Bycatch of hammerhead sharks caught by the French pelagic longline (2007-2021) and purse seine (2005-2021) fisheries in the Indian Ocean

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Abstract

Hammerhead sharks (Sphyrnidae family) are sensitive species present in the Indian Ocean that are classified as globally "Critically Endangered" for the great hammerhead (*Sphyrna mokarran* – SPK) and scalloped hammerhead (*Sphyrna lewini* – SPL), and "Vulnerable" for the smooth hammerhead (*Sphyrna zygaena* – SPZ) by the IUCN. Hammerhead sharks are occasionally bycaught by the French tuna purse seine fishery and swordfish-targeting longline fishery operating in the western Indian Ocean. Using data collected through onboard observation programs on purse seiners (2005-2021) and longliners (2007-2021), we present here an overview of available data related to hammerhead sharks: distribution, abundance indicators, status at capture, discard rate, status at release, and size distribution. We found that hammerhead sharks occur very rarely in purse seine bycatch. On the other hand, hammerhead sharks occur in 5% of the longline sets and nominal CPUEs are relatively low: below 0.077 and 0.233 individuals per 1000 hooks for SPL and SPZ respectively. The respective nominal CPUE may indicate a decreasing trend for both species. SPK is never caught in neither of the two fisheries and SPL is 3 times more frequent than SPZ in longline bycatch. SPL's survival at haulback (70%) is on average higher than SPZ's (30%) when caught by longliners. Hammerhead sharks are almost always released (97%) and the

percentage of individuals released alive is highly variable and tend to have decreased throughout the period for both SPL and SPZ. The mean sizes caught by longliners are 171 and 160 cm FL for SPL and SPZ respectively.

Keywords

Sphyrnidae | Bycatch | Longline | Purse seine | Western Indian Ocean

1. Introduction

The three hammerhead sharks (Sphyrnidae family), the great hammerhead (*Sphyrna mokarran* – SPK), the scalloped hammerhead (*Sphyrna lewini* – SPL) and the smooth hammerhead (*Sphyrna zygaena* – SPZ) are sensitive species caught in most fisheries – except for the purse seine – of the IOTC convention area (IOTC, 2021). The SPK and SPL are globally ranked as "Critically Endangered" while the SPZ is ranked as "Vulnerable" (IUCN, 2022).

Due to the paucity of data they are considered as "data-poor" and their stock have not been assessed (IOTC, 2021) except for the SPL that was included in a semi-quantitative rick assessment conducted in 2018 (Murua et al., 2018). Only the SPL is in the management plan of IOTC with an assessment scheduled in 2023 (IOTC, 2021).

We intend in this paper to provide an overview of hammerhead sharks' bycatch in the French purse seine and pelagic longline fisheries operating in the western Indian Ocean. We present here the distribution of the fishing effort and occurrences of hammerhead sharks, catch per unit of, percentage of occurrence in sets, status at haulback, fate of the individuals (retained or discarded), status at release, and size distribution.

2. Material and methods

2.1. Data

The French tropical tuna purse seine fishery operating in the western Indian Ocean is covered by several observer programs: EU-funded "Data Collection Framework" (DCF) since 2005 and industry-funded "Observateur Commun Unique et Permanent" (OCUP) since 2013 (Goujon et al., 2017). The overall yearly coverage is shown in Figure 1.

The French swordfish-targeting longline fishery of Reunion Island and Mayotte operating in the South West Indian Ocean is covered via EU-funded "Data Collection Framework" (DCF) by scientific observers (OBS) since 2007 and Captains participating in the "self-reporting program" (SRP) since 2011 (Bach at al., 2013). The overall yearly coverage is shown in Figure 2.

2.2. Analyses

For both fisheries we show the distribution of the fishing effort in sets for the purse seine (Figure 3) and in hooks deployed for the pelagic longline (Figure 4) along with the location of the sets with occurrences of the respective hammerhead shark species.

Abundance indicators such as the percentage of occurrence (= percentage of sets including a given hammerhead shark species) and the nominal catch per unit of effort (nCPUE) where the effort is the number of hooks deployed for the longline fishery were computed over the 2012-2021 period (Figure 6; Figure 7) to avoid years before 2012 with poor observer coverage (Figure 2). Because a large proportion of hammerhead sharks was not identified to the species level (recorded as *Sphyrna* spp – SPN) we reconstructed the yearly observed numbers by species by reassigning unidentified hammerhead sharks (SPN) to either of the species (SPK, SPL or SPZ) based on the relative proportion of these species each year (Table 2). The reconstructed numbers were then used to compute the nCPUEs (Table 2, Figure 6; Figure 7).

The status of individuals at haulback – alive or dead – by species and by year is presented in Figure 8. The yearly discard rate by species is presented in Table 3. The status at release – alive or dead – by species and by year is presented in Figure 9.

The number of measured hammerhead sharks (Fork Length – FL in cm) are presented in Table 4, along with the mean, minimum and maximum sizes observed for the different species. Size distributions are presented in Figure 10.

3. Results

3.1. Purse seine

Only 4 occurrences of hammerhead sharks (1 SPL, 1 SPZ and 2 SPN) were found in the bycatch of the French purse seine fishery in the 10126 observed sets (Figure 3).

3.2. Longline

Of the 4320 sets monitored either by scientific observers or fishing Captains, 232 included hammerhead sharks (5%): 0 with SPK, 48 with SPL, 29 with SPZ, and 155 with SPN (Table 1; Figure 4). Based on the distribution maps, there is no apparent pattern of distribution for the difference species (Figure 4; Figure 5).

Species composition among hammerhead sharks show that SPK was never caught by pelagic longliners and that 75% of the hammerhead sharks could not be identified at the species level (SPN) (Table 1). The latter mostly come from SRP data where Captains are not trained to discriminate

hammerhead shark species. In the 25% that were identified at the species level, 19% correspond to SPL and 7% to SPK (Table 1). SPL is about three times more frequent than SPK.

