

Bycatch of Istiophoridae species in French purse-seine fishery in the Indian Ocean (2005-2015)

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ABSTRACT. French purse-seiners operating in the western Indian Ocean mainly target tuna species (yellowfin tuna *Thunnus albacares* and skipjack tuna *Katsuwonus pelamis*) in free schools or under FADs, and occasionally catch billfishes: black marlin *Makaira indica*, blue marlin *Makaira mazara*, striped marlin *Tetrapturus audax*, Indo-Pacific sailfish *Istiophorus platypterus*, and shortbill spearfish *Tetrapturus angustirostris*. We intend in this paper to provide an overview of the data on Istiophoridae species collected by sea-going observers on French purse-seiners in the framework of DCF and OCUP programs between 2005 and 2015 in the western Indian Ocean. We present in this document (i) the number and weight (in tons) observed of each species, (ii) species composition, (iii) the occurrence of each species in FAD-associated versus tuna free school fishing operations, (iv) the spatio-temporal patterns of occurrence of billfishes, (v) yearly raised nominal catch in tons for each species including confidence intervals, and (vi) size-frequency data for each species.

KEYWORDS. Istiophoridae | Billfishes | Purse-seine fishery | FAD | Size-frequency | Western Indian Ocean

1. Introduction

French purse-seiners operate in tropical waters of the western part of the Indian Ocean. They mainly target tuna species such as yellowfin tuna *Thunnus albacares* and skipjack tuna *Katsuwonus pelamis* in free schools but also in association with natural or man-made floating objects that are acting as fishing aggregating devices (FAD) (Chassot et al., 2015).

Sets made on FADs generally contain high rates of bycatch compared to tuna free-swimming schools (FSC) that generally have lower rates of bycatch (Amandè et al., 2012; Forrestal, 2016). Bycatch include tuna species of *Auxis* genera, other frequent bony fish such as the rainbow runner *Elagatis bipinnulata* and the rough triggerfish *Canthidermis maculata*, various sharks and rays, sea turtles occasionally, and some Istiophoridae species such as the black marlin *Makaira indica* (FAO code: BLM), blue marlin *Makaira mazara* (BUM), striped marlin *Tetrapturus audax* (MLS), Indo-Pacific sailfish *Istiophorus platypterus* (SFA), and shortbill spearfish *Tetrapturus angustirostris* (SSP).

This present paper focuses on Istiophoridae species bycatch of the French tropical purse-seine fishery collected by observers. It is intended to give an overview of data managed by the *Observatoire Thonier* at the *Institut de Recherche pour le Développement* (IRD) and available for the period 2005-2015. We present in this paper: (i) the number and weight (in tons) observed of each species, (ii) species composition, (iii) the occurrence of each species in FAD-associated versus tuna free school fishing operations, (iv) the spatio-temporal patterns of occurrence of billfishes in fishing sets, (v) yearly raised weight in tons for each species including confidence intervals, and (vi) size-frequency data for each species.

2. Material and methods

2.1. Observer data

Data were collected by professional sea-going observers on French purse-seiners between 2005 and 2015 within the framework of EU-funded DCF (*Data Collection Framework*) program since 2005, and OCUP (*Observateur Commun Unique et Permanent*) since 2013 that is founded by *Orthongel* (Organisation of producers of frozen and deep-frozen tropical tuna). Data presented here include fishing trips under EU.France and France.OT (Mayotte) flags. Data are stored in IRD database *ObServe* (Cauquil et al., 2015). Observers focus their observations and sampling on discards of target species and non-target species. A total of 4060 fishing operations was monitored during 2005-2015. The coverage of observer data on the total of sets realized is presented in Figure 1. The distribution of FAD-associated and free-school sets is presented in Figure 2. Table 1 shows the yearly number and weight in tons of each billfish monitored by observers.

2.2. Indices of occurrence and abundance

2.2.1. Species composition

We provide a pie chart presenting the species composition of istiophorids for the period 2005-2015 (Fig. 3). Unidentified billfish are pooled under “BIL”.

2.2.2. Species fate

The fate of caught billfishes is presented in Figure 4. The category “kept” corresponds to individuals that were used for cooking onboard or dry/smoked preparations.

2.2.3. Occurrence in FAD-associated and free-school sets

We provide in Figure 5 the distribution of FAD-associated (FAD) and free-school (FSC) sets where at least one of Istiophoridae species occurred. The proportion of individuals of each species in FAD versus FSC sets is shown in Figure 6.

2.2.4. Spatio-temporal patterns of Istiophoridae species occurrence

Figures 7 and 8 show respectively the quarterly and yearly distributions of fishing sets where billfishes were present throughout 2005-2015.

2.2.5. Raised nominal catch

The observed weight in tons of the respective Istiophoridae species were raised according to the coverage of observer data on the total of fishing operations realized with a stratification including the year and the type of school (i.e., FAD and FSC).

The raised nominal catch and 95% confidence interval for each species were calculated by a bootstrap procedure. The bootstrap consisted in resampling with replacement (Manly, 2006) a proportion of fishing operations each year equal to the observer coverage the same year (see Fig. 1). This procedure was repeated 1000 times. The median yearly values were used as the raised nominal catch in tons. During years where the observer coverage was low, the confidence interval are expected to be larger than years where observer coverage was more important. Figure 9 shows raised nominal catch of Istiophoridae species except for shortbill spearfish for which occurrence in sets was too low.

2.3. Length frequency data

Individuals that are to be discarded are measured by observers when possible. For billfishes, the lower-jaw fork length (LJFL) is generally taken. The number billfishes that were caught and measured each year is presented in Table 2. We also provide for each species, the size-frequency distribution

of LJFL measurements made between 2005 and 2015, including yearly boxplot distributions showing minimum, first quartile, median, third quartile, maximum values, and outliers (Fig. 10).

