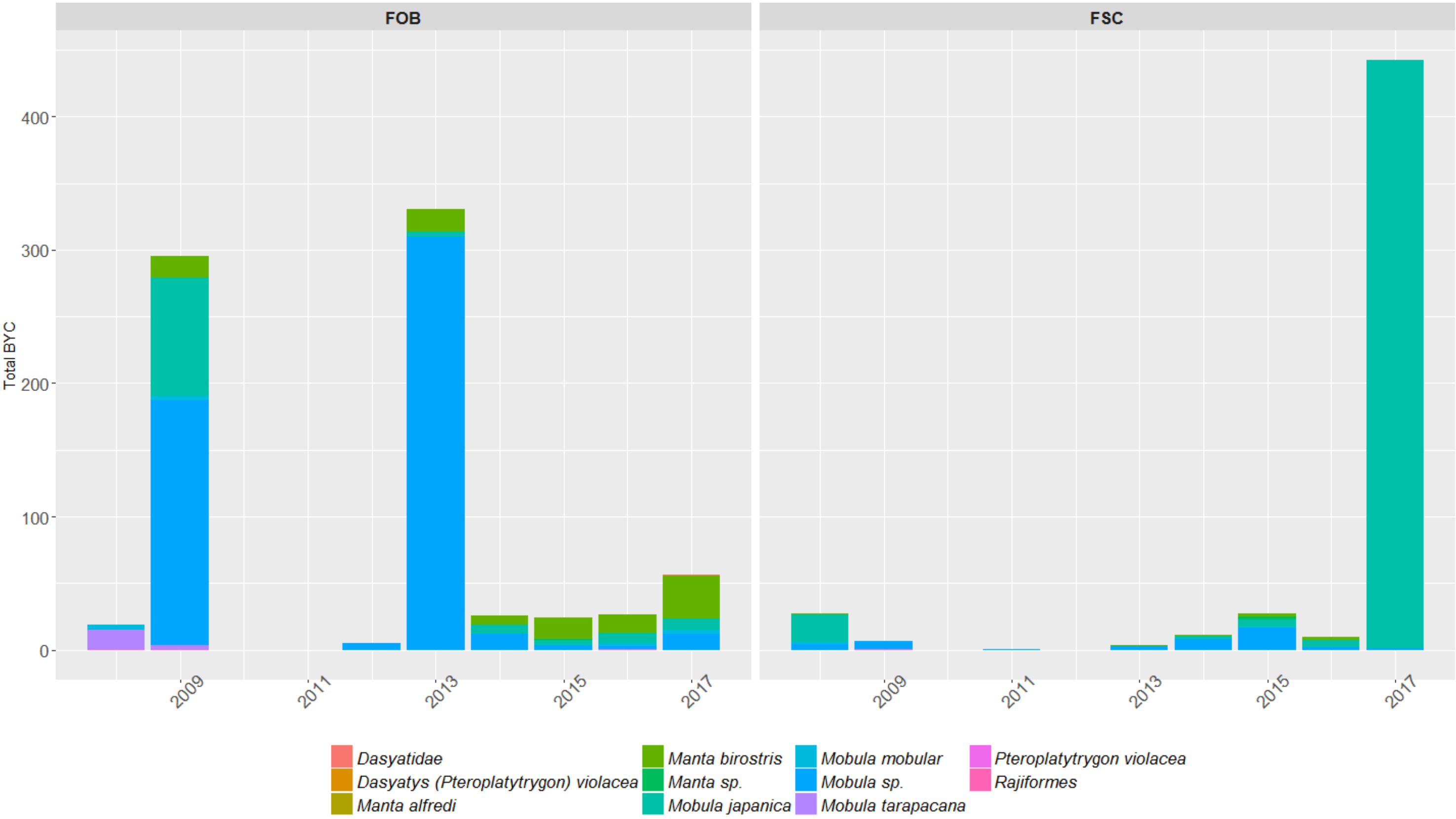

Figure9. Rays species composition by fishing mode for the period 2008-2017.