For SPL, the nCPUE ranges between 0 and 0.077 individuals per 1000 hooks (Table 2; Figure 6) and the percentage of occurrence between 0 and 1% (Figure 6). The nCPUE shows a decreasing trend over time between 2012 and 2021 which is not significant ($p = 0.291$; Figure 6) while that of the percent of occurrence is significant ($p < 0.05$; Figure 6). For SPZ, the nCPUE ranges between 0 and 0.233 individuals per 1000 hooks (Table 2; Figure 7) and the percentage of occurrence between 0 and 1% (Figure 7). Both abundance indicators show a decreasing trend over time however it is not significant ($p = 0.767$ and $p = 0.498$; Figure 7).

The status of haulback of SPL, shown as the percentage of individuals alive at haulback, ranges between 40% and 100% with a mean around 70% while that of SPZ ranges between 20% and 45% with a mean around 30% (Figure 8). Between 2007 and 2021, both species exhibit positive temporal trends in the percentage of individuals alive at haulback which is only significant in the case of SPZ ($p < 0.05$; Figure 8).

In 2007, 2010, 2015 and 2018, a total of 15 hammerhead sharks were retained on board corresponding to 3% of the catches for these species, the remaining 97% was discarded at sea (Table 3). For SPL only, 99% was discarded, and for SPZ, 100% (Table 3).

The status at release of discarded SPL and SPZ, shown as the percentage of individuals released alive, is highly variable between years, ranging from 0% to 100% (Figure 9). For both species, there is however a decreasing temporal trend which is only significant for SPL ($p < 0.05$; Figure 9).

The mean size of SPL is 171 cm FL (98 – 285) while SPZ's is 160 cm FL (98 – 208) (Table 4; Figure 10).

4. Discussion

4.1. Occurrence in purse seine and longline fisheries

Bycatch of hammerhead sharks can be considered as very negligible in the French purse seine fishery, similarly to the other purse seine fleets (IOTC, 2021). On the contrary, catch rates of hammerhead sharks in the French longline are consistent even though they are relatively low (maximum 0.077 individuals per 1000 hooks for SPL and 0.233 for SPZ). SPK was never caught in neither of the fisheries. In the pelagic longline, SPL is three times more frequent than SPZ. No spatial patterns were found in the distribution of the different hammerhead shark species.

4.2. Abundance indicators in the longline fishery

Nominal CPUEs of SPL and SPZ exhibit decreasing trends throughout 2012-2021 but these are not significant. This lack of significance may be explained by the reconstructed numbers in 2016 that

stand out in the respective time series. In 2016, this can be attributed to high catches of SPN (reassigned to SPL and SPZ in the reconstruction work conducted in this paper) in 3 individual sets (not shown) located off the southwestern coast of Madagascar, out of the core fishing area (see Sabarros et al., 2021).

4.3. Status at haulback in the longline fishery

The percentage of alive individuals at haulback is higher in SPL (70%) than SPZ (30%) suggesting than SPZ is more sensitive to capture in pelagic longlining. While the percentage of alive SPL at haulback is not showing a temporal trend, that of SPZ shows a positive trend throughout 2010-2021 that could be attributed to changes in fishing practices or only being an artefact in the data.

4.4. Discard rate in the longline fishery

Expect for rare occasions where dead hammerhead sharks were retained on board (3% of the hammerhead shark catches), they are usually discarded at sea following IOTC Resolution 17/05.

4.5. Status at release in the longline fishery

Throughout 2009-2021, the proportion of SPL and SPZ released alive has greatly varied between (0% and 100%) and appears to have decreased, at least significantly for SPL. There is obvious reason for this pattern that might however be attributed to the effect of low sample size in the data.

4.6. Sizes in the longline fishery

SPL individuals reach maturity at 163 cm FL (210 cm TL; FishBase, 2022) hence SPL caught by French longliners in the South West Indian Ocean are composed of both immature and sexually mature individuals (Figure 10). SPZ become mature at 212 cm FL (265 cm TL) (FishBase, 2022) hence those caught by French longliners are all immature individuals (Figure 10).

5. Acknowledgments

We thank the observers and Captains that collected data through CAPPER, EU DCF and OCUP data collection programs.

6. References

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7. Tables

Table 1. Hammerhead shark species composition in the French pelagic longline

FAO code	Scientific name	N sets with presence	N individuals	% of individuals
SPK	*Sphyrna mokarran*	0	0	0
SPL	*Sphyrna lewini*	48	90	19
SPZ	*Sphyrna zygaena*	29	33	7
SPN	*Sphyrna* spp	155	363	75
	Total	232	486	100

Table 2. Hammerhead sharks reconstructed numbers and nominal CPUEs in the French longline between 2012 and 2021

Year	Observed effort (hooks)	Original N			Relative proportion		Additional N		Reconstructed N		Nominal CPUE	
		SPN	SPL	SPZ	SPL	SPZ	SPL	SPZ	SPL	SPZ	SPL	SPZ
	A	B	C	D	E = C / (C + D)	F = D / (C + D)	G = B x E	H = B x F	I = C + G	K = D + H	L = 1e3 x I / A	M = 1e3 x K / A
2012	629083	26	5	4	0.56	0.44	15	11	20	15	0.032	0.024
2013	620849	13	4	0	1	0	13	0	17	0	0.027	0
2014	517828	16	2	4	0.33	0.67	5	11	7	15	0.014	0.029
2015	534119	34	1	2	0.33	0.67	11	23	12	25	0.022	0.047
2016	571080	173	1	3	0.25	0.75	43	130	44	133	0.077	0.233
2017	534686	23	1	1	0.5	0.5	12	12	13	13	0.024	0.024
2018	324803	7	1	0	1	0	7	0	8	0	0.025	0
2019	457885	9	1	0	1	0	9	0	10	0	0.022	0
2020	496928	15	0	2	0	1	0	15	0	17	0	0.034
2021	560885	3	2	2	0.5	0.5	2	2	4	4	0.007	0.007

Table 3. Fate of hammerhead sharks caught by French longliners. N: number of individuals; %: percentage; RC: retained catch; DI: discard

