Received: 23 August 2015
IOTC-2015-WPEB11-29

INTERACTIONS OF OCEANIC WHITETIP SHARKS WITH THE TUNA PURSE SEINE FISHERY IN THE INDIAN OCEAN

Mariana Travassos Tolotti[1,2], Pascal Bach[1], Evgeny Romanov[3] and Laurent Dagorn[1]

[1]Institut de Recherche pour le Développement, UMR MARBEC (IRD, Ifremer, Univ. Montpellier, CNRS)
[2]Universidade Federal de Pernambuco, Departamento de Oceanografia-Recife, Brazil
[3] CAP RUN (Centre Technique d'Appui à la Pêche Réunionnaise) – HYDRÔ REUNION, Magasin n°10, Darse de pêche hauturière, Port Ouest, 97420 Le Port, Île de la Réunion, France

Abstract

The interaction between oceanic whitetip sharks (OCS) and the purse seine fishery in the western Indian Ocean was analyzed, in order to investigate the potential of using this fishery's database to derive abundance indexes and determine population trends for the species. Observer data from the French purse seine fleet combined with a historic database from the Soviet Union were used in the analyses. The combined time series spanned from 1986 to 2014. A well-marked change on the proportion of Fishing Aggregating Devices (FADs) with the presence of oceanic whitetip sharks was observed, fluctuating around 20% from mid 80's to mid 90's and dropping to less than 10% as from 2005. The changes on the OCS/FAD proportion along the years show a clear link between the two distinct databases. The results indicate that the proportion of FADs with OCS could be relevant when deriving abundance trends for the species form multiple data sources.

1. Introduction

The oceanic whitetip shark, *Carcharhinus longimanus*, is a pelagic predator widely distributed in tropical and subtropical areas of all oceans (Compagno, 1984). It is easily distinguishable from the other species of the Carcharhinidae family by the round shape of its long pectoral and dorsal fins, as well as by the white stains in their margins. The species is commonly caught as bycatch by a variety of pelagic fishing gears, such as tuna longlines, gillnets, and purse seines (Bonfil et al., 2008).

Concerns regarding the conservation of oceanic whitetips started to rise substantially in the past decade due to increasing fishing pressure throughout the species range, associated with an acute lack of both knowledge and adequate monitoring of their catches (Baum et al., 2006). As a result, Tuna Regional Fisheries Management Organizations (RFMOs) from all oceans decided to ban landings, storing, and selling of the oceanic whitetip shark (International Commission for the Conservation of Atlantic Tuna Rec. 10-07; Inter-American Tropical Tuna Commission Rec. C-11-10; Western and Central Pacific Fisheries Commission CMM 11-04; Indian Ocean Tuna Commission Res. 13-06). The OCS has also been recently included in CITES appendix II (March 2013, CoP16 Prop. 42).

All of these measures, including the recent listing on CITES appendix II, were taken under the precautionary approach concept and represent a first step towards the conservation of OCS worldwide. Knowledge gaps concerning the species ecology and biology are still wide, imposing a barrier on the development of mitigation measures for fisheries and accurate stock assessment.

The oceanic whitetip shark is believed to have been more severely impacted by pelagic longlines, as its catch rates are usually higher in fisheries using this fishing gear (Rice and Harley, 2012). As a result, the interactions of the species with pelagic longlines have been more often investigated (Cortés et al., 2010; Semba and Yokawa, 2011; Tolotti et al., 2013; Walsh et al., 2009). In the purse seine fishery, on the other hand, these interactions received much less attention. The work presented here is a first look on how this species interacts with the purse seine fishery in the western Indian Ocean. The goal is also to investigate the potential of using this fishery's database to derive abundance indexes and determine population trends for the oceanic whitetip shark in the global pelagic realm.

2. Material and methods

2.1. French database (OT)

Data form 3,339 purse seine sets conducted by the French tuna fleet in the Indian Ocean were analyzed. The time series includes data from the mid 90's (1995 and 96) and from 2005 to 2014. Sets cover a large area of the Indian Ocean, roughly limited by the latitudes of 05°N to 20°S and by the longitudes of 070°E to 040°E (Figure 1). All French data comes from scientific observer programs, either conducted within the framework of specific European Union (EU) research projects in the 1990s, or since 2005, within continuous data collection programs under the European Data Collection Regulations (Council Regulation no. 1543/2000, Commission Regulation no. 1581/2004, Council Regulation no. 199/2008, and Commission Decision 2008/949/EC). All observer programs were developed under the same main objectives (Amandè et al., 2012; Bourjea et al., 2014).

On-board observers were evenly distributed to cover the four quarters of the year. They collected information regarding all fishing activities, including bycatch estimations and size frequencies by species. Each set was recorded on an exact geographic position basis and divided into two distinct fishing strategies, sets on Free Swimming Schools (FSC) and sets on Fish Aggregating Devices (FAD). Sets on both natural and man-made devices were recorded under the same FAD category. Whale-associated sets were treated as free-school sets and sets on whale sharks were pooled with FAD sets. All collected information is gathered in a common database managed by the *Observatoire Thonier* (OT), from where the data presented here was extracted. These observer programs were estimated to cover around 9% of the French purse seine sets in the Indian Ocean (Amandè et al., 2012; Bourjea et al., 2014).

2.2. Historic database (USSR)

Additional historic data were incorporated into the analyses in order to investigate possible changes on population trends. A total of 497 purse seine sets conducted by the Soviet Union (USSR) were analyzed. These fishing operations were carried out between 1986 and 1992

and data was collected by scientific on-board observers in the scope of various programs developed by regional fisheries research institutes and affiliated organizations. Database was developed within framework of YugNIRO[1] research activities in the Indian Ocean. The USSR sets fall inside the area covered by the OT database, roughly ranging from 05°N to 10°S and form 070°E to 050°E (Figure 2). Some fishing sets were also made in the northeastern portion of the Mozambique Channel. Each set was also recorded on an exact position basis and, similarly with OT data, were grouped into two distinct fishing strategies for comparison purposes, free swimming school (FSC) and object associated (here referred as FAD).

2.3. Data analysis

The interaction between oceanic whitetip sharks (OCS) and the tropical purse seine fisheries was analyzed in terms of occurrence per set, not taking into account the number of OCS caught per set but only the presence of the species in a set. For the spatial analysis, sets were grouped into 5°x°5 squares of latitude and longitude. The two datasets were analyzed separately and then compared. To facilitate the comparison, some figures combine the two but their origin is always indicated.

3. Results

3.1. Sampling effort

3.1.1. French database – OT

Of the 3,339 sets analyzed from the French fleet, 32% were done on FSC and 68% were done on FADs (Table 1). The proportion of the two fishing strategies varied considerably along the years, but, with the exception of 2005 and 2007, sets on FADs were always predominant (Figure 3). The number of observed sets also showed a great deal of variation throughout the time series and very low effort was recorded for the years 1996 and 2005 (Figure 4). These low numbers of observed sets are due to transition periods between observer programs. Sampling effort was considerably high on 1995, 2009, 2010 and 2014.

