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Spatio-temporal and length distributions of istiophorids in the South West Indian Ocean inferred from scientific, observer and self-reporting data of the Reunion Island-based pelagic longline fishery

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ABSTRACT. The Reunion Island longline fishery primarily targets swordfish at night but also catches tuna and istriophorids (black marlin *Makaira indica,* blue marlin *Makaira mazara*, striped marlin *Tetrapturus audax*, Indo-Pacific sailfish *Istiophorus platypterus*, and shortbill spearfish *Tetrapturus angustirostris)* often in the daytime. Using data collected by professional observers and fishermen in the framework of EU Data Collection Program between 2007 and 2014, and data collected at the occasion of scientific cruises, we intend in this paper to (i) assess the quality of billfish identification, (ii) provide spatio-temporal distributions of billfish catch per unit of effort, and (iii) length distribution for these 5 species. We found a relatively high proportion of unidentified billfish highlighting poor species recognition by some observers and fishermen in years prior to 2013. Our results demonstrate some deviation between scientist/observer data and self-reported data by fishermen for blue and striped marlins. Concerning spatio-temporal patterns of billfish catch per unit of effort, we found that higher catch per unit effort of blue and black marlin were recorded during the first and fourth quarters of the year while Indo-Pacific sailfish abundance was higher during the fourth quarter only. Shortbill spearfish and striped marlin abundance was constant throughout the year. Except for shortbill spearfish, yearly and quarterly distributions of nominal catch per unit effort for istiophorids suggests low probability of billfish bycatch. For blue and black marlin, the variation in size distribution is more important than the other species, the median length (LJFL) is about 2 m, likewise striped marlin expect some individuals exceed 3 m. Length distributions of billfish species also highlight paucity of our understanding of the biology of istiophorids. This paper provide an inventory of available data concerning billfish from various sampling programs in Reunion Island, and is intended as a starting point for further research and analyses on istiophorid biology in the South West Indian Ocean.

KEYWORDS. Istiophorids | Billfish | Longline fishery | CPUE | Length distribution | Reunion Island | South West Indian Ocean

1. Introduction

Reunion Island-based pelagic longliners that operate in the South West Indian Ocean, mainly in the French and Malagasy EEZs , primarily target swordfish *Xiphias gladius* with drifting shallow longlines that are set at night with 300 to 2000 baited hooks. As the longline is hauled in the morning additional catch of daytime predators such tuna and billfish are made; those species can also be commercialized (Bach et al., 2013, Sabarros et al., 2013). Istiophorids caught by that fleet include black marlin (*Makaira indica),* blue marlin *(Makaira mazara)*, striped marlin (*Tetrapturus audax)*, Indo-Pacific sailfish (*Istiophorus platypterus)*, and shortbill spearfish *Tetrapturus angustirostris* (Sabarros et al., 2013).

Billfish, especially marlin species, can be difficult to identify. Since 2012, an increasing effort in discriminating the different species of marlins is made by all French fisheries in agreement with the need to declare each species separately in fishing logbooks (IOTC, 2014). However, the quality of marlin species identification reported by the fishermen still have to be evaluated.

The present paper focuses on billfish bycatch data of Reunion Island longline fishery collected by scientists, professional fishery observers, and fishermen. It is intended to give an overview of data collected by the *Institut de Recherche pour le Développement* (IRD) and available for billfish between 2007 and 2014. First, we assess the quality of istiophorids species identification by fishermen involved in the self-reported data collection program. Then, we provide yearly CPUEs distributions, and size distributions of istiophorids.

2. Material and methods

2.1. Data

Longline fishing data collected between 2007 and 2014 were extracted from IRD database *ObServe* that includes data collected during (i) self-reported commercial fishing trips, (ii) observer-monitored commercial cruises, and (iii) scientific surveys undertaken by IRD and CAP RUN (Cauquil et al., 2015).

2.1.1. Self-reporting program (SRP)

IRD launched in May 2011 a self-reporting data collection program with the collaboration of CAP RUN in the framework of EU project Data Collection Framework (DCF). Data are directly collected by collaborative fishermen on their commercial trips. Information reported by fishermen using dedicated forms and templates include the description of gear rigging, fishing strategy, catch, bycatch and depredation. In return, fishermen obtain financial compensations as well as a summary of data on their own activities. The selection of collected data in the frame of the SRP corresponds to a compromise between data collected by observers, fishermen's knowledge and incentives for data reporting and current international and national legislation. In this context, data obtained from the SRP are closely similar to those collected by observer with exception of a less precise taxonomic resolution, absence of biological information (Bach et al., 2013, Cauquil et al., 2015). Also, captures are reported by lot, not by individual.

A total of 1 195 SRP fishing operations (representing an fishing effort of 1 522 764 hooks) were analyzed in this study.

2.1.2. Observer program (OBS)

The observer program of longliners based in Reunion Island was initiated in March 2007 and was developed in the frame of the European Data Collection Framework. Data collected by sea-going observers are more exhaustive than SRP. As in SRP program, data collection templates include gear rigging, fishing strategy, catch, bycatch and depredation. However, catch and depredation data are reported for individual captures (species, capture status, fate, depredation and predator group when identification was possible for each fish caught, and position along the longline), and whenever possible, biometry and biology data is collected (length, sex, stomach fullness, Bach et al., 2008, Cauquil et al., 2015).

A total of 546 OBS fishing operations representing 712 699 hooks set were analyzed in this study.

2.1.3. Scientific surveys (SCI)

Instrumented longlines are generally used during scientific cruises. Catch and depredation data collected during those surveys are more detailed than observer data; additional data such as hooking time, hooking place, sex and additional measurement data are collected (Cauquil et al., 2015).

A total of 82 SCI fishing operations, representing 48 586 hooks set, were analyzed in this paper. Those surveys concern scientific programs such as Ecological-Based Artificial Bait (EBAB), PROSpection and habitat of large PElagic fish in the EEZ of Reunion Island (PROSPER), Mitigating Adverse Ecological Impacts of Open Ocean Fisheries (MADE), CAPturability of exploited great PElagic with longliners through EEZ from the Seychelles (CAPPES), and the South West Indian Ocean Fisheries Project (SWIOFP). These surveys were carried out in Reunion Island and Tromelin EEZs, as well as in the Mozambique Channel between 2007 and 2012.

2.2. Data quality and species identification

Despite continuous efforts of RFMOs (IOTC, 2012) and local scientists focused on the facilitation and improvement of marlin species identification, correct identification of these species is still an issue for both fishermen (and sometimes scientific observers). Marlin identifications made by observers were checked using digital photograph archives and validated or not by an experienced biologist. Non-validated identifications were degraded to a group level *unidentified marlin* and coded as *BIL** in the database. *BIL** includes the three marlin species: *M. indica, M. nigricans*, and *T. audax*, while the FAO alpha3 code *BIL* corresponds to the *Istiophoridae* family. BIL code was commonly attributed to escaped istiophorid individuals (for observer data) and data collected by fishermen.

2.3. Yearly and quarterly distributions of nominal CPUE

We provide yearly 1°-square nominal catch per unit of effort (CPUE) distributions for black marlin, blue marlin, striped marlin, Indo-Pacific sailfish and shortbill spearfish for the period that is covered by SRP, OBS and SCI programs: 2011-2014 (Figs. 2A-E). We do not present data prior to 2011 as the availability of data is limited to OBS and SCI (less than 100 sets monitored per year; see Tab. 1).

In order to assess the spatio-temporal seasonality of istiophorids species, we provide quarterly distributions of CPUE for each species using data pooled for the 2007-2014 period (Figs. 3A-E).

2.4. Length frequency distribution

Billfish were measured when possible during OBS and SCI cruises. The number individuals that were measured each year is presented in Table 2. The most collected measure for billfish is the lower jaw-fork length (LJFL; Nakamura, 1985).

We provide for each billfish species, the length distribution including LJFL measurements made between 2007 and 2014 (Fig. 4). Also, we present for each species yearly length distribution as boxplots including min, first quartile, median, third quartile, and maximum values (Fig. 5).