Year	SPL			SPZ			SPN			ALL		
	N	N	%	N	N	%	N	N	%	N	N	%
	RC	DI	DI	RC	DI	DI	RC	DI	DI	RC	DI	DI
2007	-	-	-	-	-	-	1	0	*0*	1	0	*0*
2008	-	-	-	-	-	-	-	-		-	-	
2009	0	2	*100*	-	-	-	0	7	*100*	0	9	*100*
2010	0	19	*100*	0	8	*100*	12	17	*59*	12	44	*79*
2011	0	51	*100*	0	7	*100*	0	7	*100*	0	65	*100*
2012	0	5	*100*	0	4	*100*	0	26	*100*	0	35	*100*
2013	0	4	*100*	-	-	-	0	13	*100*	0	17	*100*
2014	0	2	*100*	0	4	*100*	0	16	*100*	0	22	*100*
2015	0	1	*100*	0	2	*100*	1	33	*97*	1	36	*97*
2016	0	1	*100*	0	3	*100*	0	173	*100*	0	177	*100*
2017	0	1	*100*	0	1	*100*	0	23	*100*	0	25	*100*
2018	1	0	*0*	-	-	-	0	7	*100*	1	7	*88*
2019	0	1	*100*	-	-	-	0	9	*100*	0	10	*100*
2020	-	-	-	0	2	*100*	0	15	*100*	0	17	*100*
2021	0	2	*100*	0	2	*100*	0	3	*100*	0	7	*100*
Total	**1**	**89**	***99***	**0**	**33**	***100***	**14**	**349**	***96***	**15**	**471**	***97***

Table 4. Size measurements of hammerhead sharks in the French pelagic longline. Lengths are in cm. FL: Fork Length

FAO code	Size type	N measured	Mean length	Min length	Max length
SPL	FL	30	171	98	285
SPZ	FL	17	160	98	208

8. Figures

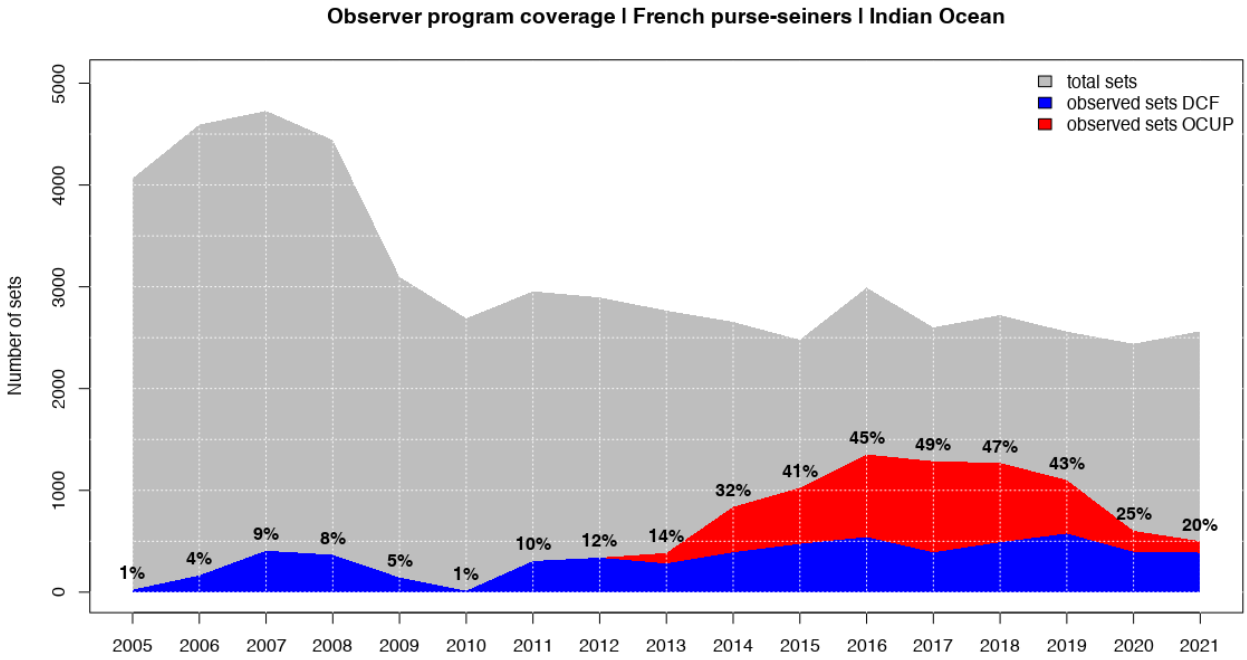

Figure 1. Yearly observed effort and coverage for French purse seiners between 2005 and 2021