Table 1. Summary results of the interactions between oceanic whitetip sharks and the tuna purse seine fisheries in the Indian Ocean.

	OT		USSR	
	FSC	FAD	FSC	FAD
Number of sets	1055	2284	238	259
Number of sets with OCS	30	135	12	45
Number of OCS caught	48	249	20	175
Proportion (OCS occurrence/set)	0.03	0.06	0.05	0.17
Sets ratio (%)	0.32	0.68	0.48	0.52
OCS occurrence ratio (%)	0.18	0.82	0.21	0.79
OCS catch ratio (%)	0.16	0.84	0.10	0.90

[1] Southern Scientific Research Institute of Marine Fisheries and Oceanography, Kerch, Crimea.

Regarding the spatial distribution of sets, both fishing strategies share the same area (Figure 1). Two effort hot spots are observed for sets on FADs, one inside the Mozambique Channel and another one right around the Equator (from 05° north to south) and between the meridians of 045° and 055° east. The sets on the Mozambique Channel are seasonal, occurring mildly on the 1st quarter of the year and also on the 2nd, when it reaches its peak. There are no sets in the Mozambique Channel during the 3rd and 4th quarters. Still concerning the Channel, the number of sets was remarkably high in 2009 and 2010 when compared with the other years of the time series. Sets on FSC were more frequent in the area bonded by the 05°S and the 10°S parallels and by the 050°E and 060°E meridians.

3.1.2. USSR

In the Soviet Union database the number of sets per fishing strategy was more proportionately balanced, with 259 out of 497 sets done on FADs and 238 on FSC (52% and 48%, respectively – Table 1). This proportion also varied along the years, but remained relatively balanced for most part of the time series (Figure 3). The exceptions were the years 1989, when almost 100% of observed sets were on FSC, and 1991, when no FSC sets were observed. Some variation is seen on the number of observed sets throughout the time series, but not as pronounced as seen on the OTT database (Figure 4). Sampling effort below average is seen on 1988 and 1992.

Sets of both fishing strategies were done on the same area, with FAD sets being more widely spread (Figure 2). The latter strategy was more frequently observed along a "corridor" between 050°E and 065°E, ranging from the Equator up to 05°N and down to 10°S in the squares bounded by 060°E and 065°E. Sets on FSC were mostly concentrated in the square between the Equator and the 05°S parallel and between the 060°E and 065°E meridians. Fishing sets in the Mozambique Channel were only observed during its peak season on the 2nd quarter of the year. Both FSC and FAD sets were observed inside the channel, with a great predominance of sets on FADs.

3.2. OCS occurrence

3.2.1. French database – OT

A total of 165 sets were recorded with the presence of OCS, with 297 oceanic whitetip sharks caught on both fishing strategies (Table 1). The presence of OCS was more frequent on FAD sets, but the presence of this species on FSC sets was not negligible as 16% of sharks were caught with this fishing strategy. Overall, OCS was present in 3% of FSC sets and in 6% of FAD sets. Along the years, the proportion on FAD sets varied and a marked change was observed between mid 90's and the rest of the time series (Figure 4). The proportion of FADs with the presence of OCS went somewhere from 20 to less then 10% between these two periods. The exception is a peak in 2011 and minor one in 2014. Another remark is the extremely low values, way below 5%, seen in 2009 and 2010. The presence of OCS on FSC sets did not vary as much, remaining below 5% for most of the time series (Figure 4). A very high value is seen in 1995, but this must be regarded with caution since its derived from a low sample size, only 9 sets. Interestingly, high proportion peaks are also seen in 2011 and 2014.

The catches of OCS on FADs was highly associated with the equatorial zone, there are no catch records of the species above the 10°N and very few below 10°S (Figure 5). Even with the considerably high effort on the Mozambique Channel during the 2nd quarter the presence of OCS in this area was very weak. A seasonal pattern is not evident. Occurrences were more frequently recorded on the 1st and 3rd quarters. The big 10 degrees square off Tanzania and Kenya and up to the 050°E is an area with frequent occurrences all year round, with the exception of the 4th quarter. Catches on FSC were also more frequent on the equatorial zone, although more occurrences were recorded below the 10°S parallel (Figure 6). The species was more present on FSC sets during the 2nd and 4th quarters, but highest occurrence level was observed on the 3rd. This "hot spot" also needs to be looked at with caution as observed fishing effort in this square is very low, only 2 sets.

3.2.2. USSR

From the historic data, 57 sets were recorded with the presence of OCS, totaling 195 oceanic whitetip sharks caught on both fishing strategies (Table 1). The presence of OCS was also more frequent on FAD sets, representing 90% of the total number of sharks caught. Combining the years, OCS was present in 5% of FSC sets and in 17% of FAD sets. The proportion of FADs with OCS did not varied a great deal throughout the time series, remaining at round 20% (Figure 4). The year of 1987 was the exception showing a value below 10%. No sharks were caught on FADs in 1988 and 1989, which could be explained by the low sample size of these years. The presence of OCS on FSC sets exhibited a crescent trend, varying from 3% in 1986 to 16% in 1990 (Figure 4). Despite the reasonable sample size in 1989, no OCS catch was reported for this year. A zero catch scenario is also seen in 1992.

Spatially, the presence of OCS on FAD sets varied between the quarters of the year, which might suggest a seasonal effect (Figure 7). The species was much more frequent on FAD sets from the second half of the year (3rd and 4th quarters). A similar spatial pattern is seen in these two quarters as their higher proportion squares occur in the same area. These squares are located along the Equator, up to 05°N, from the 050°E to the 065°E meridians. The Mozambique Channel was not heavily sampled as on the OT database, but the few sets conducted on the 2nd quarter resulted on a few OCS catches. The occurrence of OCS on FSC sets is very low and dispersed across the fishing area, which prevents the identification of spatial patterns (Figure 8). On most of the 5 degrees squares where FSC sets were observed no OCS catch was recorded.

4. Discussion

The oceanic whitetip shark is believed to associate with floating objects. This statement is supported by catch data from tuna purse seine fisheries setting on fishing aggregating devices, either natural or manmade (Clarke et al., 2013; Torres-Irineo et al., 2014). The species is the second mostly caught shark by the tropical tuna purse seine fishery and its catch rates are considerably higher on FAD sets (Amandè et al., 2012; Santana et al., 1998; Stretta et al., 1998). This pattern, suggesting an associative behavior around drifting objects, was also observed on both OT and USSR databases. Still, the number of OCS caught with free-swimming tuna schools was meaningful, constituting at least 10% of total OCS catch. This result indicates that the association of oceanic whitetip sharks with free-swimming tuna

is not a rare random event, as, although not often, it occurs systematically. Sets on FSC should be taken into account when estimating population size.