3. Results

3.1. Billfish catches

During 1 844 fishing operations monitored between 2007 and 2014 representing a total effort of 2 296 839 hooks (Tab. 1), 633 billfish were caught (Tab. 2); among them: 31% of shortbill spearfish, 16 % of blue marlin, 15% of Indo-Pacific sailfish, 7% of striped marlin, 4% of black marlin, 22% of unidentified istiophorids (BIL) and 5% of unidentified marlins (BIL*).

3.2. Data quality and species identification

The amount of non-identified marlins among the billfish catch data collected by observers was relatively stable until 2012 (up to 50% in 2011 and up to 70% in 2012). Then, it dropped to less than 5% (Fig. 1A). High proportions of non-identified marlins are the result of downgrading process described above reflecting poor species recognition by certain observers in those years.

Similarly, the proportion of unidentified marlins in SRP was significantly higher in 2011-2012 (Fig. 1B). Since 2013, an effort is being made on species identification by fishermen by wide distribution of IOTC identification cards (IOTC, 2012) and by individual fishermen training by CAP RUN. The comparison of OBS and SRP in 2013 and 2014 shows that the relative proportion of the 3 marlin species (black marlin, blue marlin and striped marlin) is similar between OBS and SRP with, by order of importance, blue marlin, striped marlin and black marlin (Fig. 1A). In 2014, both observer and self-reported data demonstrated increased proportion of blue marlin in the catch. In the same time the relative proportion of striped marlin was much higher in SRP data than in OBS data (Fig. 1B).

3.3. Yearly distribution of nominal CPUE

Maximum CPUE values reach 4 fish caught per 1000 hooks for blue marlin, black marlin and shortbill spearfish, 2.5 for Indo-Pacific sailfish, and 2 for striped marlin. CPUE values are most of the time relatively low: < 0.1 for black marlin and striped marlin, < 0.5 for blue marlin and Indo-Pacific sailfish and between 0.2 and 0.5 for shortbill spearfish (Figs. 2A-E).

In 2013-2014 there were more records of blue marlin, striped marlin and black marlin than in 2011-2012 because of improved identification and reporting in SRP (Fig. 1B).

3.4. Spatio-temporal seasonality of nominal CPUE

Highest CPUE of blue and black marlins were recorded during the first and fourth quarters of the year while Indo-Pacific sailfish CPUE is higher during the fourth quarter only. Compared to the other species, shortbill spearfish and to a lesser extent striped marlin, are the only species which abundance is constant throughout the year (Figs. 3A-E).

3.5. Length frequency distribution

The median LJFL for blue marlin, black marlin, striped marlin and Indo-Pacific sailfish is approximately 2 m, while it is 1.5 m for shortbill spearfish (Figs. 4 and 5). Most of the catch are adults, and catch of juvenile are very infrequent, nearly nonexistent. Black marlin individuals are longer than blue marlin ones but with fewer individuals measured. The variation of size distribution is more important for blue and black marlins, for which some individuals exceed 3 m. Variation in size is relatively low in Indo-Pacific sailfish and shortbill spearfish but there are some isolated small individuals of about 1 m long.

4. Discussion

4.1. Billfish identification

This preliminary analysis of the data collected by various sampling programs shows that self-reporting data may serve as a source of important complimentary information on billfish occurrence and distribution. However such data should be always treated with caution until every record can be validated by other means (photo or genetic identification). Cross-checking of observers identification is also important routine in scientific observation programs.

Our data show a particular deviation between research/observers data and self-reporting data for two marlin species: blue and striped marlin. In particular, the higher abundance of striped marlin in the data collected by fishermen in 2014 (Figure 1B) can either be explained by incorrect identification by fishermen (mistaking blue for striped marlin) or lower coverage of fishing effort by observers.

We believe that fishermen error is a more plausible explanation despite all the efforts in training and identification card distribution. Fishermen nature and identification approach are commonly focused on bright external marks such as color and stripes despite training. Therefore, misidentification between blue marlin and striped marlin is common. Similarly, misreporting of dead blue marlin as black marlin based on no stripes absence, obscure colors and relative rigidity of pectoral fins due to *rigor mortis* were observed for both fishermen and scientific observers.

To reduce such kind of mistakes, a dedicated training for the vessel's crew and not just for ship captains may improve the situation. Also, species identification cards and poster posted onboard, for major marlin species: *M. nigricans*, *M. indica* and *T. audax*, might help reduce the percentage of error.

4.2. Billfish spatio-temporal patterns

Except for shortbill spearfish, that occurs in catches throughout the year, yearly and quarterly distributions of nominal catch per unit effort for istiophorids show relatively low CPUE values, suggesting low probability of billfish bycatch.

Data collected in the Reunion Island pelagic longline fishery does not support earlier assumption on more inshore distribution for black marlin and offshore distribution of blue marlin. However hypothesis is not rejected due to insufficient volume of data.

This lack of data leads naturally to the need of complementary studies, tagging and sampling programs, taking advantage of the recent expertise in large pelagic tagging acquired at the occasion of PROSPER scientific cruises (carried out by IRD and CAP RUN in the South West Indian Ocean), and potential collaboration with deep-sea recreational fishers.

4.3. Billfish size distribution

Species length distributions also highlight paucity of our understanding of istiophorid biology. The longliners catch consists of almost exclusively adult billfish; that is economically and ecologically advantageous. However, life cycle, distribution and habitat selection of younger individuals are unknown for the Indian Ocean basin. While it is commonly acknowledged that biggest observed individuals for blue and black marlins, exceeding 3 meters (mostly blue marlins in our study) are females (Pepperell, 2010), the actual age and growth rate estimations for Indian Ocean billfish species are unknown. Further studies based on traditional approaches (aging, trophic ecology, conventional tagging) and on state of art technology (electronic tagging and tracking, genetics) are certainly needed to improve our knowledge of such poorly studied but important and magnificent component of pelagic ecosystem.

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6. Tables

Year	Sets				Hooks				Total EUREU hooks	% coverage	
	All	SCI	OBS	SRP	All	SCI	OBS	SRP		OBS	SRP
2007	20	0	20	0	21 499	0	21 499	0	4 273 000	0.5	0.26
2008	26	12	14	0	25 424	7 728	17 696	0	3 128 234	0.57	0.26
2009	86	0	71	15	103 789	0	94 429	9 360	3 631 503	2.6	0.26
2010	90	27	57	6	86 631	11 507	71 694	3 430	3 781 552	1.9	0.09
2011	242	36	92	114	266 105	19 159	114 268	132 678	3 769 249	3.03	3.52
2012	491	7	89	395	634 447	10 192	118 520	505 735	3 367 938	3.52	15.02
2013	495	0	99	396	644 391	0	132 807	511 584	4 042 075	3.29	12.66
2014	394	0	104	290	524 552	0	151 785	372 767	3 573 445	4.25	10.43
Total	**1 844**	**82**	**546**	**1 216**	**2 306 838**	**48 586**	**722 698**	**1 535 554**	**29 566 996**	2.44	5.19

Table 1. Summary of the number of sets and hooks monitored during scientific cruises (SCI), observer (OBS) and self-reported trips (SRP).

Year	Species	Caught	Measured	LJFL-measures
2007	BIL*	0	0	0
	BLM	0	0	0
	BUM	2	2	1
	MLS	8	2	1
	SFA	4	0	0
	SSP	2	1	1
2008	BIL*	0	0	0
	BLM	0	0	0
	BUM	2	2	2
	MLS	0	0	0
	SFA	46	46	15
	SSP	23	23	5
2009	BIL*	2	2	2
	BLM	3	3	1
	BUM	12	12	10
	MLS	2	2	1
	SFA	22	22	7
	SSP	19	15	5
2010	BIL*	5	5	5
	BLM	0	0	0
	BUM	19	19	10
	MLS	16	14	10
	SFA	24	24	15
	SSP	25	24	17
2011	BIL*	25	23	23
	BLM	2	2	2
	BUM	44	44	14
	MLS	5	5	5
	SFA	38	37	37
	SSP	26	26	23
2012	BIL*	41	20	20
	BLM	1	1	1
	BUM	14	13	12
	MLS	3	0	0
	SFA	20	17	17
	SSP	27	23	23
2013	BIL*	0	0	0
	BLM	5	4	4
	BUM	26	24	21
	MLS	16	15	13
	SFA	1	1	1
	SSP	15	14	12
2014	BIL*	2	2	2
	BLM	4	4	3
	BUM	38	36	35
	MLS	5	5	5
	SFA	11	11	11
	SSP	28	28	27