3. Results

3.1. Species composition and fate

During 4060 fishing operations monitored between 2005 and 2015, 854 istiophorids were caught (Tab. 1), with among them: 45% of black marlin, 32% of blue marlin, 9% of striped marlin, 5% of Indo-Pacific sailfish, 1% of shortbill spearfish, and 8% of unidentified istiophorids BIL (Fig. 3).

Fifty one percent of the billfishes were discarded dead and 3% discarded alive. The rest (46%) was retained for cooking onboard or various dry/smoked preparations (Fig. 4).

3.2. Billfishes in FAD versus FSC sets

Eighteen percent of FAD-associated sets had at least one billfish compared to 9% in the case of free-swimming tuna school sets (Fig. 5). Unlike the other Istiophoridae species that appear more often present in FAD sets (between 60 and 80% depending on the species), the Indo-Pacific sailfish occurred more often in tuna free-school sets (Fig. 6).

3.3. Spatio-temporal patterns of billfishes occurrence

The proportion of sets with istiophorids varied between 10% and 19% across the year with no spatial pattern in the distribution of sets with istiophorids associated with the quarter of the year (Fig. 7).

Sets with billfishes varied between 7% and 20% throughout 2005-2015. The occurrence of billfishes in sets do not show any spatial patterns across years (Fig. 8).

3.4. Raised nominal catch in tons

The raised nominal catch in tons is presented for black marlin, blue marlin, striped marlin and sailfish (Fig. 9). The resampling of the bootstrap procedure could not be done in 2005 and 2010 were the observer coverage was too low (1%; Fig. 1).

The raised nominal catch of each species shows variations throughout the period and the confidence intervals are rather large (Tab. 1; Fig. 9). BLM nominal catch fluctuated between 12 and 66 tons and showed a decreasing trend throughout 2005-2015. MLS and SFA displayed a comparable pattern with variations respectively comprised between 6 and 164 tons, and less than 1 ton and 4 tons. Contrastingly, BUM nominal catch exhibited an increasing trend over the period considered (2005-2015) while fluctuation between 3 and 45 tons.

3.5. Length frequency distribution

The mean LJFL for black marlin, blue marlin, striped marlin, Indo-Pacific sailfish and shortbill spearfish are respectively 235, 231, 219, 160, and 120 cm (Tab. 2 and Fig. 9). There was no trend in size evolution throughout 2005-2015 for all 5 Istiophoridae species (Fig. 9).

4. Discussion

4.1. Species composition

Black and blue marlins are the most common billfishes in French purse-seine fishery while Indo-Pacific sailfish and shortbill spearfish are rather uncommon. Only 8% billfish could not be identified which is mostly due to the fact that large billfish individuals are directly released by the crew before the observer can take a good look at them.

4.2. Billfishes in FAD versus FSC sets

Billfish species most often occur in FAD-associated sets as generally found in the literature (e.g., Gaertner et al., 2002; Amandè et al., 2012; Forrestal, 2016) except for the Indo-Pacific sailfish, suggesting that the Indo-Pacific sailfish does not aggregate around FADs but rather follows free-swimming schools of yellowfin tuna.

4.3. Spatio-temporal patterns of billfishes occurrence

Billfishes do not exhibit marked spatial and temporal distribution patterns in the western Indian Ocean suggesting they are not associated to particular areas in particular seasons.

4.4. Raised nominal catch in tons

Bootstrapped nominal catch could be calculated except for years with a very low coverage rate of sea-going observers. In 2010 for instance, as a consequence of piracy in the western Indian Ocean, very few observers were able to embark on French purse-seiners because ship-owners preferred embarking French soldiers for protection against pirates.

Trends in nominal catch for the black marlin, striped marlin and sailfish are decreasing while the fishing power and effort of French purse-seiners has been increasing, notably sets made on FADs (Maufroy et al., 2015). This suggests that the abundance of billfish species has certainly decreased during the past decade as it was demonstrated using data from other fisheries (e.g., longline fishery; IOTC, 2015).

Raised nominal catch for each species reveal that raising observed catch data from poorly represented species such as Istiophoridae species brings wide interval of confidence suggesting caution with this

kind of data and the strict necessity to provide confidence intervals with raised data. However, confidence intervals of estimations from observer data improve with increase observer data coverage. In the Indian Ocean, the coverage by observer programs was 43% in 2015 and this is expected to improve in the next years thanks to OCUP program that is founded by the fishing industry and that complements EU-founded observer program. In the Atlantic Ocean the observer coverage is already at 100% since 2014 (source: IRD).

4.5. Length data

Marlins (black, blue and striped) caught by purse-seiners are larger specimens than the ones caught by French longliners operating in the southwestern part of the Indian Ocean, i.e., south to purse-seiners operating area, while the Indo-Pacific sailfish and shortbill spearfish are smaller (Chevallier et al., 2015).

5. References

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6. Tables

Table 1. Summary table of yearly number and weight in tons of Istiophoridae species monitored by observers on French purse-seiners between 2005 and 2015, percentage of sets where species occurred, and raised nominal catch in tons with 95% confidence interval.