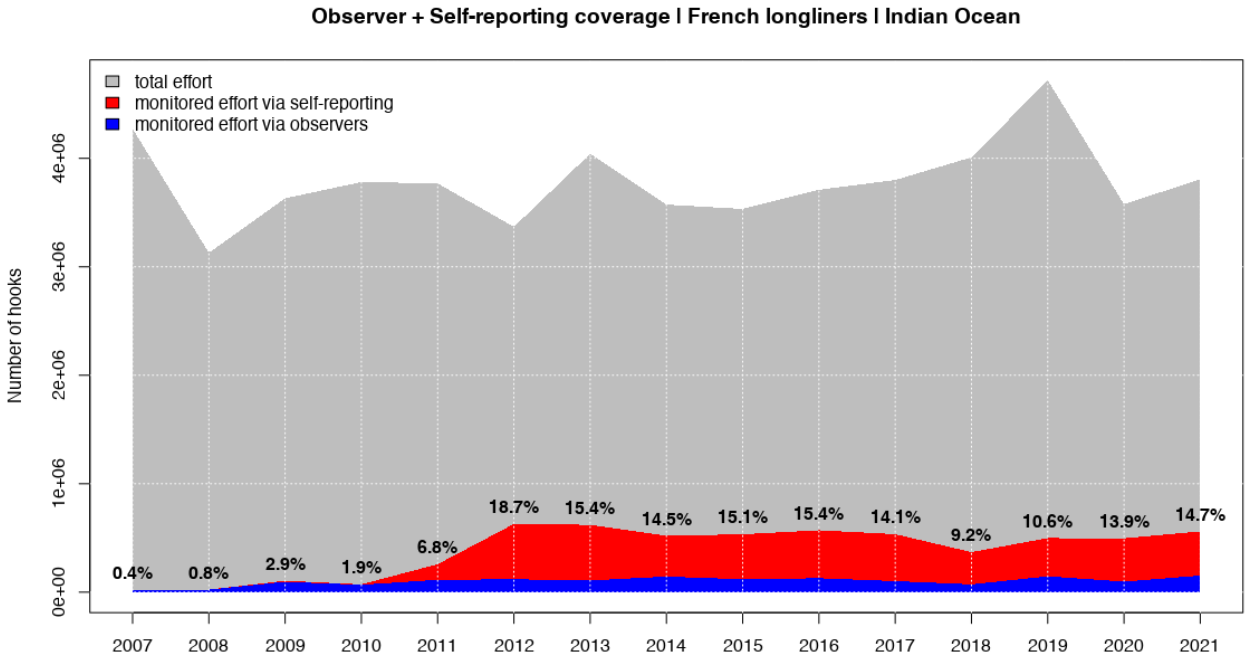

Figure 2. Yearly monitored effort and coverage for French longliners between 2007 and 2021

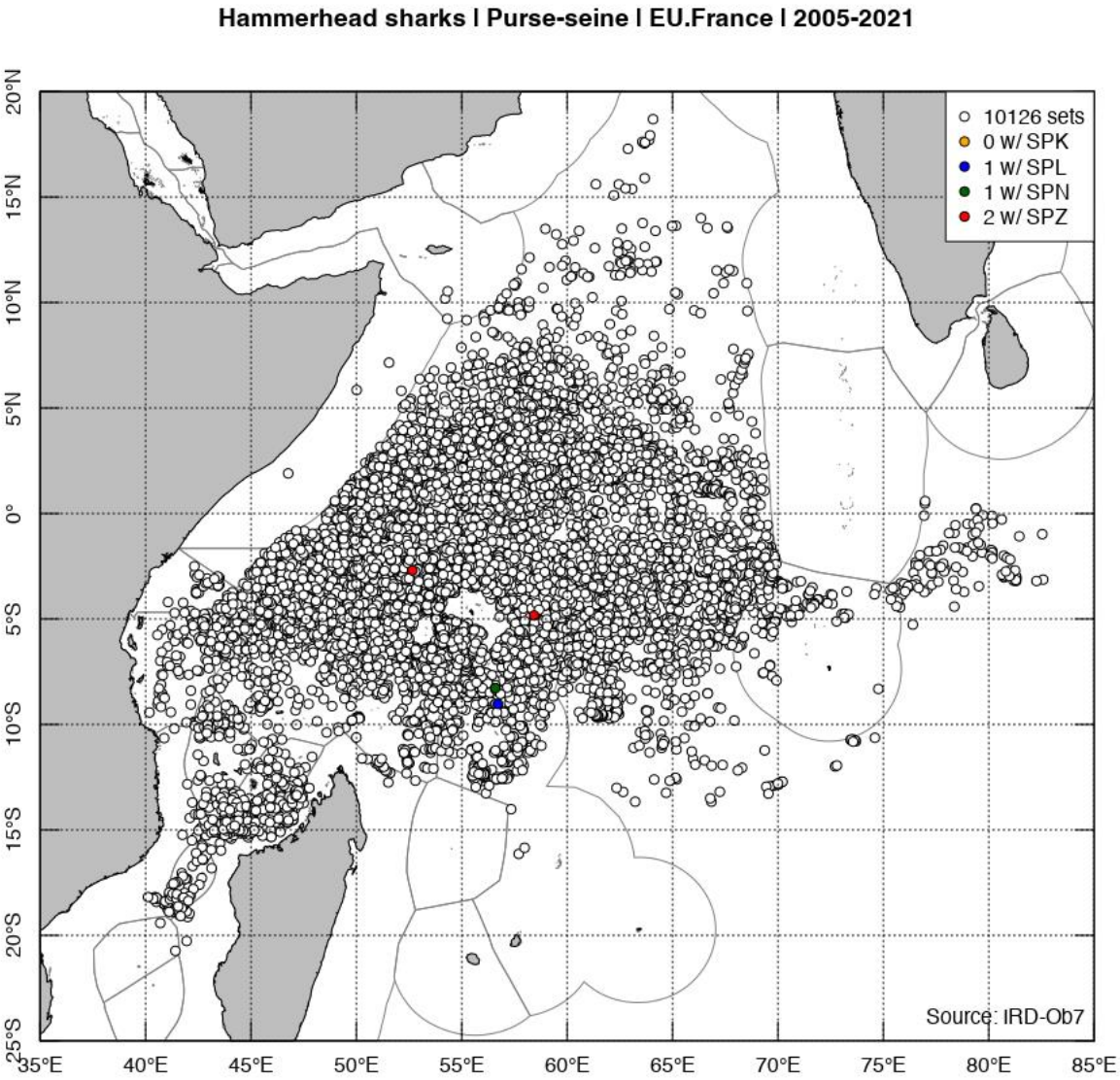

Figure 3. Distribution of the French purse seine fishery observed effort showing hammerhead sharks' occurrences between 2005 and 2021