Table 2. Summary of the number of billfish caught, measured, LJFL-measured by FAO code per year. BIL correspond to unidentified marlins (can be BLM or BUM or MLS).*

7. Figures

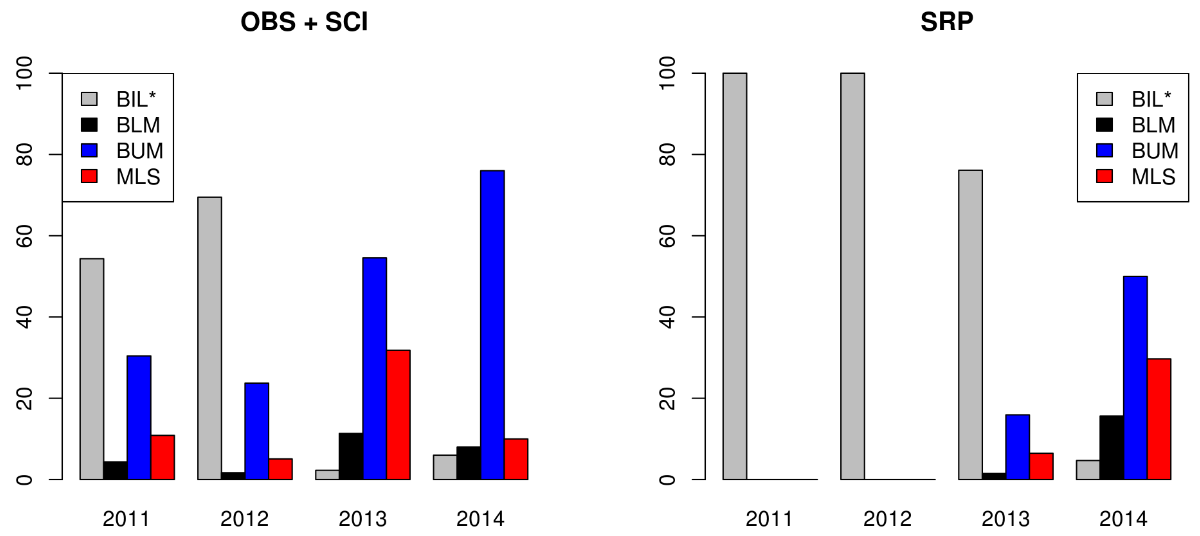

Figure 1. Identification of Makaira mazara (BLM), Makaira indica (BUM) and Tetrapturus audax (MLS) within OBS, SCI and SRP programs between 2011 and 2014. BIL corresponds to unidentified marlins (can be BLM or BUM or MLS).*

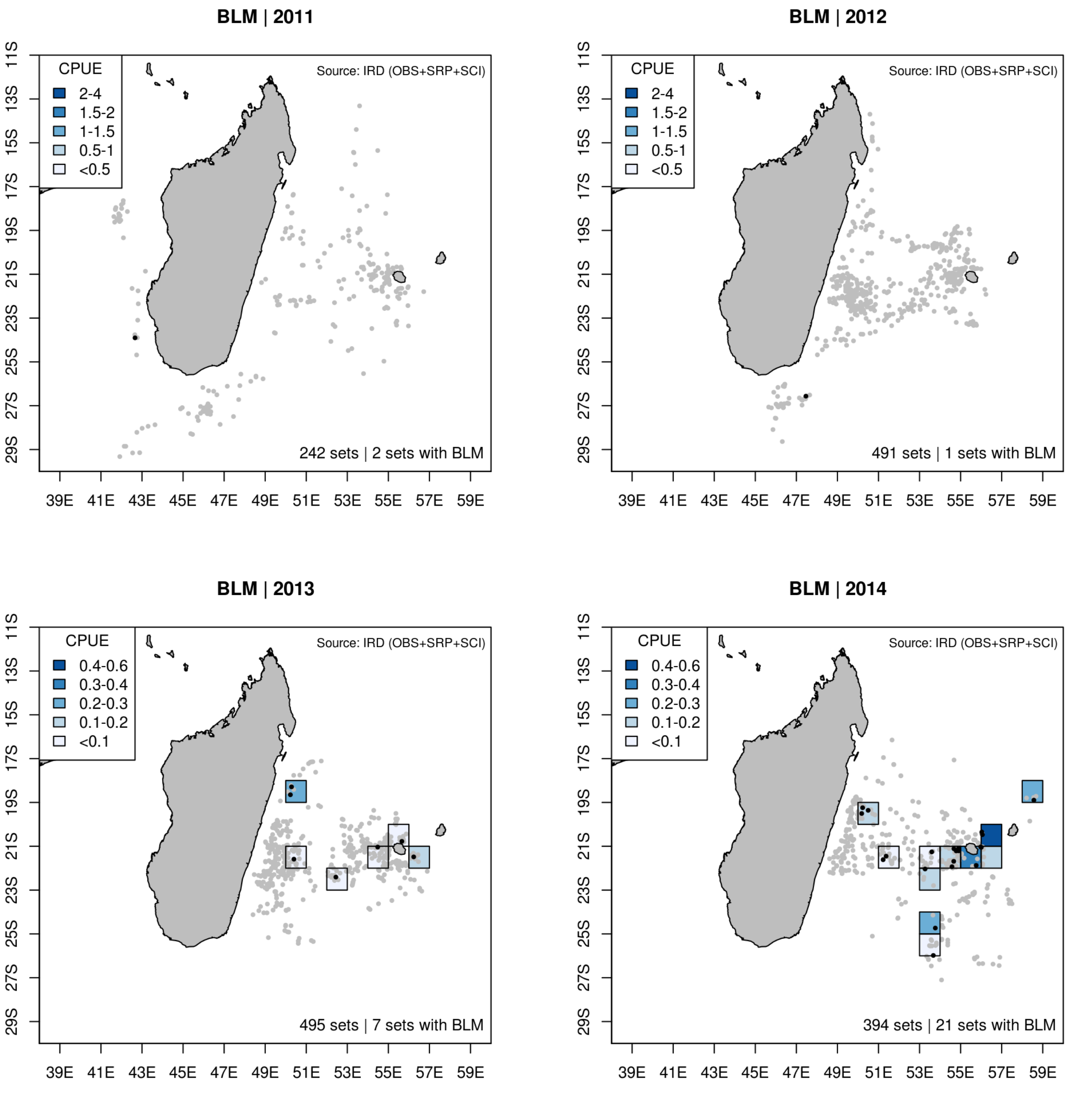

Figure 2A. Yearly distribution of black marlin (BLM) nominal catch per unit effort.