When looking at the database as a whole, historic and recent, a well-marked change on the proportion of FADs with the presence of oceanic whitetip sharks is seen on the time series chart (Figure 4). From mid 80's to mid 90's this proportion fluctuated around 20% and dropped to less than 10% as from 2005. There are a few odd peaks and troughs, but, as the general pattern is quite evident, this could be a result of noise due to variations on sample size and area. Taking into account that the number of fish aggregating devices has greatly increased since the 90's (Dagorn et al., 2013b; Maufroy et al., 2015), the decrease in the proportion of FADs with OCS by more than 10% could indicate an important population decline. Following the simple line of thought that a greater number of FADs would increase the chances of an OCS finding and associating with one, we would expect to see an increase on the proportion of FADs with the species (assuming, of course, the population size remained stable). The data, however, shows that this in not the case. The populations of oceanic whitetip sharks are believed to have suffered substantial declines in the Atlantic and Pacific Oceans (Baum and Blanchard, 2010; Rice and Harley, 2012). Similar studies have not been conducted in the Indian Ocean, but this first analysis may indicate similar scenario. Another possible interpretation for the decline of OCS occurrence per FAD could be a sharp increase on FAD densities combined with a small and stable population size. In this scenario, the proportion OCS/FAD would simply decrease because there aren't enough sharks to aggregate around that many FADs. The analyzed data do not provide a straightforward interpretation, as both hypotheses seem plausible. A thorough analysis taking other factors into account, especially FAD density trends, is necessary to draw more definite conclusions.

The data shown on Figure 4 comes from two distinct databases (USSR and OT), yet the changes on the OCS/FAD proportion along the years show a clear link between them. Proportions derived from the early years of the OT database are at the same magnitude order of the proportions derived from the historic database (USSR). This indicates that this index (proportion of FADs with OCS) could be relevant when deriving trends form multiple data sources. The proportion of sets on FSC with the presence of oceanic whitetip seems to have decreased between historic and recent data, however this change was minor and a well-defined trend is not evident. As discussed above, the capture of OCS on free swimming schools in not negligible, but still is very sparse. Being an index derived from an less frequent event, the proportion of OCS on FSC sets is more subject to noise than the proportion on FAD sets, making it more difficult to pick up trends and requiring a much bigger sample size. This issue becomes more evident when looking at the spatial distributions of the occurrence of OCS/FSC sets on Figure 8. Even though the FSC catches should be taken into account on population size estimates, when it comes to deriving indexes and examining trends the focus should be on FAD sets.

Seasonal patterns could not be distinguished when looking at the distributions of oceanic whitetip occurrences per set. The data, however, indicates that there is a spatial component to be considered. The Mozambique Channel was heavily sampled on the OT database, but both total catch and occurrence rate were very low in this area (Figures 5 and 6). The

extremely low values of FADs with OCS seen in Figure 4 seem to be influenced by this spatial component. In the years in question, 2009 and 2010, the number of sets inside the Channel was around 6 times higher than the other years. Since, according to the analyzed data, the species is less observed in purse seiners catches in this area these high effort values pulled the OCS/FAD proportion down. This is an interesting result to be investigated further, specially considering that the Mozambique Channel is an area with great density of floating objects (Dagorn et al., 2013a). The oceanic whitetip shark is wide-ranging pelagic shark known to travel thousands of kilometers (Howey-Jordan et al., 2013; Filmalter et al., 2012; Musyl et al., 2011). The horizontal movements of the species appear to be random, and this fact combined with its low catch rates might prevent seasonal patterns from emerging when looking at the distribution of occurrences. Therefore, the absence of marked seasonal patterns on the analyzed databases could simply be a result of the migratory nature of the species.

Using longline data to derive bycatch population trends is typically problematic, as small variations on gear type and fishing strategy can greatly impact the catchability of a species, which interferes on the relationship between its catch rate and its actual abundance (Ward, 2008). Abundance trends for the oceanic whitetip have been heavily questioned due to standardization problems (Baum et al., 2003; Burgess et al., 2005) and question marks still remain regarding the species population status. The proportion of fishing aggregating devices with the presence of oceanic whitetip sharks could potentially provide a simple population trend index, with the advantage of a probably lower catchability bias when compared to pelagic longline catches. To further investigate population size trends for the endangered OCS derived from the purse seine fishery, however, key information on the evolution of FAD densities is also required. The number of drifting objects has clearly increased, but estimations of by how much and at which rate are still lacking.

5. Acknowledgments

This work was made possible thanks to the European Data Collection Framework and the *Observatoire Thonier* of IRD. The authors would also like to acknowledge *France Filière Pêche* for providing a fellowship to M.T. Tolotti.

6. References

Amandè, M.J., Chassot, E., Chavance, P., Murua, H., De Molina, A.D., Bez, N., 2012. Precision in bycatch estimates: The case of tuna purse-seine fisheries in the Indian Ocean. ICES J. Mar. Sci. 69, 1501–1510. doi:10.1093/icesjms/fss106

Baum, J., Medina, E., Musick, J.A., Smale, M., 2006. Carcharhinus longimanus [WWW Document]. IUCN Red List Threat. Species. URL www.iucnredlist.org (accessed 8.18.15).

Baum, J.K., Blanchard, W., 2010. Inferring shark population trends from generalized linear mixed models of pelagic longline catch and effort data. Fish. Res. 102, 229–239. doi:10.1016/j.fishres.2009.11.006

Baum, J.K., Myers, R. a, Kehler, D.G., Worm, B., Harley, S.J., Doherty, P. a, 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science 299, 389–392. doi:10.1126/science.1079777

Bonfil, R., Clarke, S., Nakano, H., Camhi, M.D., Pikitch, E.K., Babcock, E.A., 2008. The biology and ecology of the oceanic whitetip shark, Carcharhinus longimanus. Sharks open Ocean Biol. Fish. Conserv. 128–139.

Bourjea, J., Clermont, S., Delgado, A., Murua, H., Ruiz, J., Ciccione, S., Chavance, P., 2014. Marine turtle interaction with purse-seine fishery in the Atlantic and Indian oceans: Lessons for management. Biol. Conserv. 178, 74–87. doi:10.1016/j.biocon.2014.06.020

Burgess, G.H., Beerkircher, L.R., Cailliet, G.M., Carlson, J.K., Cortés, E., Goldman, K.J., Grubbs, R.D., Musick, J. a., Musyl, M.K., Simpfendorfer, C. a., 2005. Is the collapse of shark populations in the Northwest Atlantic Ocean and Gulf of Mexico real? Fisheries 30, 19–26. doi:10.1577/1548-8446(2005)30[19:ITCOSP]2.0.CO;2

Clarke, S.C., Harley, S.J., Hoyle, S.D., Rice, J.S., 2013. Population Trends in Pacific Oceanic Sharks and the Utility of Regulations on Shark Finning. Conserv. Biol. 27, 197–209. doi:10.1111/j.1523-1739.2012.01943.x

Compagno, L.J. V, 1984. Fao Species Catalogue Vol . 4 , Part 1 Sharks of the World. Fao Fish. Synopsis 4, 249.