FAO code	Scientific name	Year	Observed number	Observed weight	% of sets with species	Raised weight	Inf. CI	Sup. CI
BLM	<i>Makaira indica</i>	2005	2	0.212	8.33	-	-	-
		2006	11	0.975	5.36	40.185	7.238	121.172
		2007	29	2.024	3.43	18.084	1.708	64.24
		2008	111	8.817	12.16	65.86	11.845	205.61
		2009	12	0.968	5.37	33.15	6.545	127.2
		2010	2	0.137	13.33	-	-	-
		2011	26	3.393	6.86	35.25	3.084	96.002
		2012	15	1.722	3.93	12.419	2.295	53.331
		2013	31	3.121	6.49	20.191	3.315	55.011
		2014	79	6.48	6.21	19.905	8.72	32.116
		2015	66	5.84	4.13	14.098	6.531	23.368
BUM	<i>Makaira nigricans</i>	2005	0	0	0	-	-	-
		2006	0	0	0	-	-	-
		2007	3	0.204	0.74	3.972	1.89	15.083
		2008	3	0.525	0.81	14.888	8.631	32.9
		2009	12	1.728	6.71	29.62	4.668	164.367
		2010	0	0	0	-	-	-
		2011	13	1.37	3.27	17.335	2.756	82.177
		2012	22	2.452	5.06	18.483	3.013	60.5
		2013	55	6.733	10.91	44.592	10.951	106.231
		2014	79	9.819	7.52	29.782	16.043	46.981
		2015	85	9.594	5.67	22.703	13.6	33.087
MLS	<i>Tetrapturus audax</i>	2005	0	0	0	-	-	-
		2006	1	0.363	0.6	163.168	100.621	326.337
		2007	25	7.41	4.66	53.419	5.41	183.128
		2008	2	0.726	0.27	53.681	42.715	91.258
		2009	1	0.263	0.67	95.522	59.701	197.013
		2010	0	0	0	-	-	-
		2011	9	2.092	1.96	18.834	8.026	214.003
		2012	2	0.422	0.56	15.275	7.943	30.82
		2013	6	0.836	1.04	13.221	7.685	31.782
		2014	5	1.497	0.48	6.001	1.865	14.586
		2015	22	5.442	1.44	12.798	3.767	24.655

Table 1 (continued). Summary table of yearly number and weight in tons of Istiophoridae species monitored by observers on French purse-seiners between 2005 and 2015, percentage of sets where species occurred, and raised nominal catch in tons with 95% confidence interval.

FAO code	Scientific name	Year	Observed number	Observed weight	% of sets with species	Raised weight	Inf. CI	Sup. CI
SFA	<i>Istiophorus platypterus</i>	2005	6	0.08	8.33	-	-	-
		2006	0	0	0	-	-	-
		2007	3	0.026	0.49	0.554	0.395	1.094
		2008	3	0.082	0.54	3.764	1.451	6.502
		2009	1	0.025	0.67	3.315	2.368	5.525
		2010	1	0.02	6.67			
		2011	9	0.183	1.63	2.579	0.651	9.007
		2012	7	0.079	1.12	1.542	0.691	3.353
		2013	4	0.088	1.04	1.455	0.144	3.603
		2014	4	0.015	0.24	0.116	0.052	0.19
		2015	8	0.192	0.48	0.508	0.066	1.177
SSP	<i>Tetrapturus angustirostris</i>	2005	0	0	0	-	-	-
		2006	1	0.012	0.6	5.214	2.98	10.428
		2007	0	0	0	-	-	-
		2008	1	0.01	0.27	0.839	0.65	1.293
		2009	0	0	0	-	-	-
		2010	0	0	0	-	-	-
		2011	2	0.032	0.65	2.107	0.616	3.851
		2012	1	0	0.28	0.031	0.024	0.047
		2013	0	0	0	-	-	-
		2014	0	0	0	-	-	-
		2015	2	0.01	0.1	0.069	0.064	0.074
BIL	Unidentified Istiophoridae	2005	0	0	0	-	-	-
		2006	1	0.098	0.6	43.871	29.247	153.549
		2007	4	0.158	0.98	6.272	1.982	18.542
		2008	1	0.05	0.27	3.928	2.826	5.714
		2009	1	0.05	0.67	6.63	4.736	14.641
		2010	0	0	0	-	-	-
		2011	15	0.731	3.92	11.088	2.284	33.598
		2012	6	0.261	1.69	3.712	0.628	10.197
		2013	4	0.22	1.04	3.124	1.736	8.409
		2014	12	1.185	1.31	3.645	0.556	8.129
		2015	28	3.007	2.02	6.815	1.305	14.167

Table 2. Number of billfish measured and mean size observed.

FAO code	Scientific name	Captured	Measured	Measure type	Length (cm)
BIL	Unidentified Istiophoridae	72	20	LJFL	215
BLM	<i>Makaira indica</i>	384	237	LJFL	237
BUM	<i>Makaira nigricans</i>	272	198	LJFL	231
MLS	<i>Tetrapturus audax</i>	73	71	LJFL	219
SFA	<i>Istiophorus platypterus</i>	46	23	LJFL	160
SSP	<i>Tetrapturus angustirostris</i>	7	4	LJFL	120