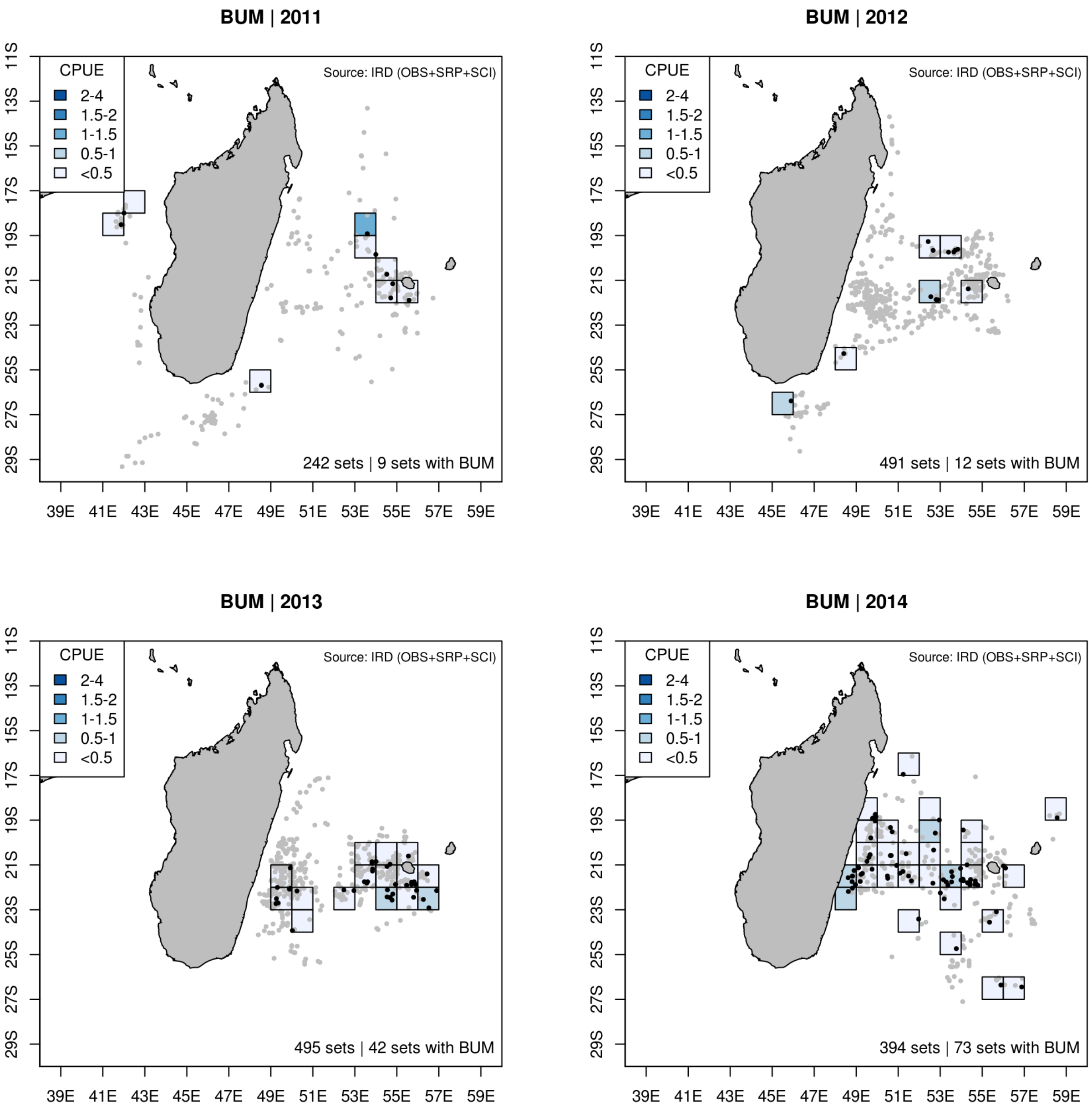

Figure 2B. Yearly distribution of blue marlin (BUM) nominal catch per unit effort.

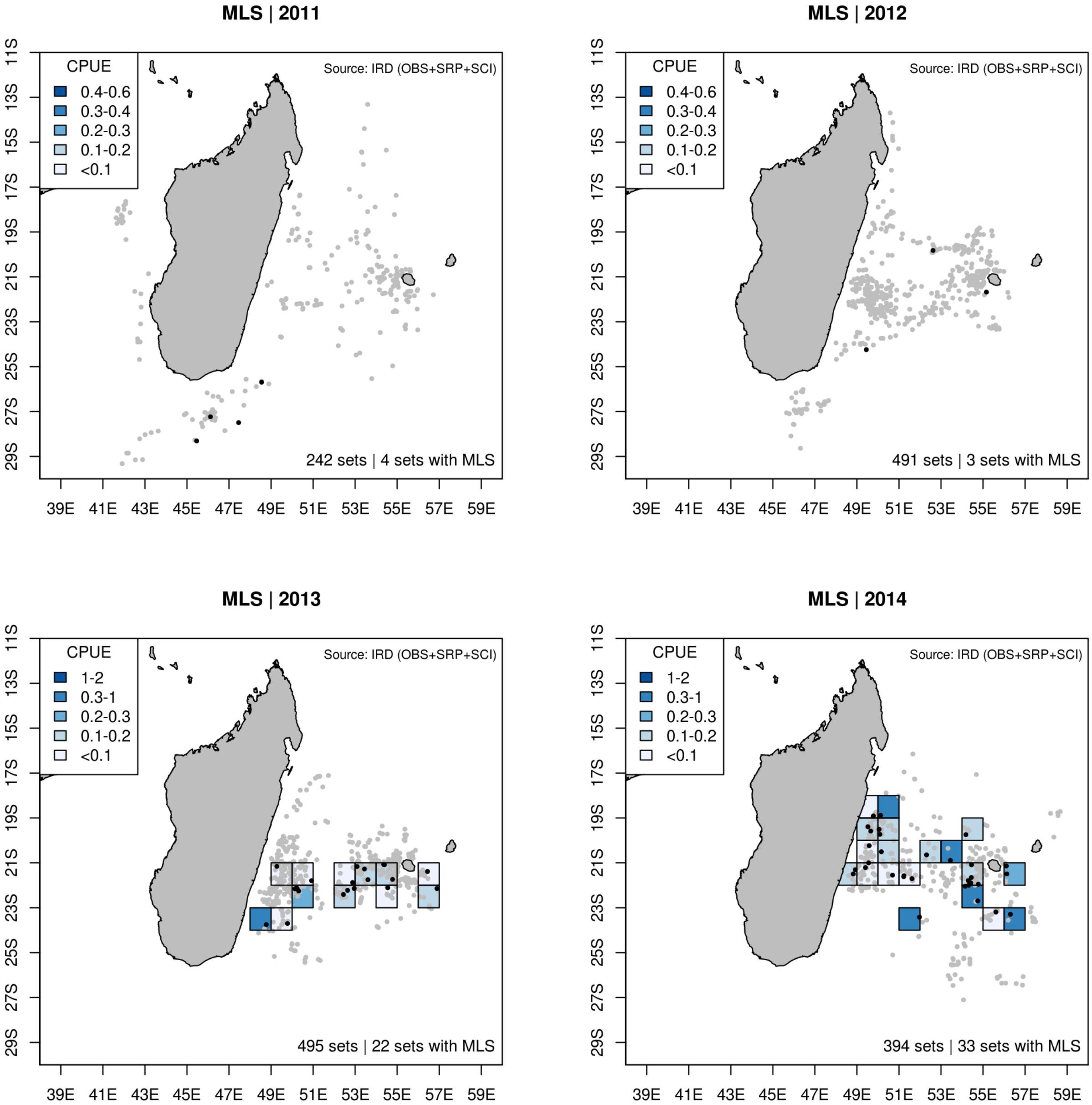

Figure 2C. Yearly distribution of striped marlin (MLS) nominal catch per unit effort.