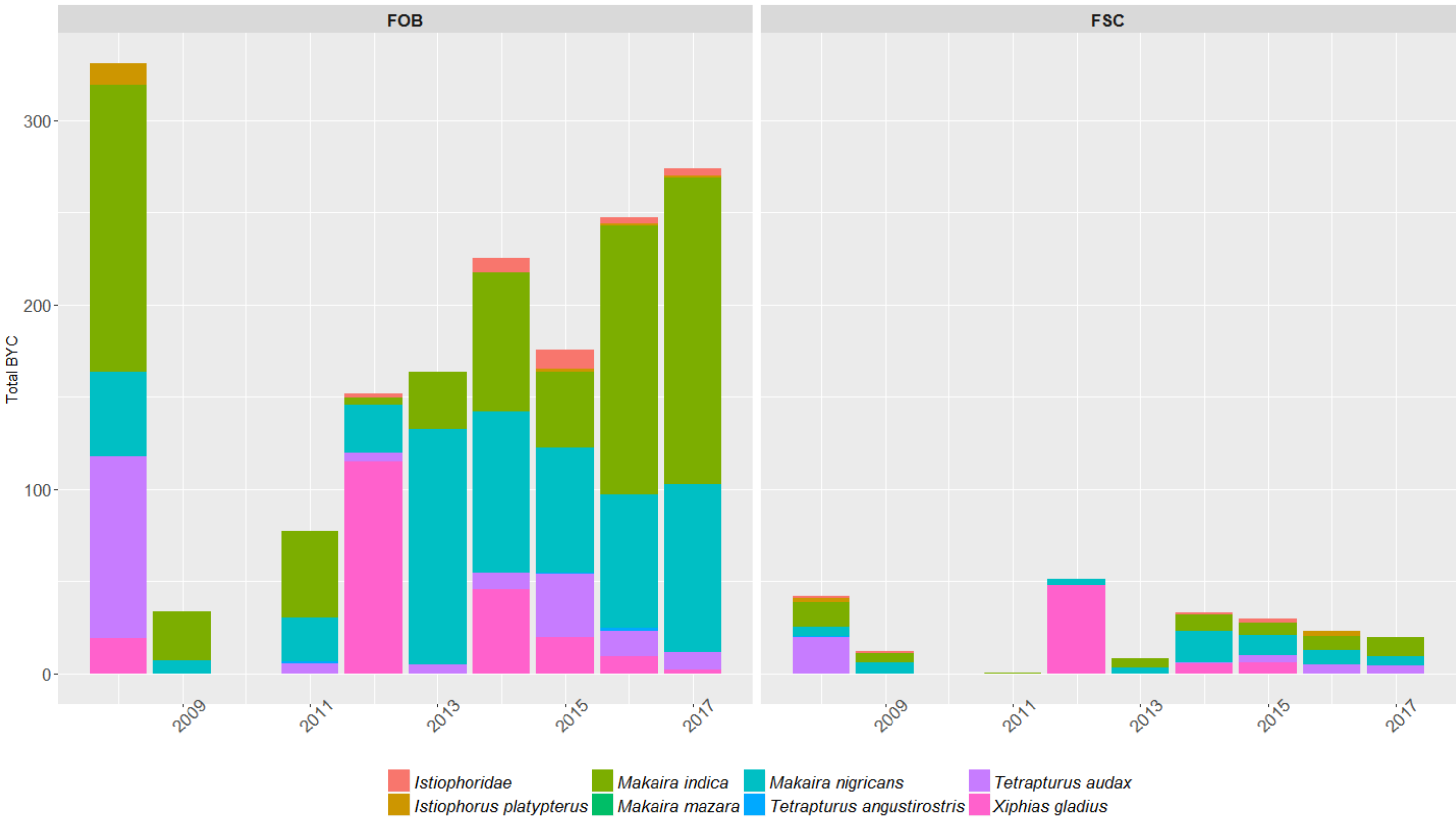

Figure10. Billfishes species composition by fishing mode for the period 2008-2017.

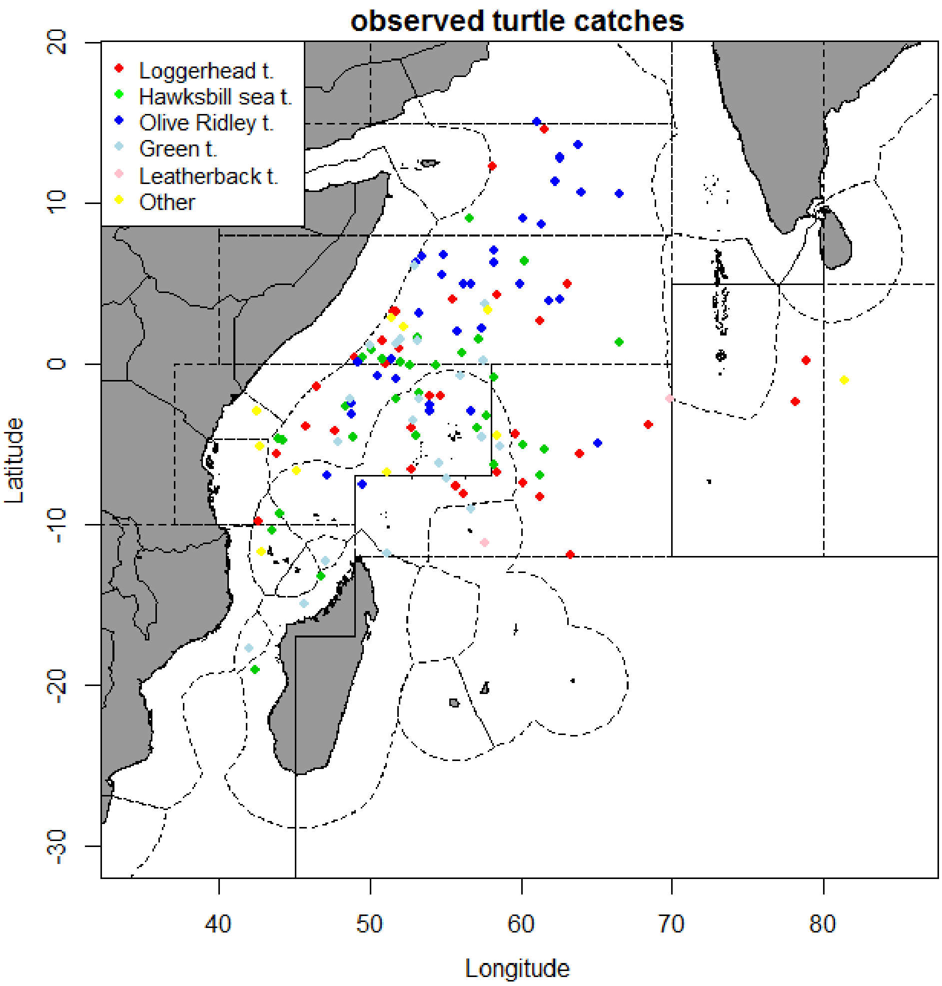

Figure 11. Observed interactions with sea turtles during the period 2008-2017.