7. Figures

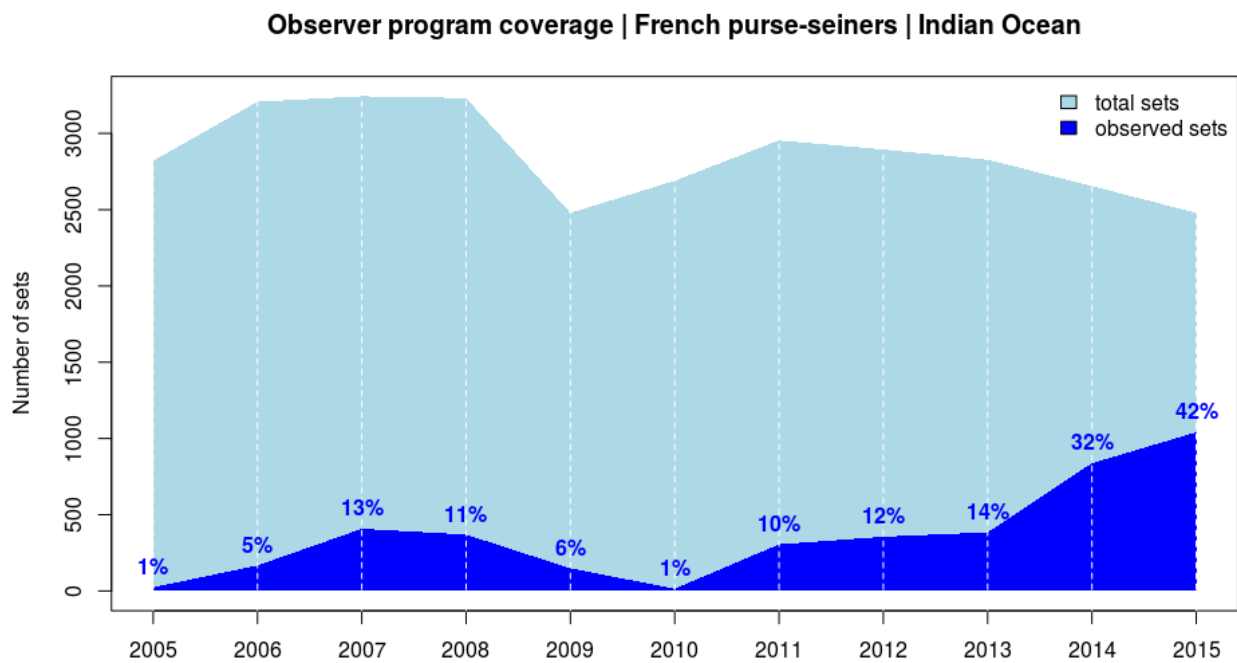


Figure 1. Observer programs (DCF and OCUP) coverage between 2005 and 2015 in the Indian Ocean.

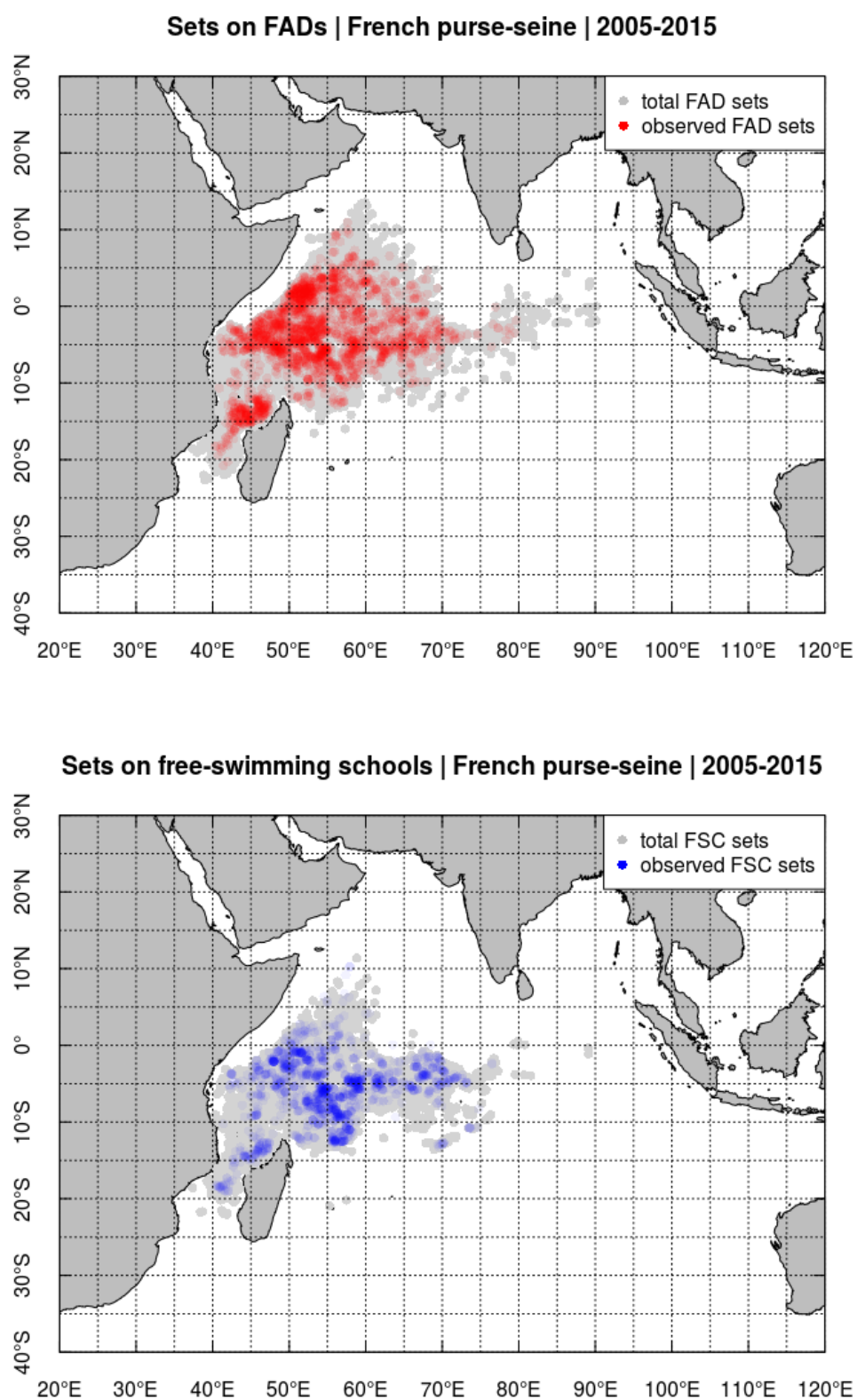


Figure 2. Distribution of observed free school and FAD-associated sets for the period 2005-2015.