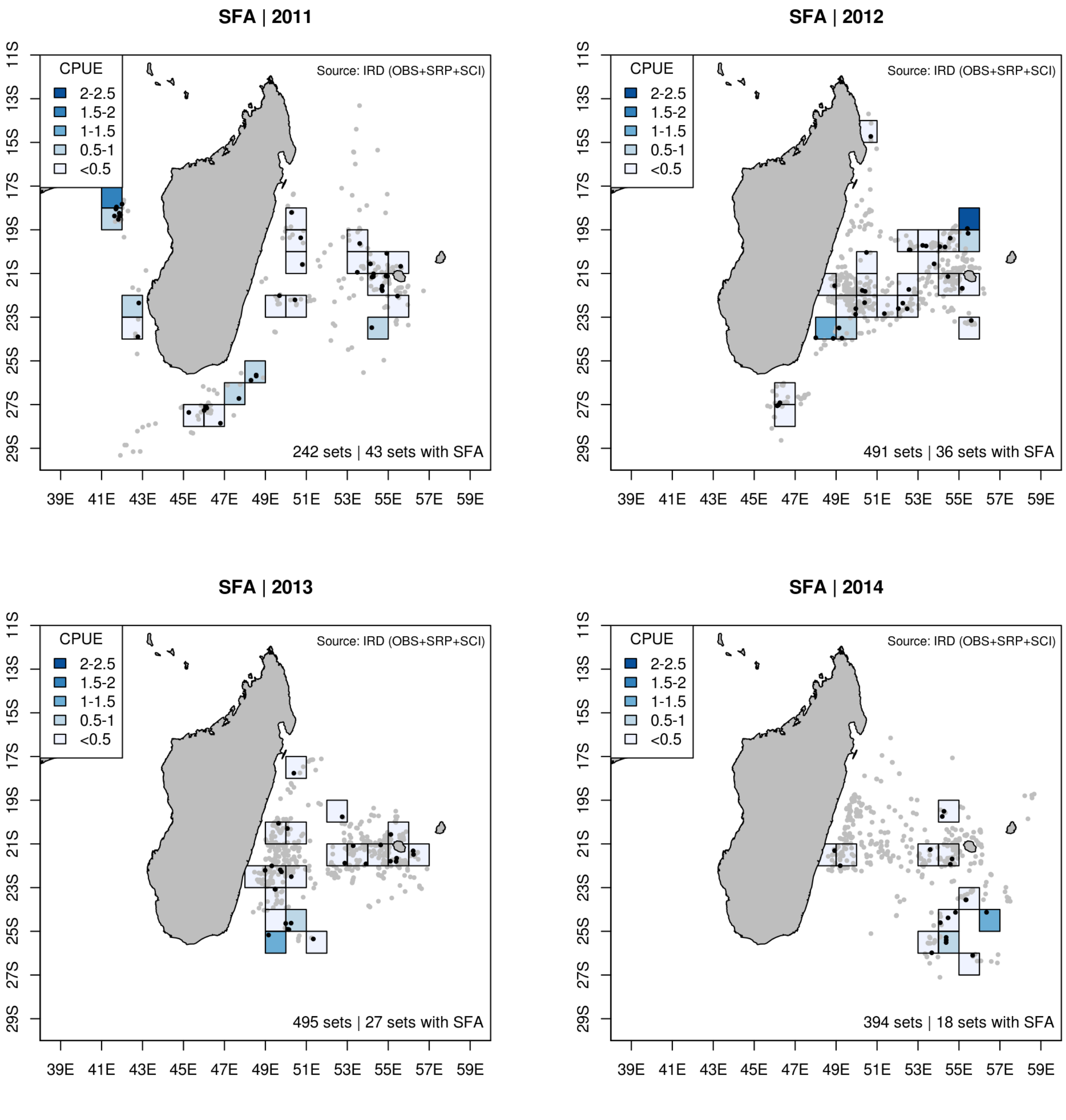

Figure 2D. Yearly distribution of Indo-Pacific sailfish (SFA) nominal catch per unit effort.

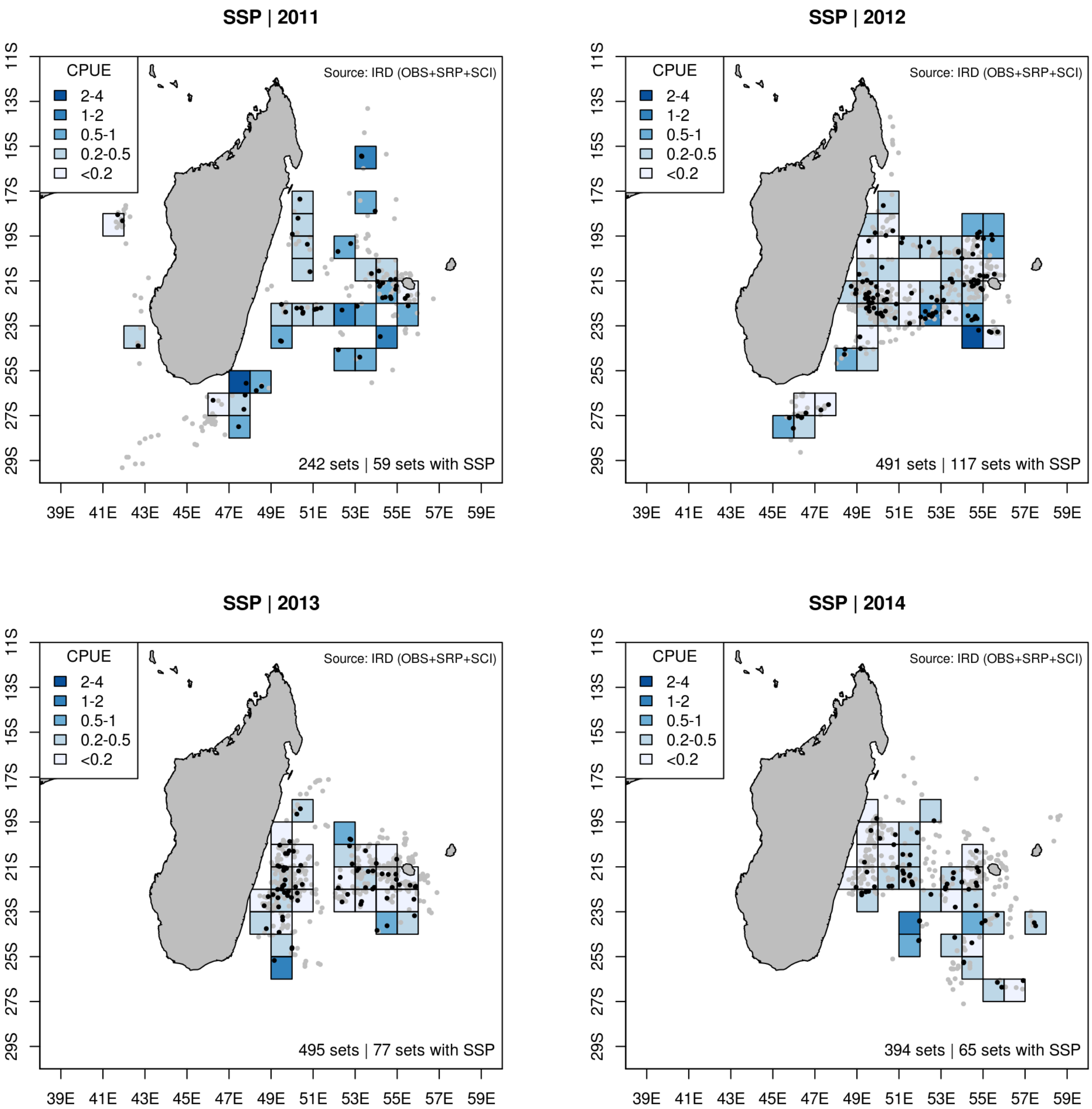

Figure 2E. Yearly distribution of shortbill spearfish (SSP) nominal catch per unit effort.