Cortés, E., Arocha, F., Beerkircher, L., Carvalho, F., Domingo, A., Heupel, M., Holtzhausen, H., Santos, M.N., Ribera, M., Simpfendorfer, C., 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. Aquat. Living Resour. 23, 25–34. doi:10.1051/alr/2009044

Dagorn, L., Bez, N., Fauvel, T., Walker, E., 2013a. How much do fish aggregating devices (FADs) modify the floating object environment in the ocean? Fish. Oceanogr. 22, 147–153. doi:10.1111/fog.12014

Dagorn, L., Holland, K.N., Restrepo, V., Moreno, G., 2013b. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? Fish Fish. 14, 391–415. doi:10.1111/j.1467-2979.2012.00478.x

Filmalter, J., Forget, F., Poisson, F., Vernet, A.-L., Bach, P., Dagorn, L., 2012. Vertical and horizontal behaviour of silky, oceanic white tip and blue sharks in the western Indian Ocean (No. WPEB08–23).

Howey-Jordan, L. a., Brooks, E.J., Abercrombie, D.L., Jordan, L.K.B., Brooks, A., Williams, S., Gospodarczyk, E., Chapman, D.D., 2013. Complex Movements, Philopatry and Expanded Depth Range of a Severely Threatened Pelagic Shark, the Oceanic Whitetip (Carcharhinus longimanus) in the Western North Atlantic. PLoS One 8. doi:10.1371/journal.pone.0056588

Maufroy, A., Chassot, E., Joo, R., Kaplan, D.M., 2015. Large-Scale Examination of Spatio-Temporal Patterns of Drifting Fish Aggregating Devices (dFADs) from Tropical Tuna Fisheries of the Indian and Atlantic Oceans. PLoS One 10, e0128023. doi:10.1371/journal.pone.0128023

Musyl, M.K., Brill, R.W., Curran, D.S., Fragoso, N.M., McNaughton, L.M., Nielsen, A., Kikkawa, B.S., Moyes, C.D., 2011. Postrelease survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. Fish. Bull. 109, 341–368. doi:10.1186/1471-2199-9-107

Rice, J., Harley, S., 2012. Stock assessment of oceanic whitetip sharks in the western and central Pacific Ocean. West. Cent. Pacific Fish. Comm. WCPFC-SC8-.

Santana, J.C., Molina, A.D. De, Molina, R.D. De, Ariz, J., Stretta, J.M., Domalain, G., 1998. Lista faunistica de las especies asociadas a las capturas de atun de los flotas de cerco comunitarias que faenan en las zonas tropicales de los oceanos Atlantico e Indico. Collect. Vol.Sci. Pap. ICCAT 48, 129–137.

Semba, Y., Yokawa, K., 2011. Trend of standardized CPUE of oceanic whitetip shark (Carcharhinus longimanus) caught by Japanese longline fishery in the Indian Ocean 1–9.

Stretta, J.-M., Delgado De Molina, A., Ariz, J., Domalain, G., Santana, J.C., Séret, B., 1998. Analyse des prises d'élasmobranches par les senneurs français et Espagnols en Atlantique tropical oriental, en 1995. Collect. Vol. Sci. Pap. ICCAT 48, 81–89.

Tolotti, M.T., Travassos, P., Frédou, F.L., Wor, C., Andrade, H.A., Hazin, F., 2013. Size, distribution and catch rates of the oceanic whitetip shark caught by the Brazilian tuna longline fleet. Fish. Res. 143, 136–142. doi:10.1016/j.fishres.2013.01.014

Torres-Irineo, E., Amandè, M.J., Gaertner, D., de Molina, A.D., Murua, H., Chavance, P., Ariz, J., Ruiz, J., Lezama-Ochoa, N., 2014. Bycatch species composition over time by tuna purse-seine fishery in the eastern tropical Atlantic Ocean. Biodivers. Conserv. 23, 1157–1173. doi:10.1007/s10531-014-0655-0

Walsh, W. a., Bigelow, K. a., Sender, K.L., 2009. Decreases in Shark Catches and Mortality in the Hawaii-Based Longline Fishery as Documented by Fishery Observers. Mar. Coast. Fish. 1, 270–282. doi:10.1577/C09-003.1

Ward, P., 2008. Empirical estimates of historical variations in the catchability and fishing power of pelagic longline fishing gear. Rev. Fish Biol. Fish. 18, 409–426. doi:10.1007/s11160-007-9082-6