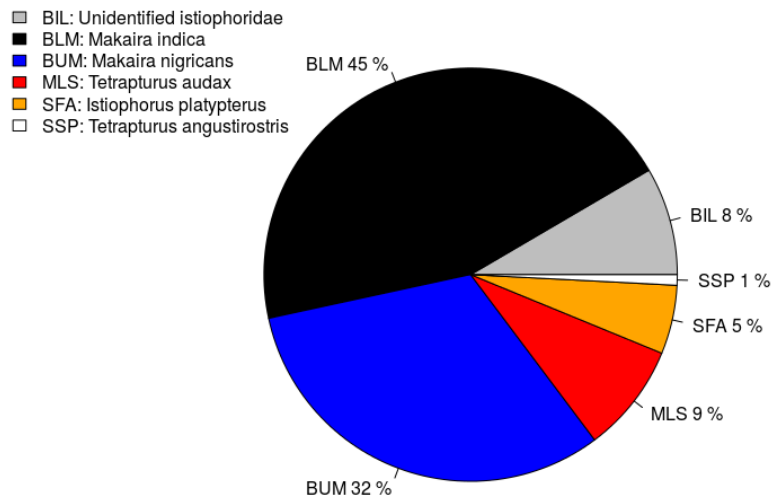


Figure 3. Istiophoridae species composition in purse-seine sets for the period 2005-2015.

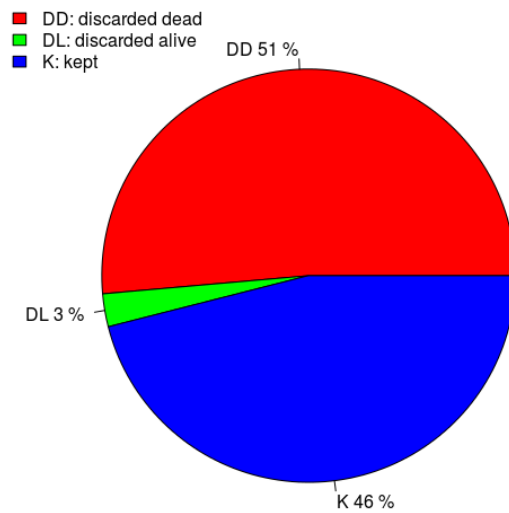


Figure 4. Istiophoridae fate in French purse-seine for the period 2005-2015.

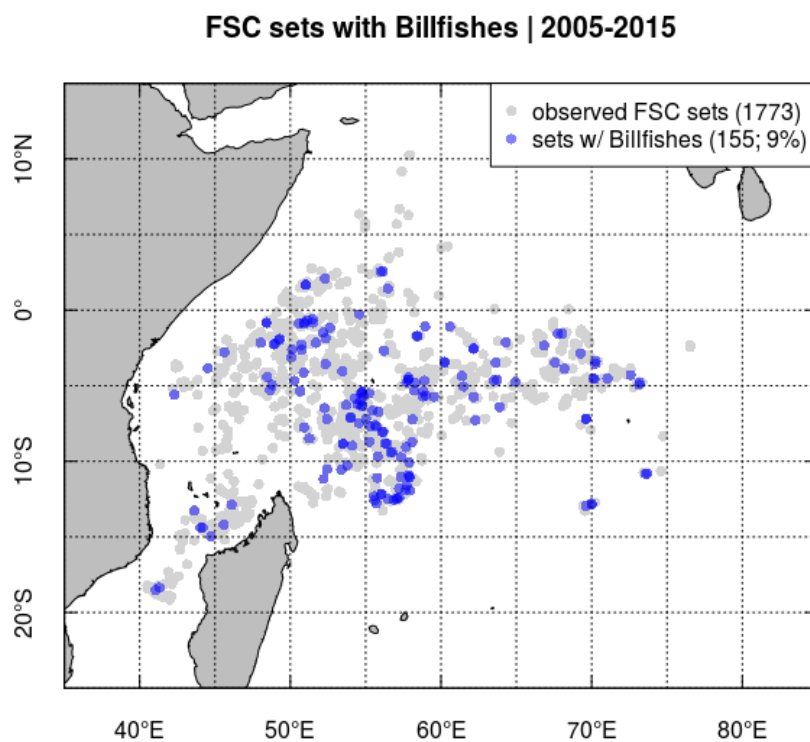
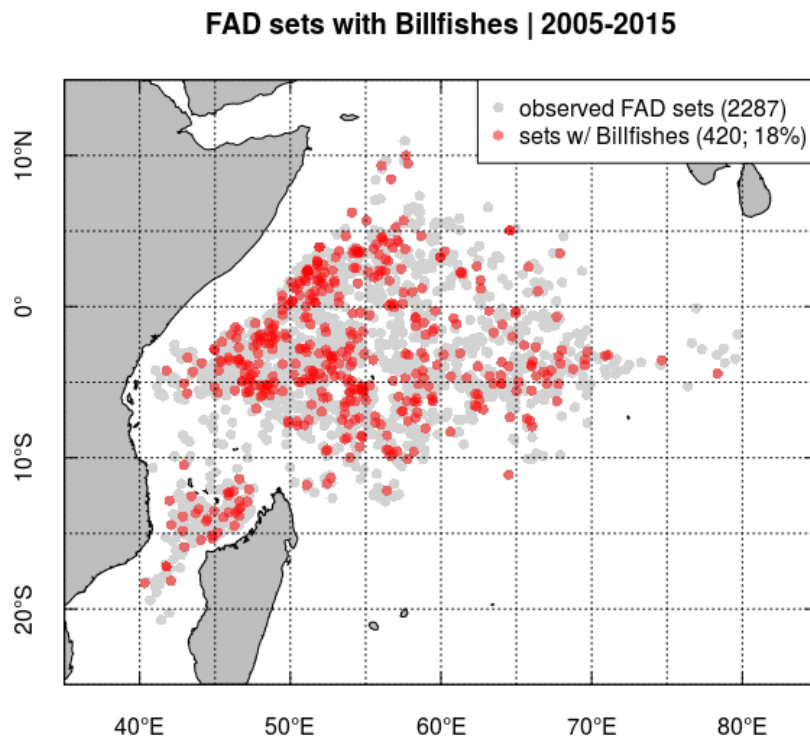


Figure 5. *Istiophoridae* species occurrence in FAD versus FSC sets.