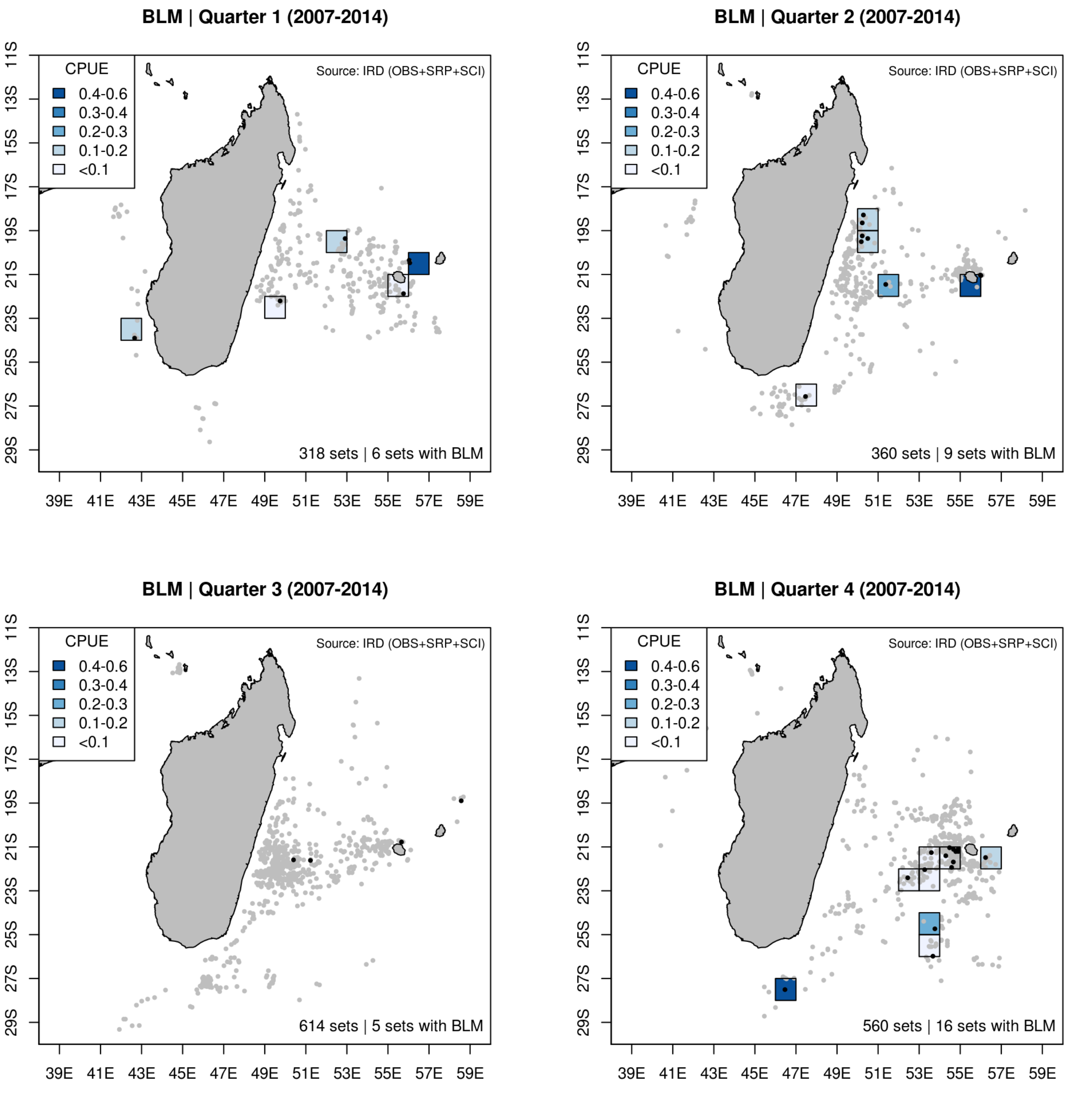

Figure 3A. Quarterly distribution of black marlin (BLM) nominal CPUE including 2007-2014 data.

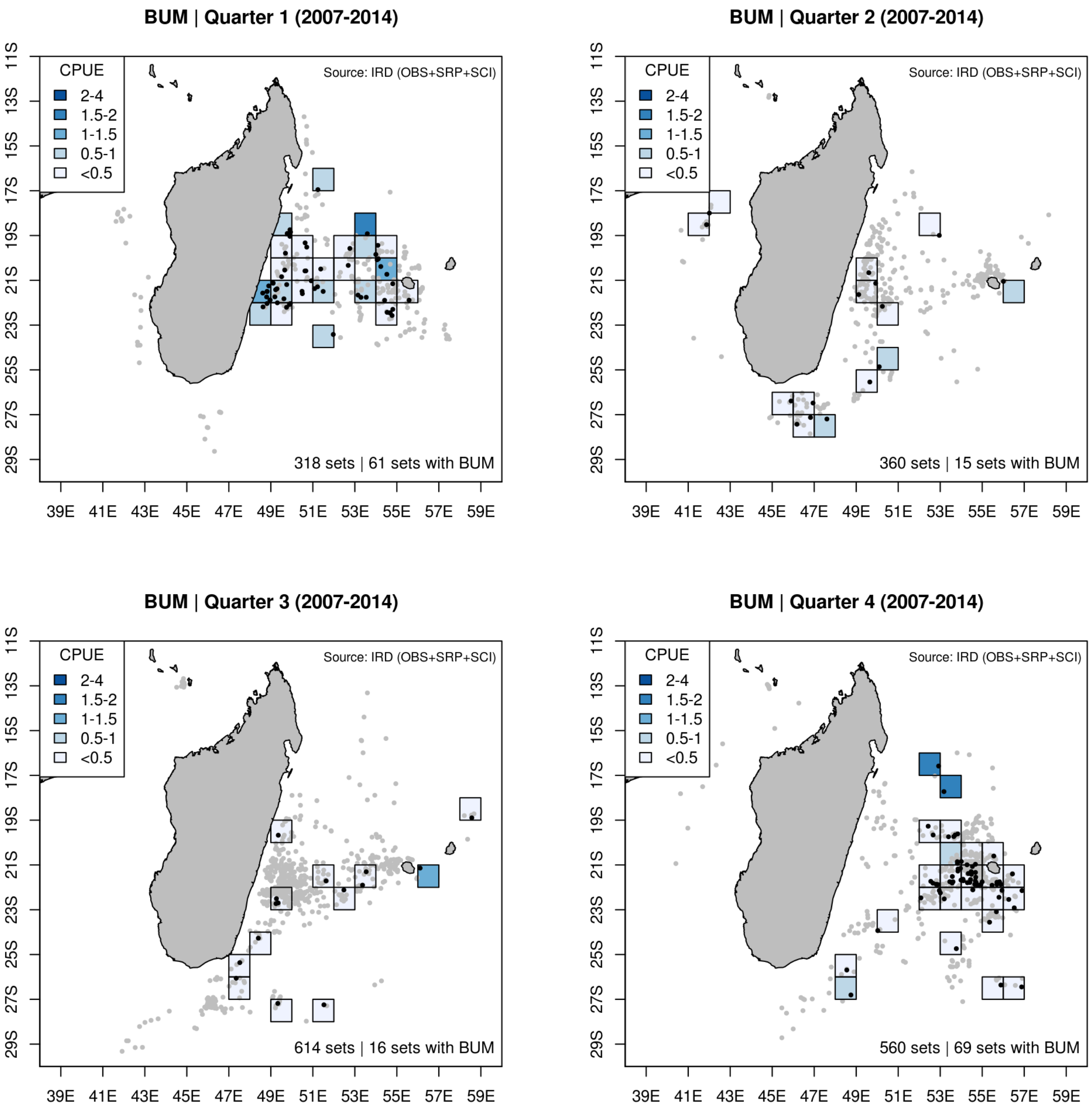

Figure 3B. Quarterly distribution of blue marlin (BUM) nominal CPUE including 2007-2014 data.