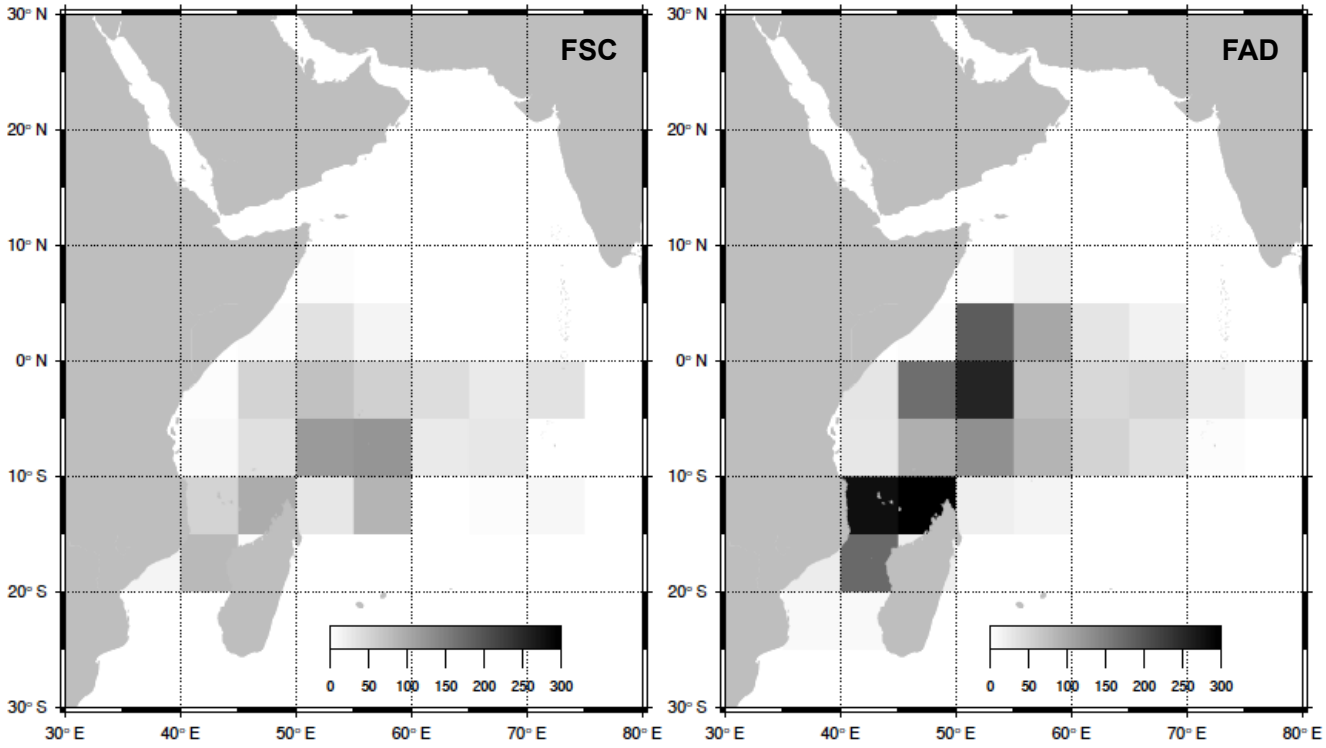

Figure 1. Distribution of the observed fishing sets from the French tuna purse seine fleet (OT) operating in the western Indian Ocean between 1995 and 2014. Right panel represents sets on Free Swimming Schools (FSC) and left panel sets on Fish Aggregating Devices (FAD).

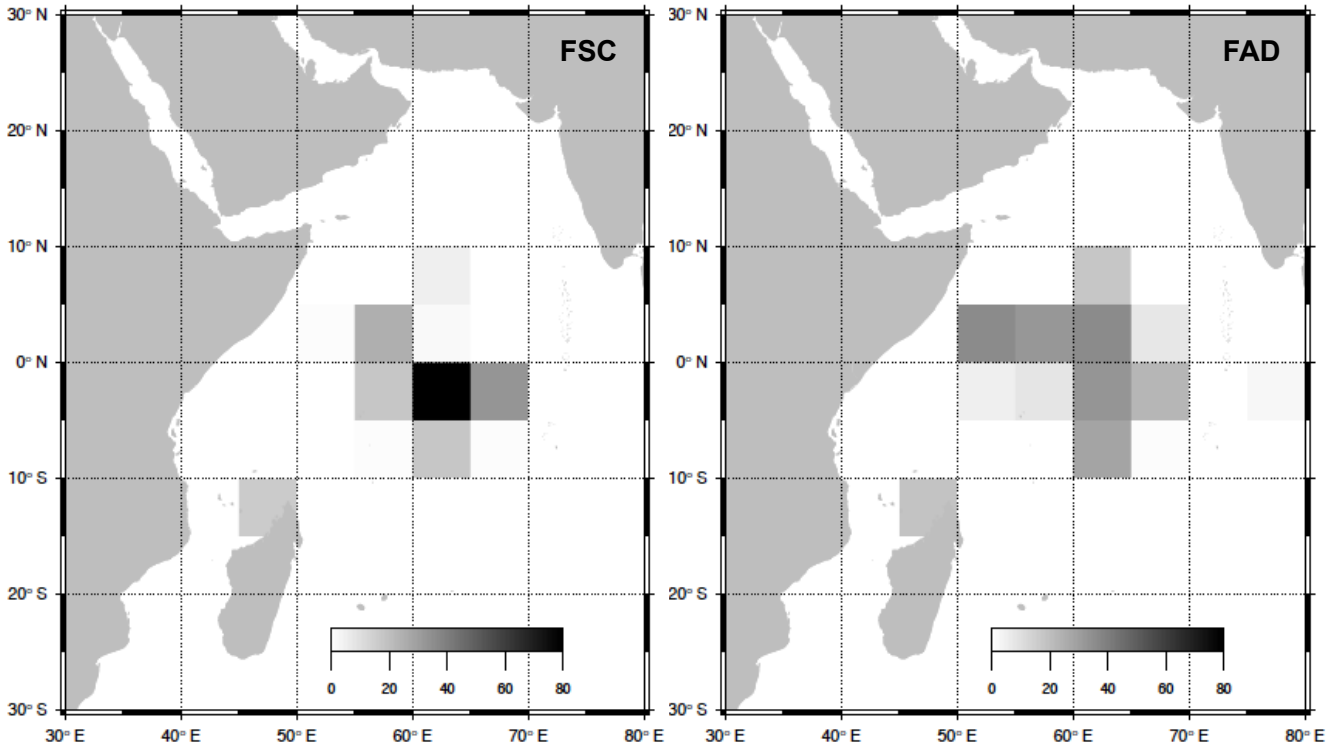

Figure 2. Distribution of tuna purse seine sets from the Soviet Union historic surveys (USSR) conducted in the western Indian Ocean between 1986 and 1992. Right panel represents sets on Free Swimming Schools (FSC) and left panel sets on Fish Aggregating Devices (FAD).

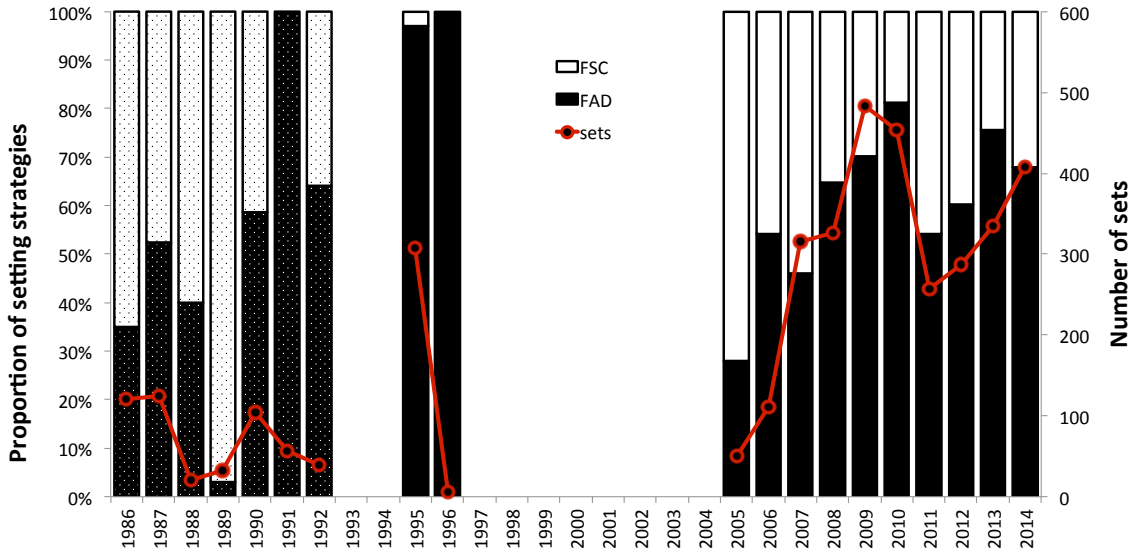

Figure 3. Observed tuna purse seine sets in the western Indian Ocean highlighting the proportion between sets on Free Swimming Schools (FSC) and on Fish Aggregating Devices (FAD). The shaded bars represent the historic database from USSR.