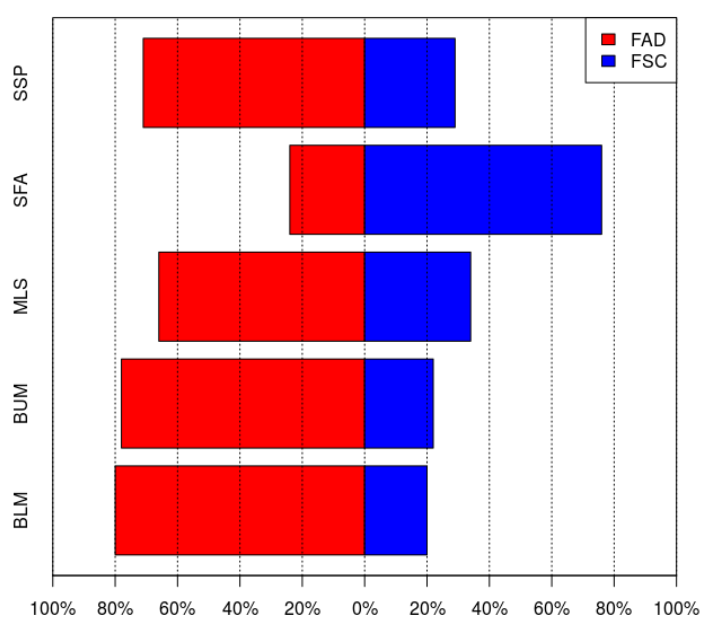


Figure 6. Relative occurrence of Istiophoridae species in FAD-associated (FAD) versus free-swimming tuna school (FSC) sets for the period 2005-2015. BLM: black marlin; BUM: blue marlin; MLS: striped marlin; SFA: Indo-Pacific sailfish; SSP: shortbill spearfish.

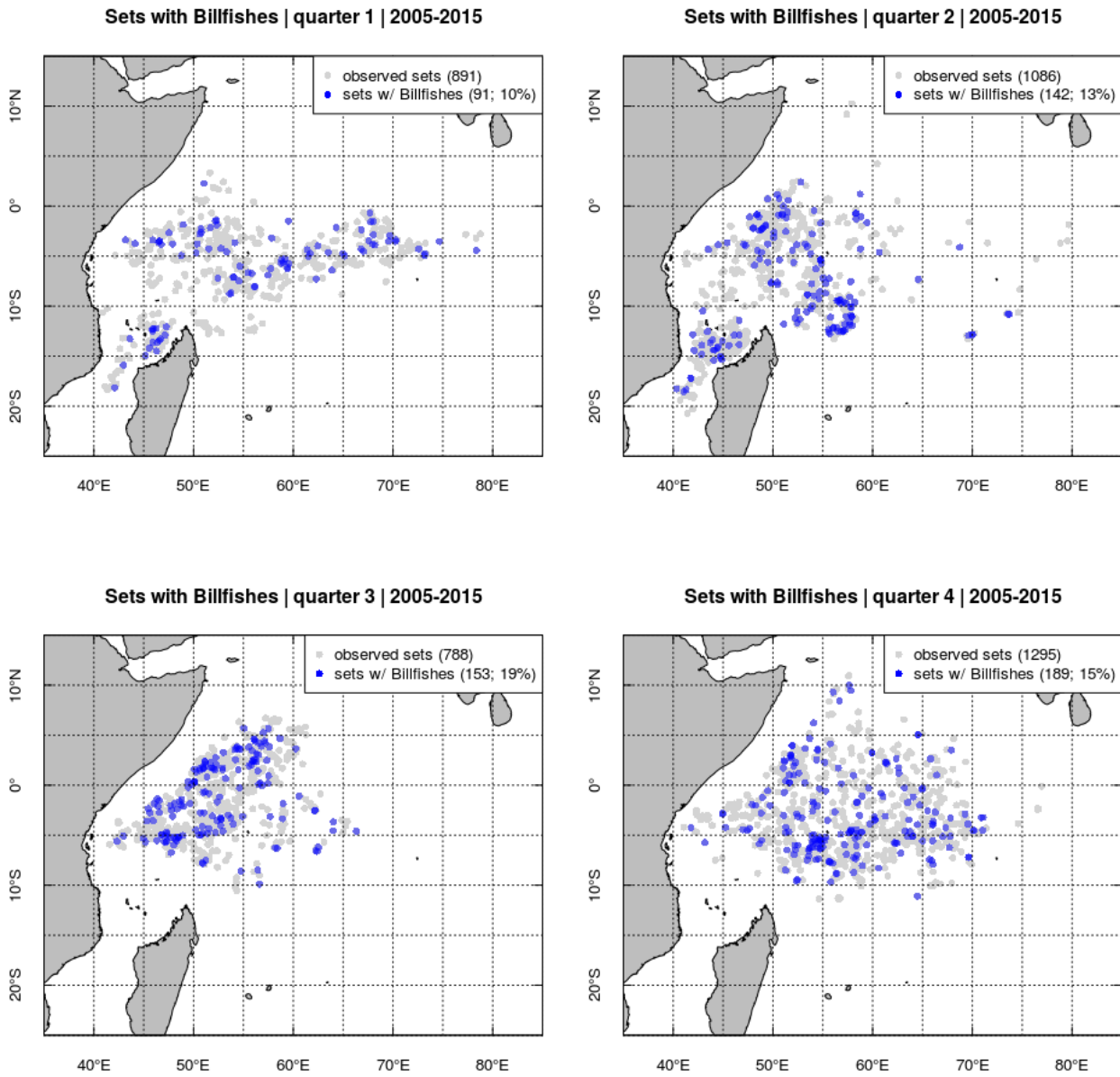


Figure 7. Quarterly distribution of fishing sets with occurrence of *Istiophoridae* species for the period 2005-2015.