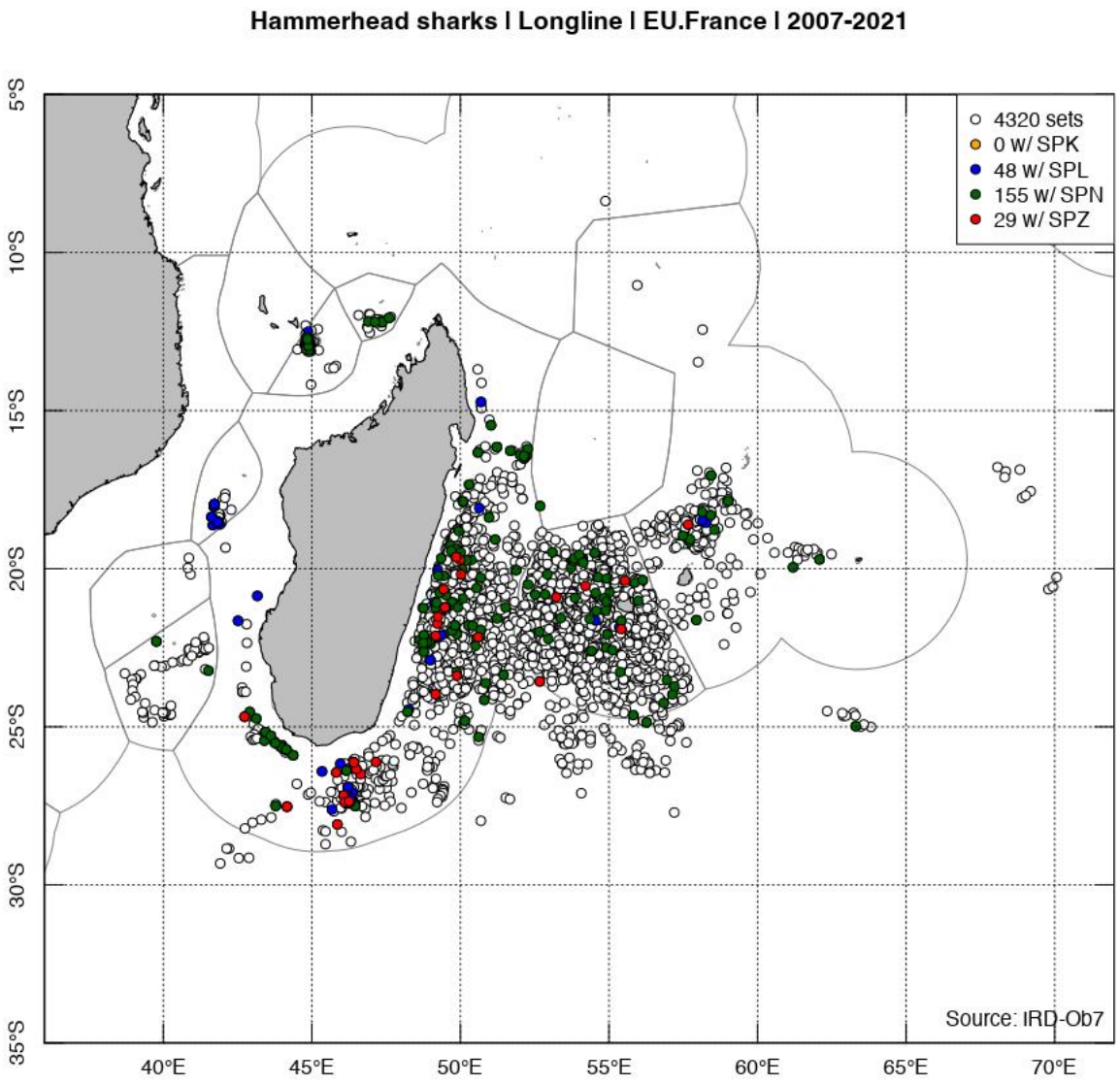

Figure 4. Distribution of the French longline fishery observed and self-reported effort showing hammerhead sharks' occurrences between 2007 and 2021

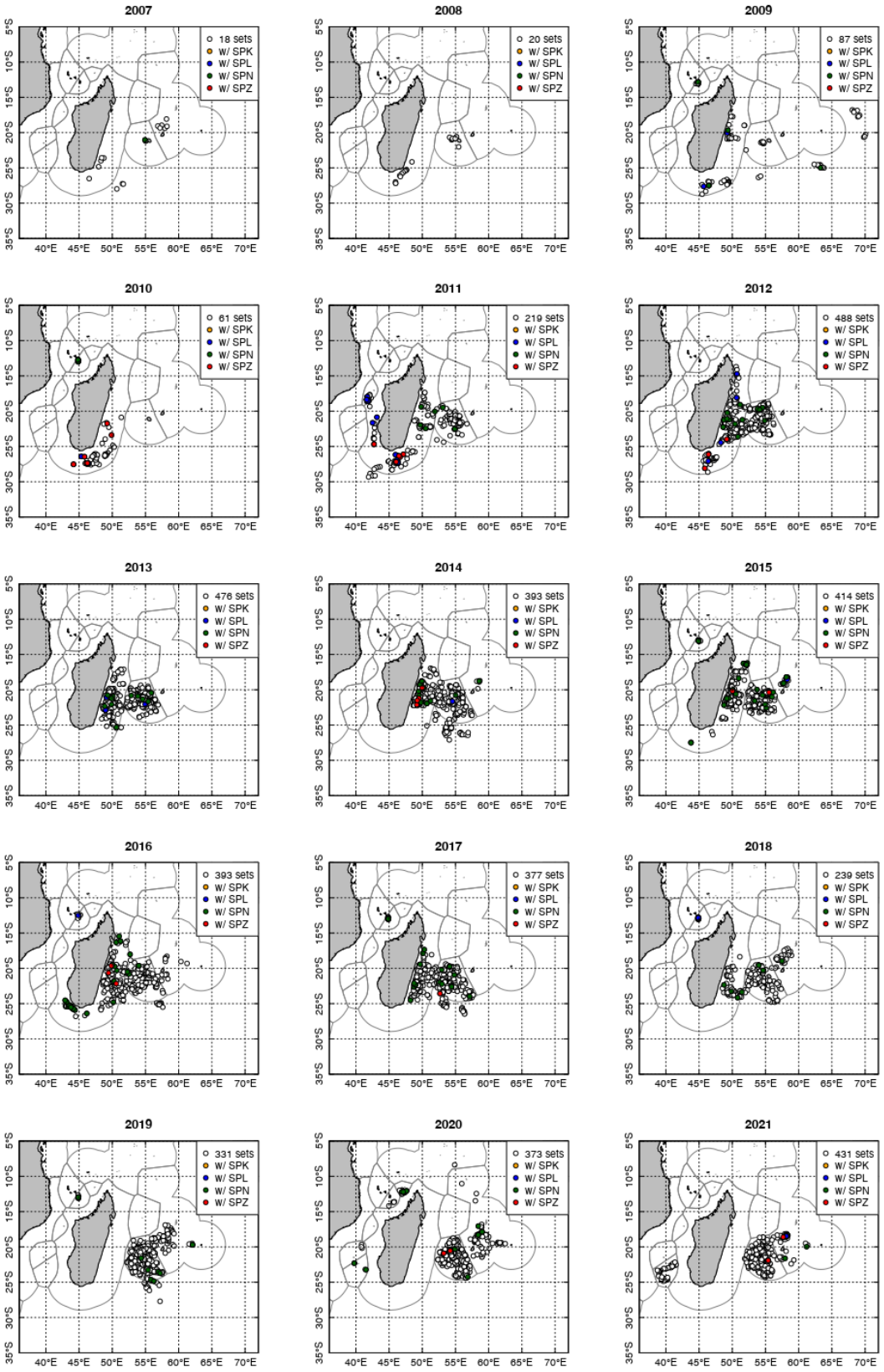

Figure 5. Yearly distribution maps of the French longline fishery observed and self-reported effort showing hammerhead sharks' occurrences between 2007 and 2021