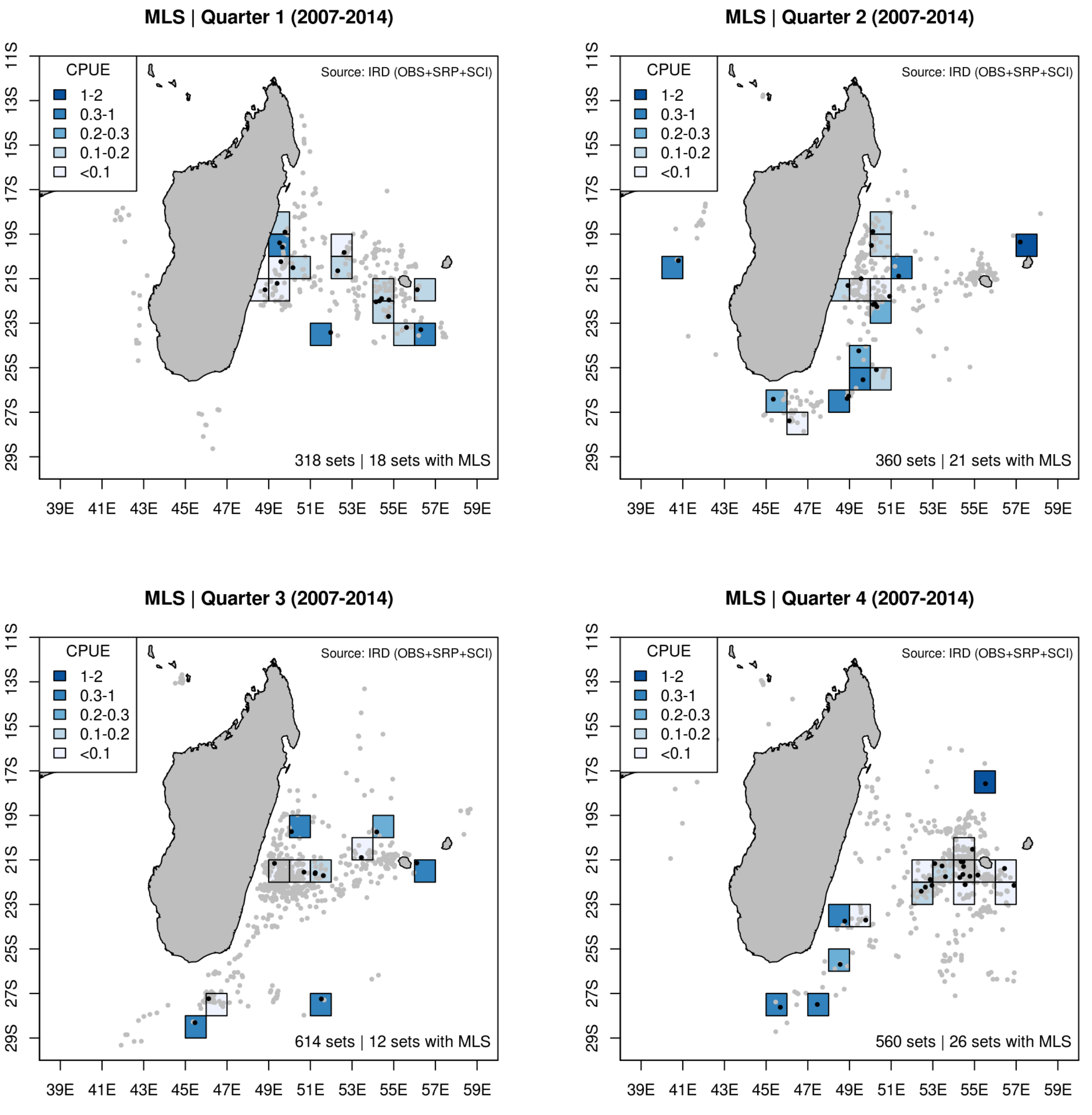

Figure 3C. Quarterly distribution of striped marlin (MLS) nominal CPUE including 2007-2014 data.

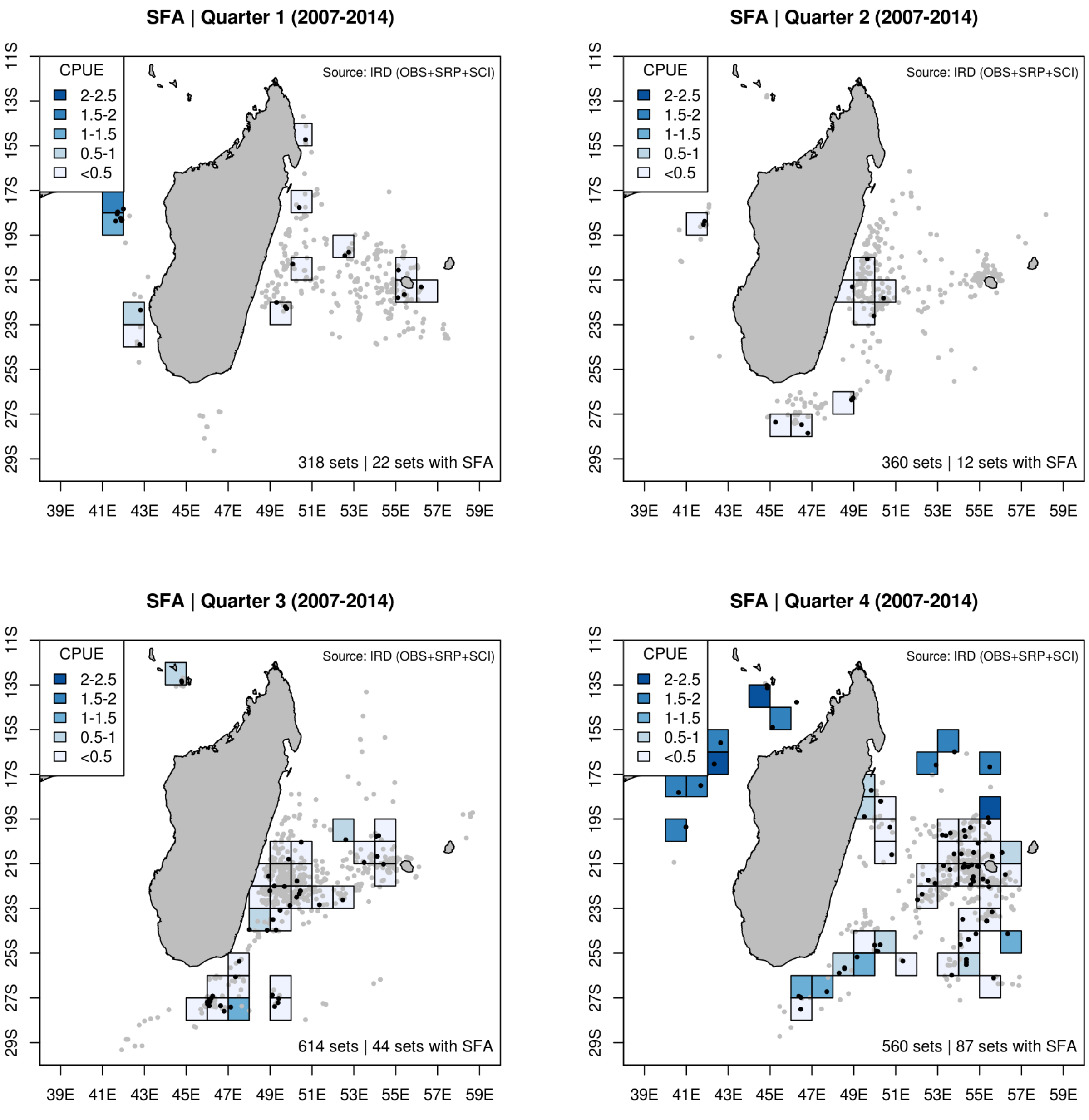

Figure 3D. Quarterly distribution of Indo-Pacific sailfish (SFA) nominal CPUE including 2007-2014 data.