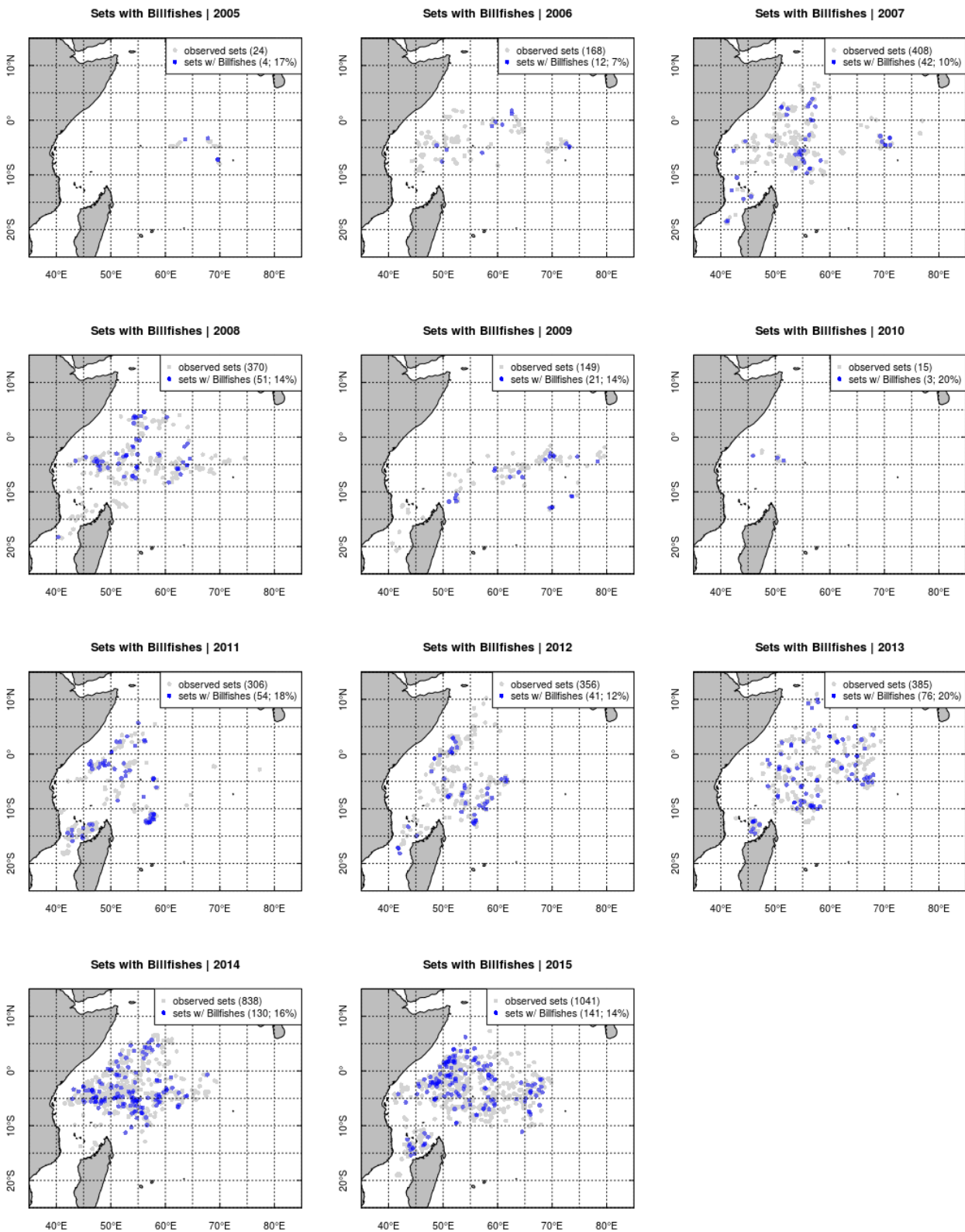


Figure 8. Yearly distribution of fishing sets with occurrence of *Istiophoridae* species for the period 2005-2015.