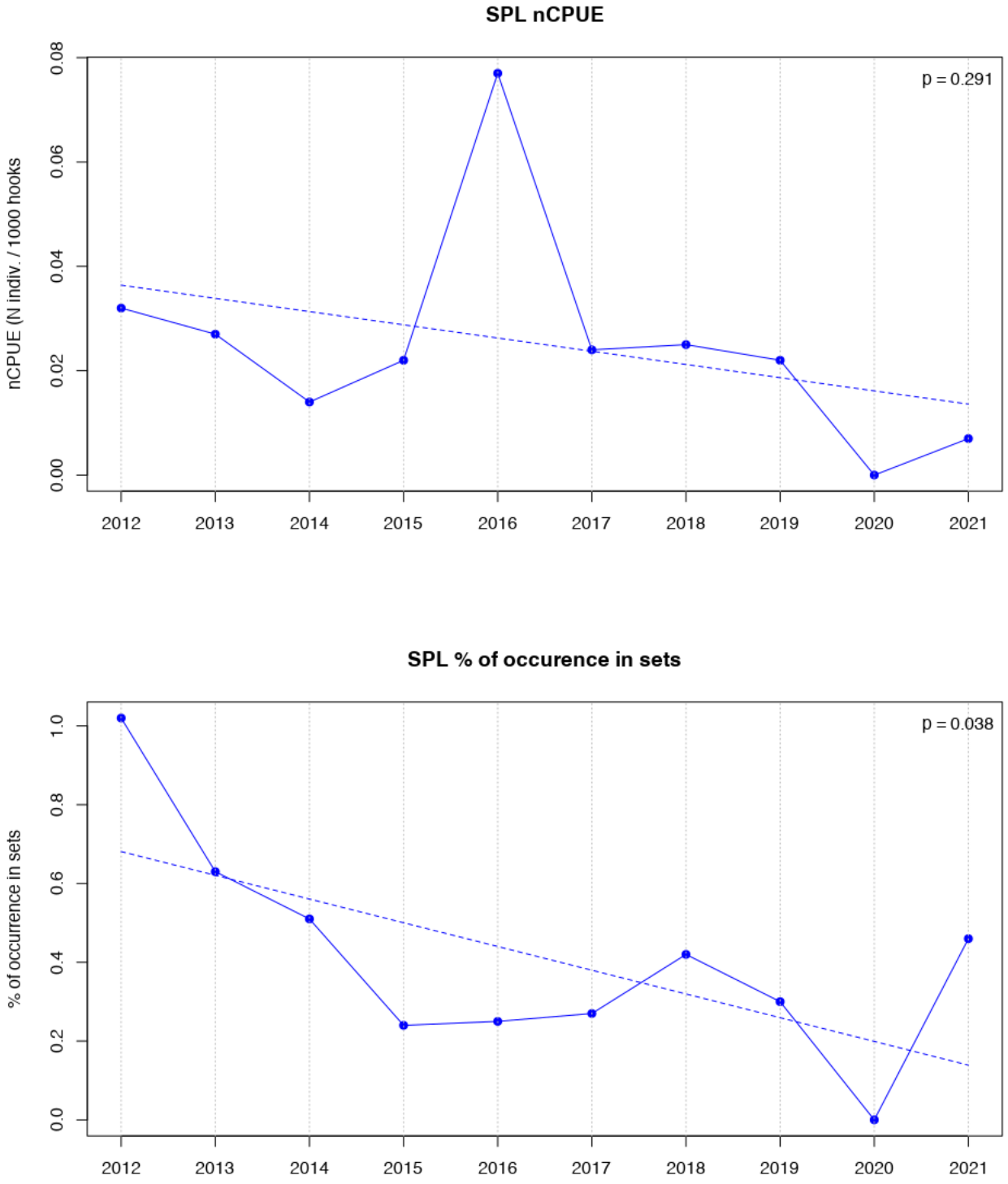

Figure 6. Nominal catch per unit of effort (Number of individuals per 1000 hooks) and percentage of occurrence of SPL in the French longline fishery between 2012 and 2021. The broken line represents the temporal trend