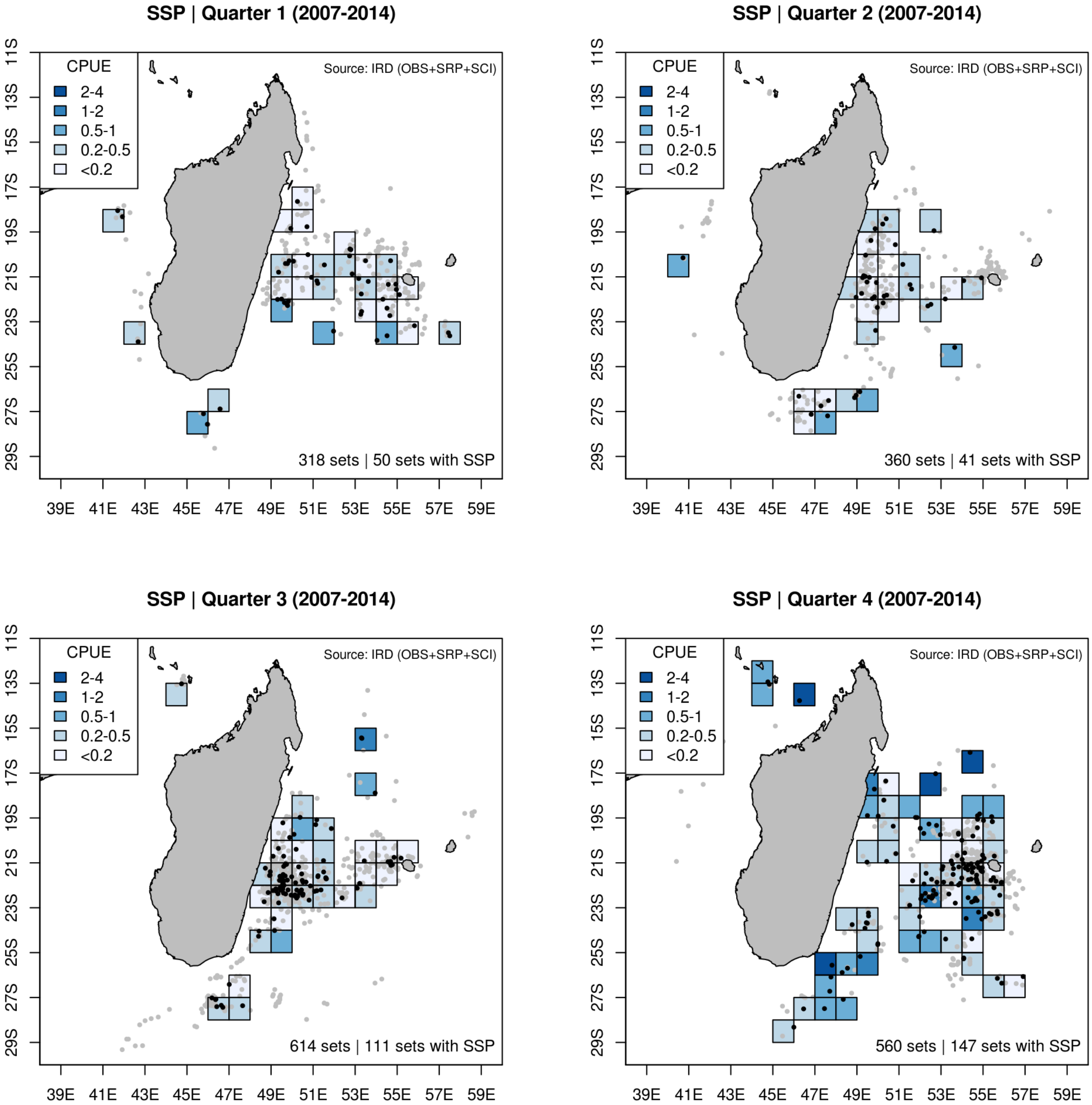

Figure 3E. Quarterly distribution of shortbill spearfish (SSP) nominal CPUE including 2007-2014 data.

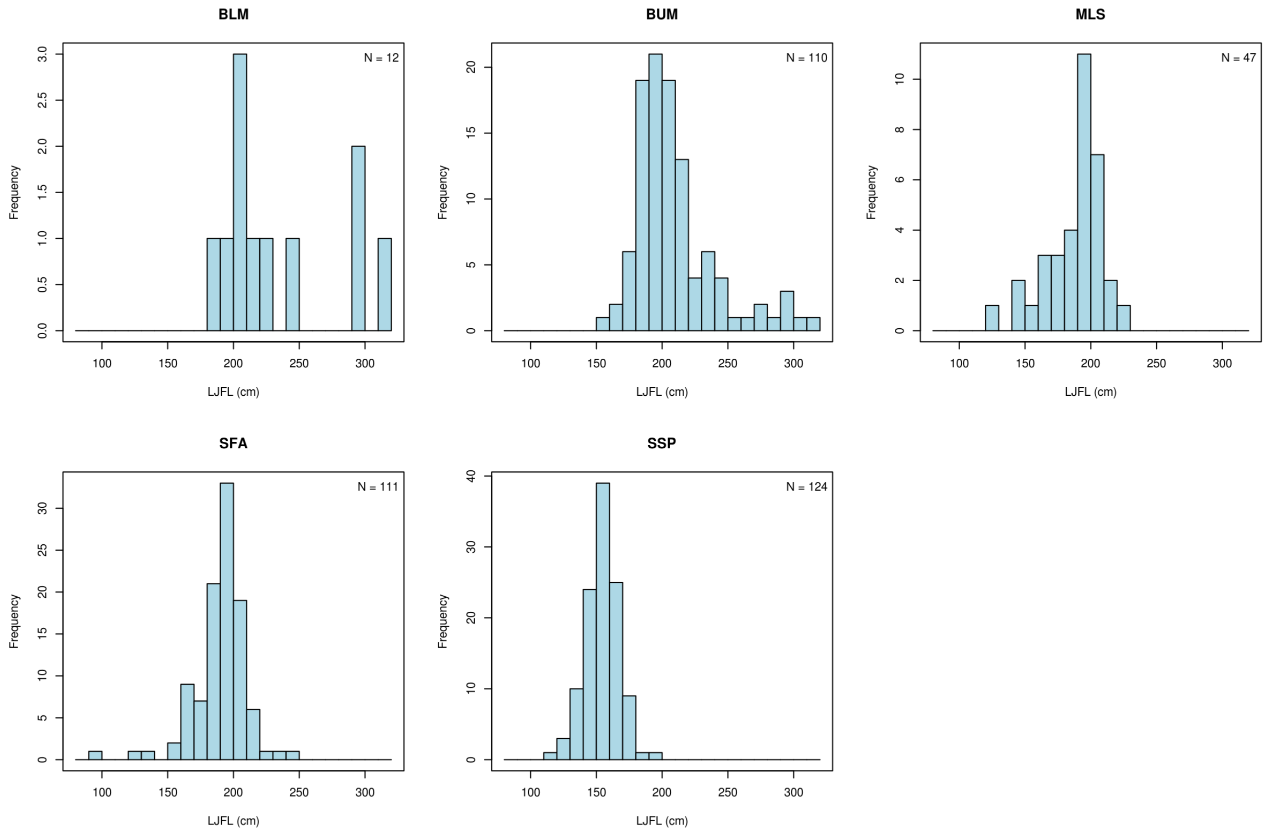

Figure 4. Length distribution of istiophorids measured during scientific and observer-monitored commercial cruises between 2007 and 2014.

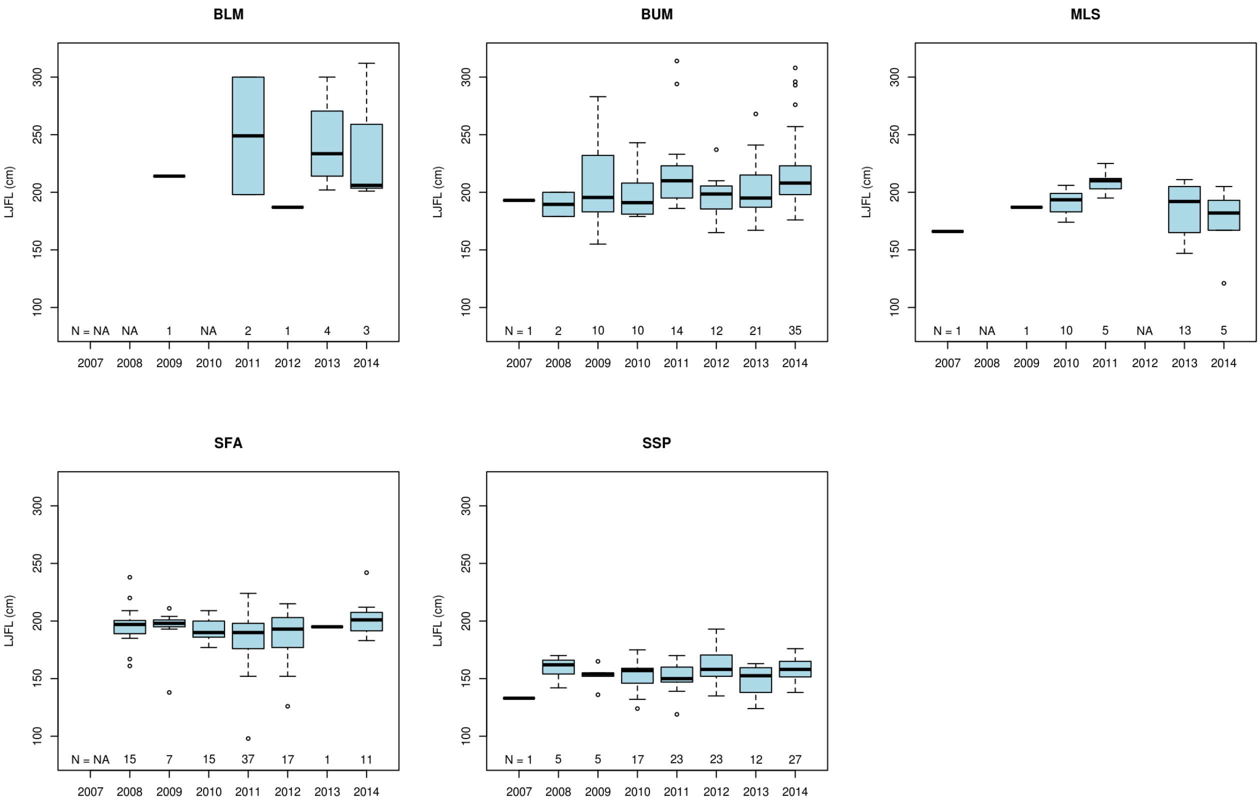

Figure 5. Yearly length distribution (boxplots) of istiophorids measured during scientific and observer-monitored commercial cruises between 2007 and 2014.