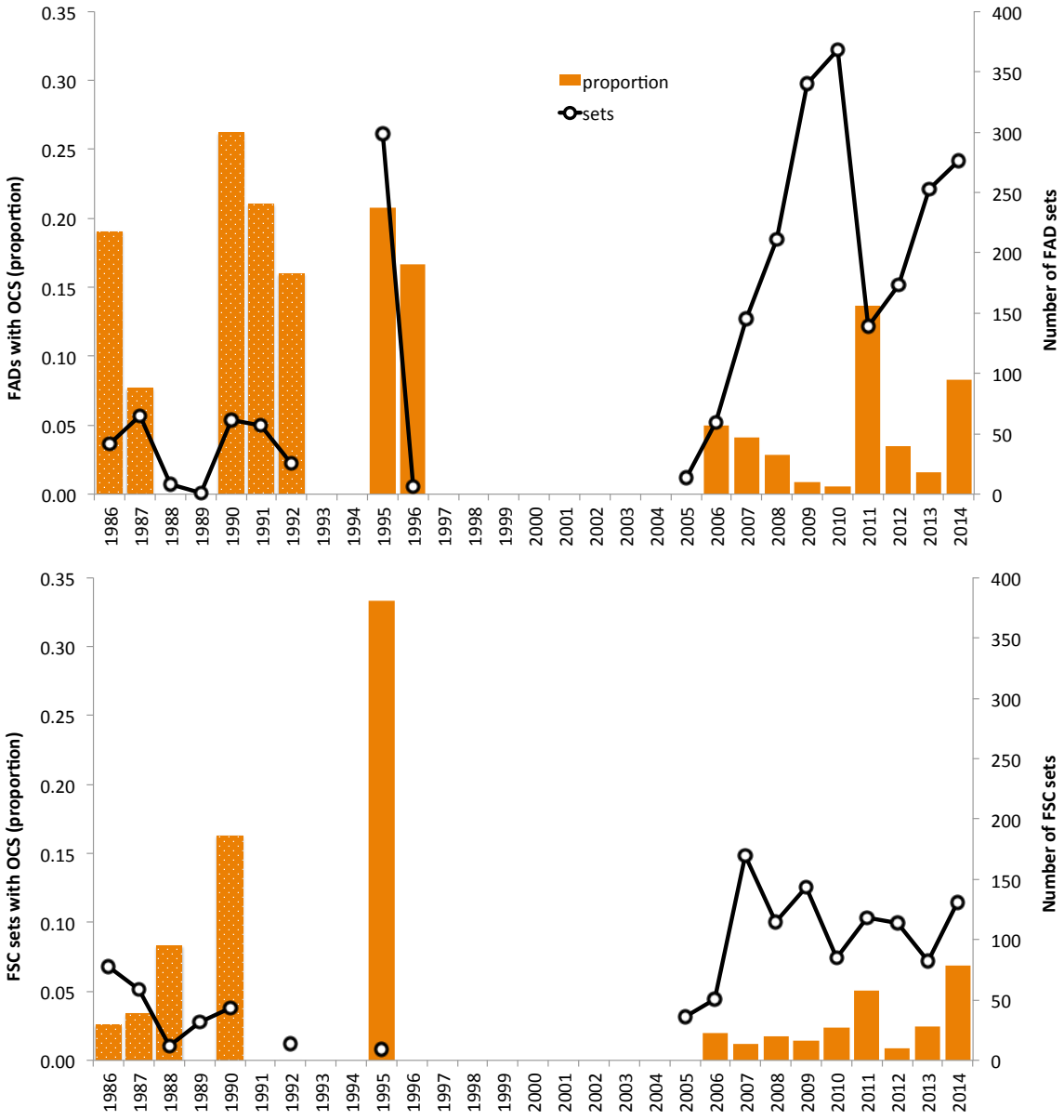

Figure 4. Proportion between sets with the presence of oceanic whitetip sharks (bars) and the total number of sets (points). Top panel shows the proportion on FAD sets and bottom panel on FSC. The shaded bars represent the historic database from USSR.