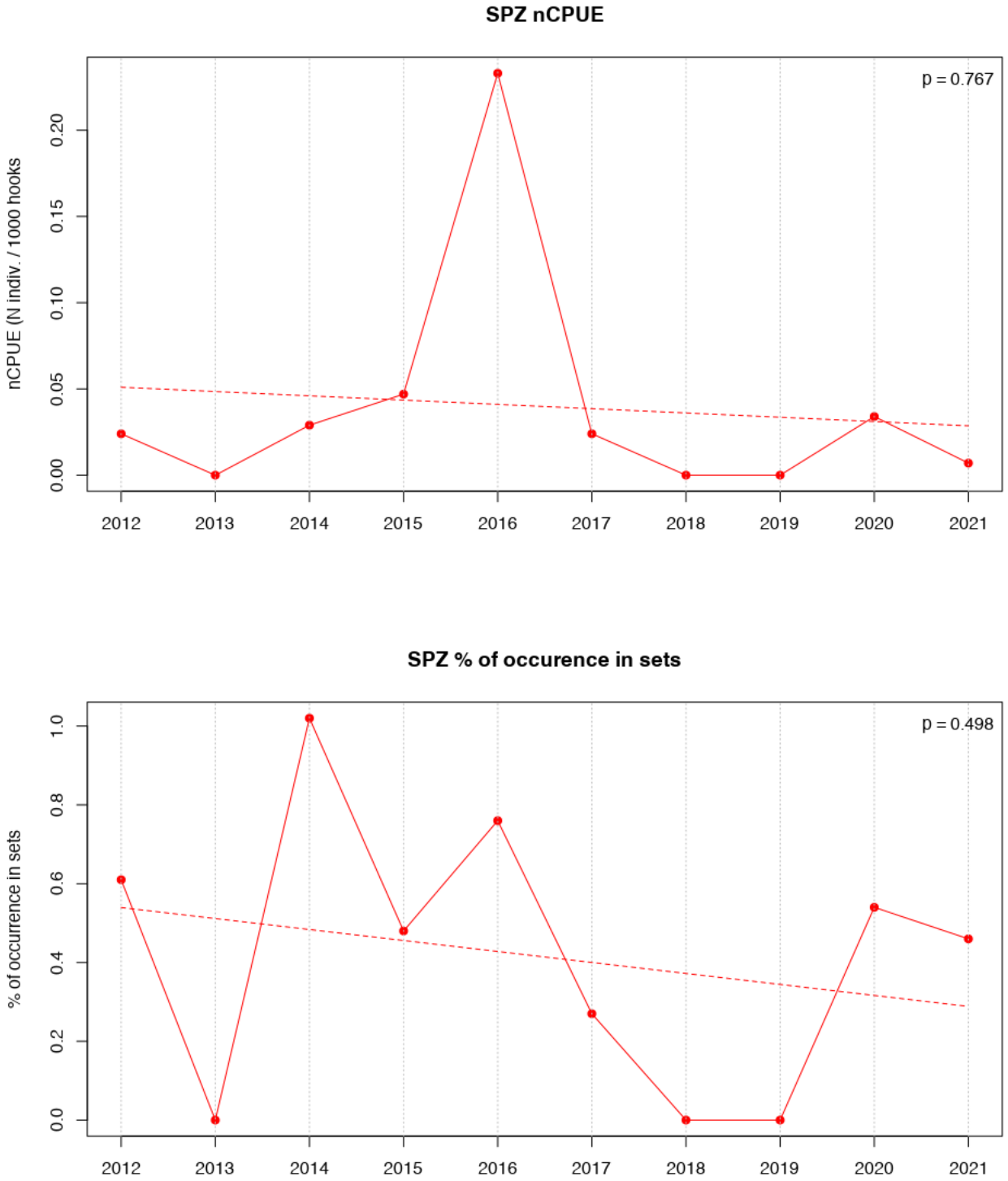

Figure 7. Nominal catch per unit of effort (Number of individuals per 1000 hooks) and percentage of occurrence of SPZ in the French longline fishery between 2012 and 2021. The broken line represents the temporal trend

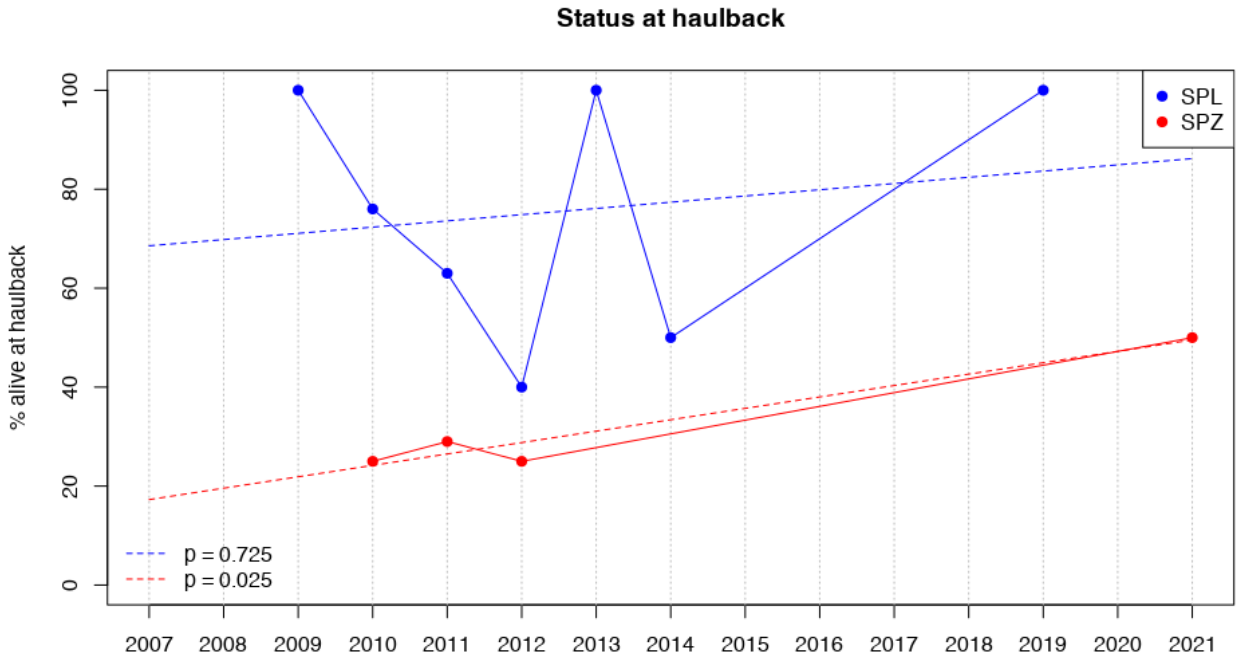

Figure 8. Status at haulback of hammerhead sharks (SPL and SPZ) caught by French longliners