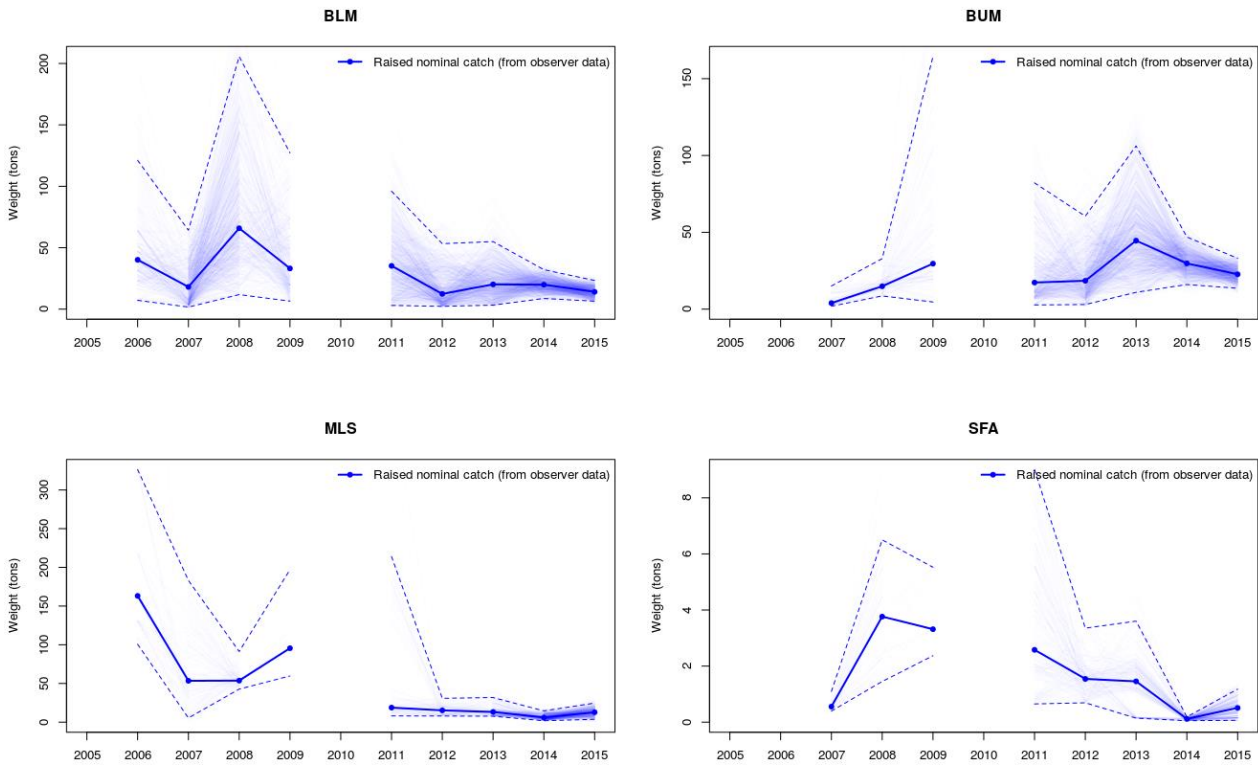


Figure 9. Raised nominal catch in tons for black marlin (BLM), blue marlin (BUM), striped marlin (MLS) and Indo-Pacific sailfish (SFA) for the period 2005-2015. The bold line is the median of bootstrapped time series, dotted lines represent the 95% confidence interval.

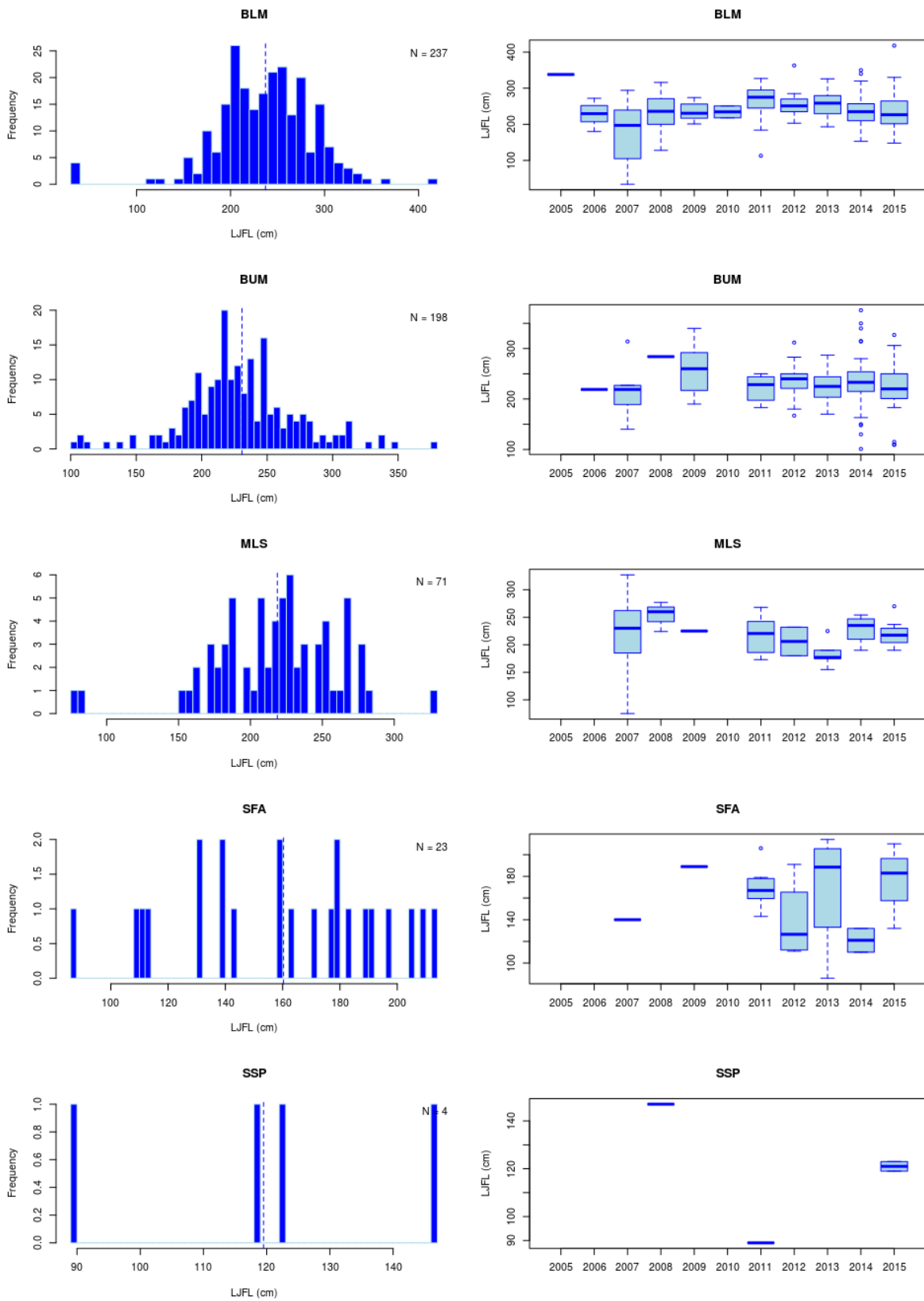


Figure 10. Overall and yearly length distributions in cm of Istiophoridae measured by observers between 2005 and 2015. LJFL = lower-jaw fork length.