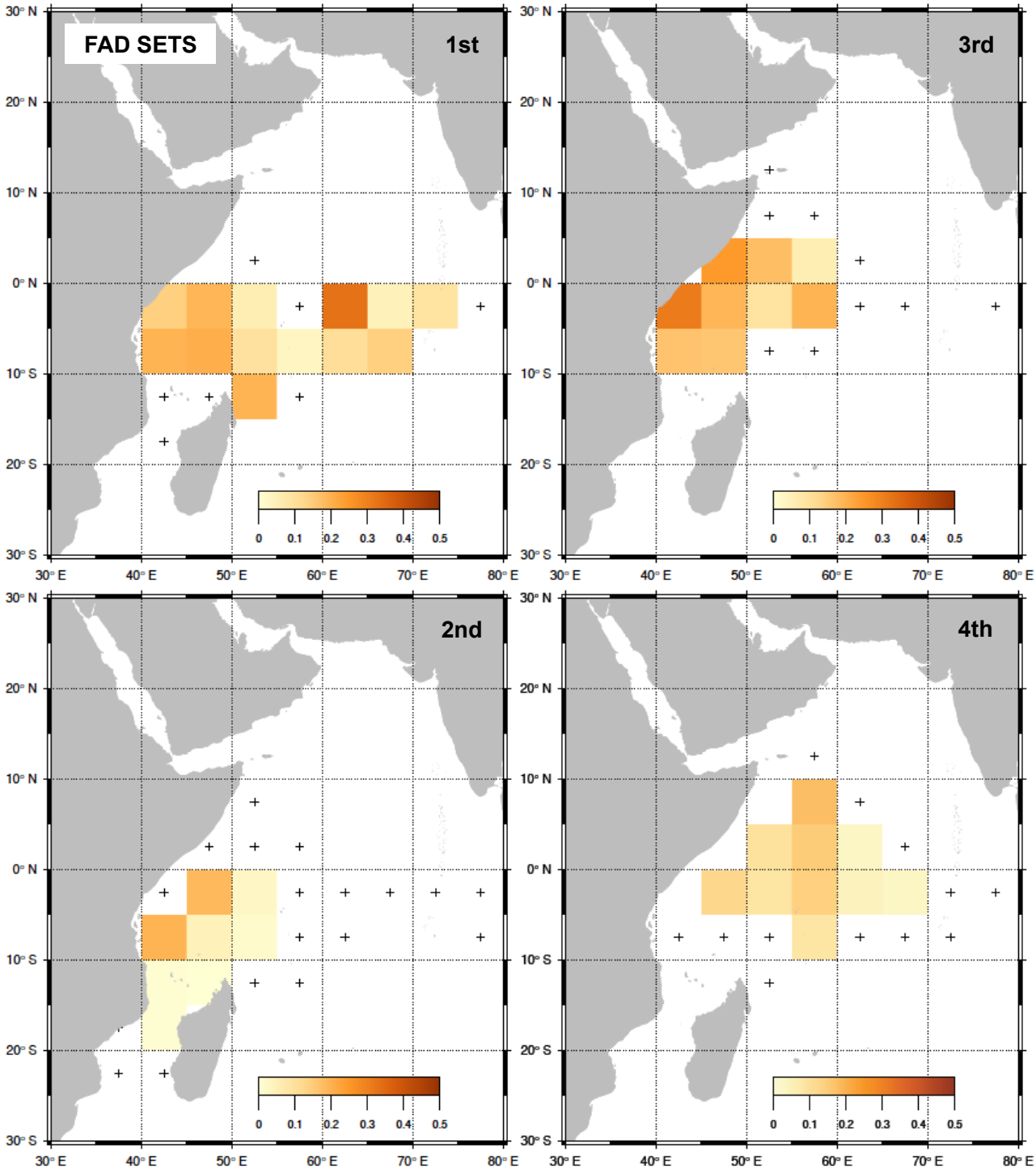

Figure 5. Quarterly distribution of the proportion of oceanic whitetip sharks on FAD sets from the French tuna purse seine fleet (OT) operating in the western Indian Ocean between 1995 and 2014.

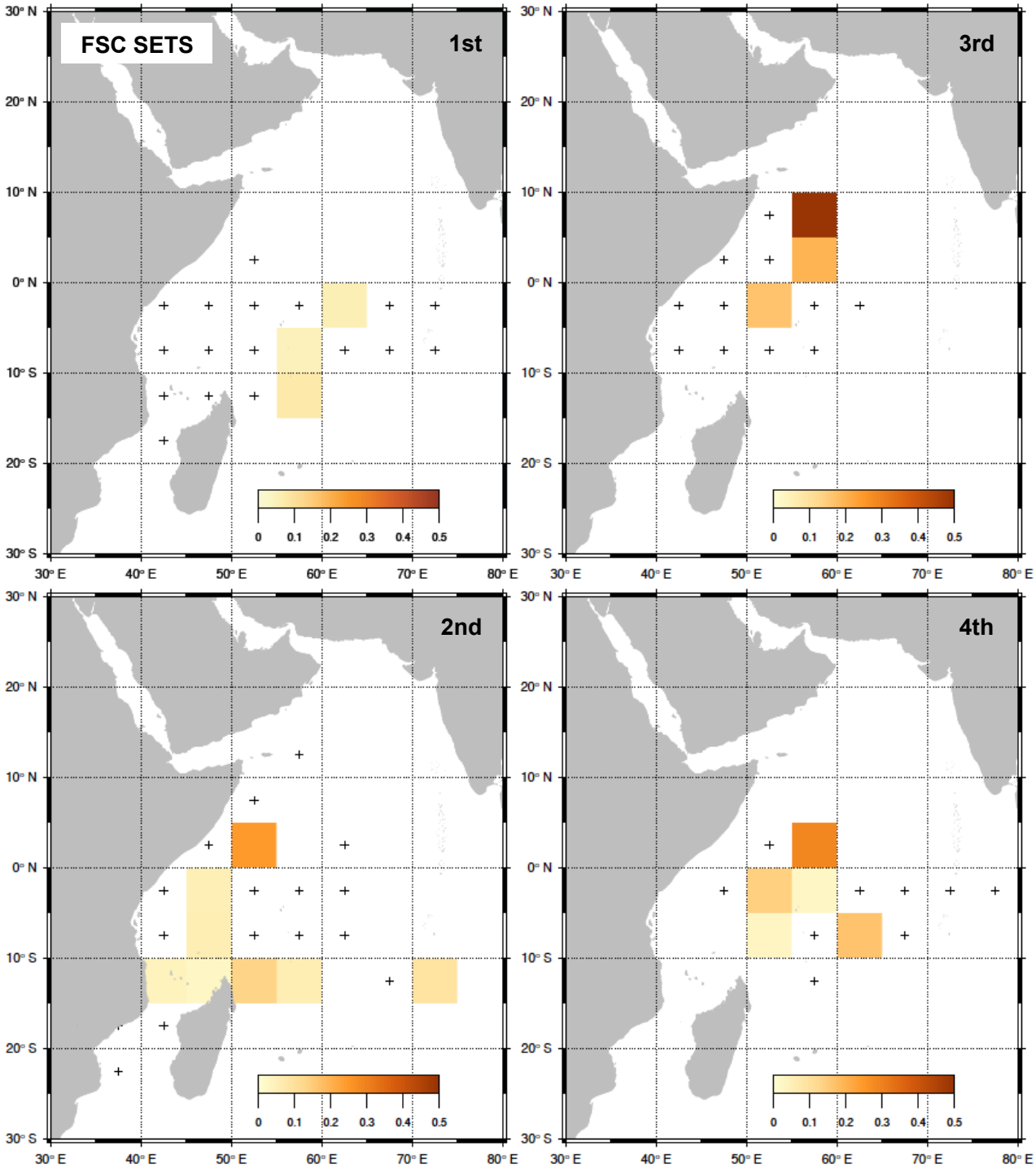

Figure 6. Quarterly distribution of the proportion of oceanic whitetip sharks on FSC sets from the French tuna purse seine fleet (OT) operating in the western Indian Ocean between 1995 and 2014.