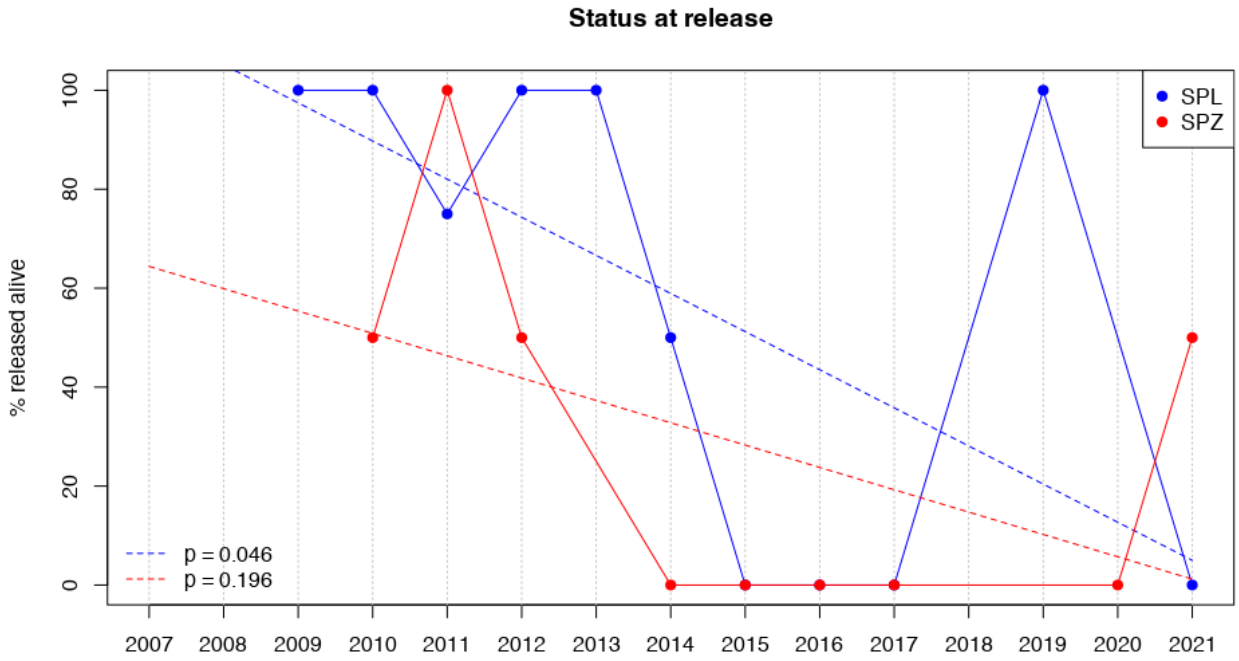

Figure 9. Status at release of hammerhead sharks (SPL and SPZ) caught by French longliners

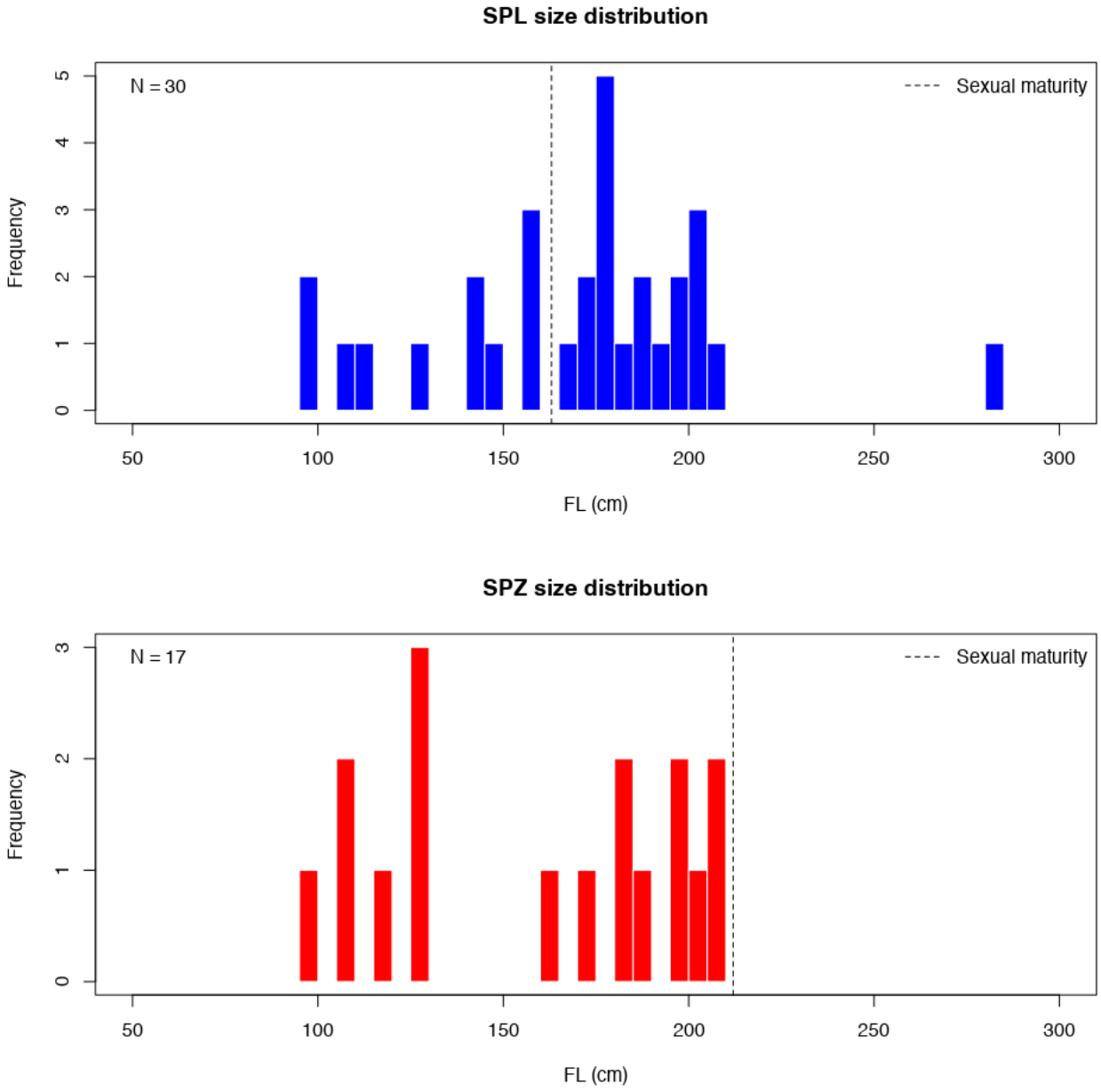

Figure 10. Size distribution of SPL and SPZ caught by French longliners between 2007 and 2021