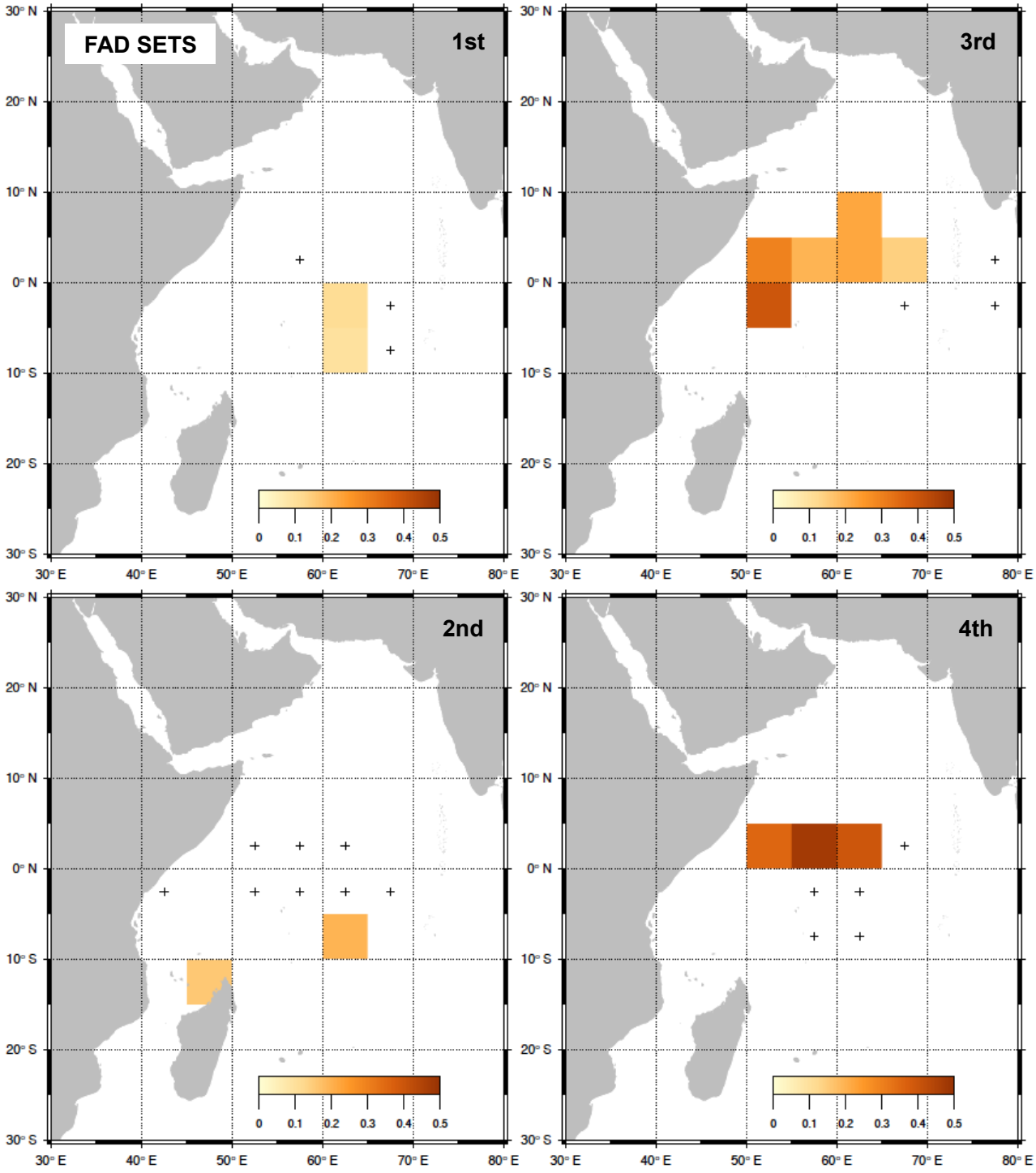

Figure 7. Quarterly distribution of the proportion of oceanic whitetip sharks on FAD sets from the Soviet Union historic surveys (USSR) conducted in the western Indian Ocean between 1986 and 1992.

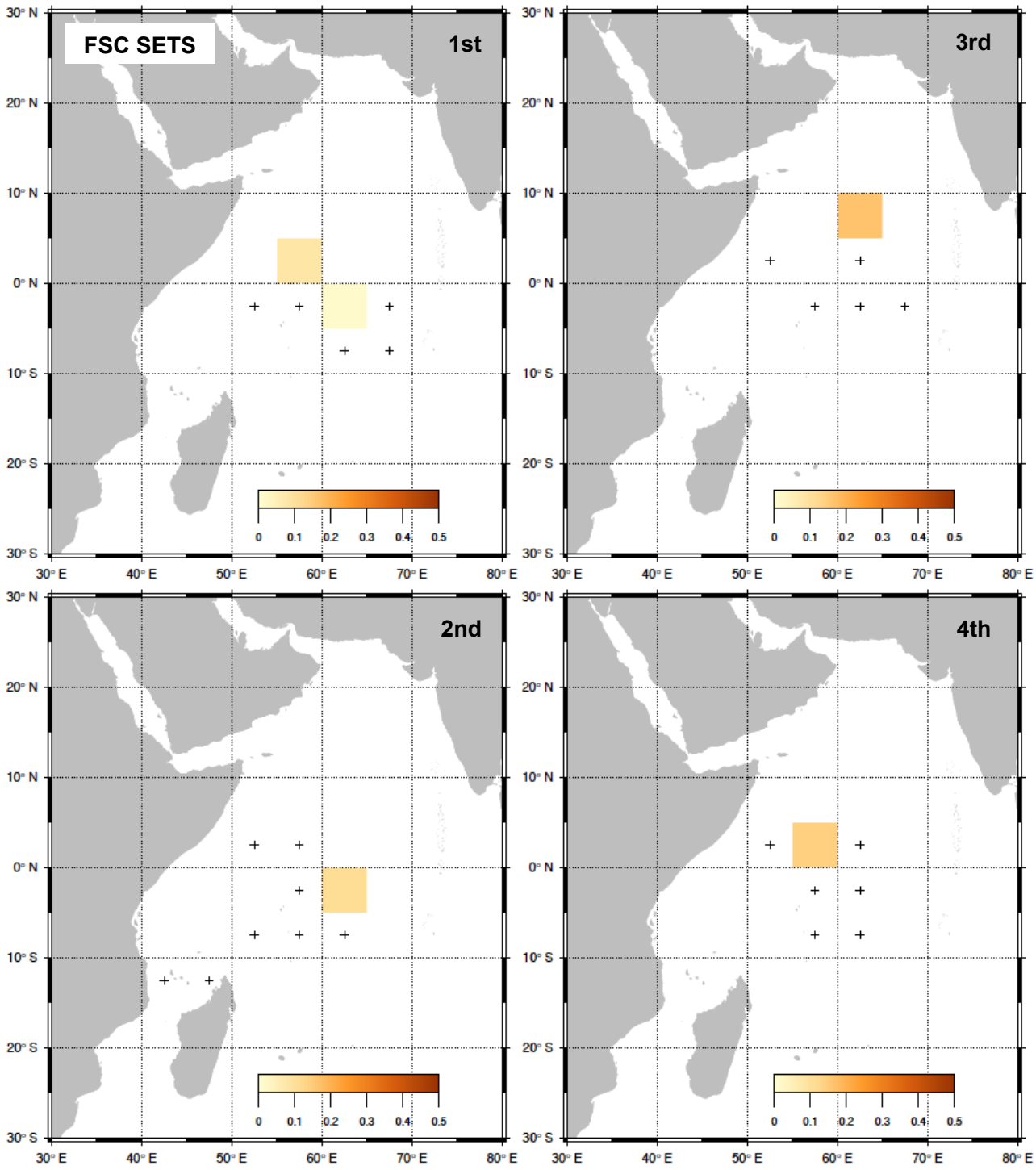

Figure 8. Quarterly distribution of the proportion of oceanic whitetip sharks on FSC sets from the Soviet Union historic surveys (USSR) conducted in the western Indian Ocean between 1986 and 1992.