Assessment on accidentally captured silky shark post-release survival in the Indian Ocean tuna purse seine fishery

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Satellite Archival tagging programs are key to evaluate post-release mortality of Endangered, Threatened, and Protected species that are caught incidentally in fishing operations. This work presents results of a tagging program conducted on purse seiners under ECHEBASTAR company, aimed at assessing post-release survival of silky sharks caught in association with tuna schools and released according to the Code of Good Practices. In two fishing trips carried out during 2020 and 2021, sixty silky sharks were tagged (28 and 32 silky sharks in the first and second trip, respectively) with 37 SPATs and 23 MiniPATs. A vitality index based on state and behavior at release was also assigned to all the sharks caught accidentally. The overall predicted silky shark survival was close to 40% based on vitality index derived from tagged sharks. Shark survivorship decreased as the fishing operation advanced and vitality index declined. This post-release survival estimate duplicates previous estimations obtained in purse seiners. The experience gained over time in the correct application of best practices and fauna release devices installed on-board (i.e., the bycatch conveyor belt) contribute to reducing shark mortality in the purse seiner fishery.

KEYWORDS: Silky shark, C. falciformis, post-release survival, FADs, purse seiner, tropical tuna

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1. Introduction

Due to the increasing fishing pressure, silky shark abundance, as is the case for other pelagic sharks, has markedly decreased during the last half century (Herath & Maldeniya, 2013; Pacoureau et al., 2020). This species is currently listed as vulnerable by the IUCN Red List of Endangered Species[4]. In the Indian Ocean the Ecological Risk Assessments (ERAs) identified silky sharks among the species with higher vulnerability risk for longline and purse seine (Murua et al., 2012; 2018). Silky shark catch is conducted mainly by gillnets and longlines in the Indian Ocean (Herath 2012, IOTC, 2022). A preliminary data stock assessment indicated that the population status of silky sharks in the Indian Ocean is uncertain (Ortiz de Urbina, 2018; IOTC, 2022; Cramp et al. 2021). In general, reported catch is considered an underestimation and uncertainties exist due to issues regarding lack of reporting to species level (Murua et al. 2013; IOTC, 2022). Based on reconstructed catches using observer catch ratios (e.g. silky shark catch over total tuna target catch), silky shark could be the second major species of shark caught in the Indian Ocean (Murua et al., 2013).

Due to their aggregating behaviour around FADs and the overlap of the juvenile silky shark habitat with tropical tuna purse seine fishery, silky sharks are common in FAD sets and it is the most important bycatch shark species for tropical tuna purse seiners (i.e., 95% of the shark interactions) (Filmalter et al., 2011; Gilman 2011; Garcia and Herrera, 2018; Hutchinson et al., 2019, Ruiz et al., 2018). Despite this, FAD purse seine shark bycatch ratios remain low in comparison to other fisheries (Garcia and Herrera, 2018; Perez-Roda et al., 2019; Gilman et al., 2020; Murua et al. 2021).

To reduce shark mortality, EU and Seychellois purse seine vessels have adopted shark bycatch best handling and safe release practices (Poisson et al., 2014; Grande et al., 2019; Maufroy et al., 2020; Zolett and Swimmer, 2019; Wain et al., 2022). Among those best practices, some vessels have adapted the upper or lower decks by installing specific release devices for fauna such as hoppers, ramps, and bycatch release conveyor belts (Murua et al., 2021). Post release survival studies in purse seiners have indicated that shark mortality is highly dependent on the landing stage at which is handled and released (e.g., entangled in the net, 1st brail, posterior brails) and the state of the specimen at release (Poisson et al. 2014b, Hutchinson et al., 2015, Filmalter et al., 2015b, Eddy et al., 2016; Onandia et al., 2021). The latest post-release survival estimates carried out in the Indian Ocean indicate that the application of best practices for handling and release could contribute up to 43% of bycaught sharks surviving, in vessels with a bycatch release device. In this particular case, being a combination of adequate implementation of best release practices in the working deck plus having a conveyor belt in the lower deck to quickly release sharks that were not detected in the upper deck (Murua et al., 2021; Onandia et al., 2021). If combined with other mitigation measures, both active and passive measures (i.e., the use of non-entangling FADs, implementing fishing strategies such as avoiding sets on small schools to minimize bycatch; release sharks from the net), shark mortality could be reduced by 60-65% (Restrepo et al., 2016, 2019).

This document aims to update the work of Onandia et al. (2021) and further investigate the post-release survivorship of silky sharks in the Indian Ocean using POP-UP tagging when released with best handling and release practices with the help of specialised release equipment in tuna purse seine vessels. This study has been supported by ECHEBASTAR fishing company.

[4] https://www.iucnredlist.org/ja/species/39370/117721799

2. Material and Methods

2.1. Field work

Two fishing trips were carried out in two purse seine vessels from ECHEBASTAR Company in the Indian Ocean. The first trip took place from 22 October to 23 November 2020 and the second trip from 30 September to 19 October 2021. The survey area comprises the waters north of Seychelles up to 9ºN latitude and between longitudes 50ºE and 63ºE in the Western Indian Ocean (Fig. 1).

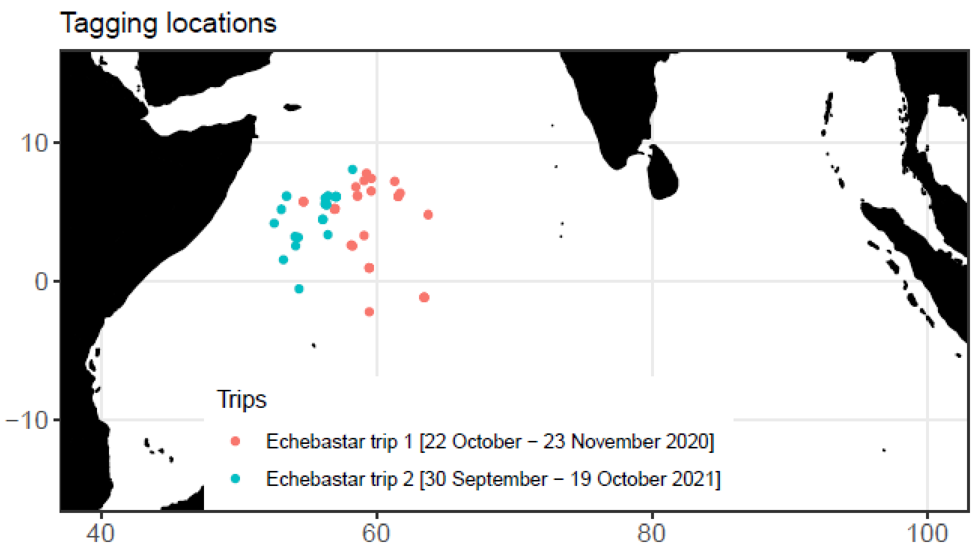

Fig 1. Positions of sets in which Silky sharks (*C. Falciformis*) were tagged with SPAT or MiniPATs in 2020 (n =28) and 2021 (n =32)

In each interaction with *C. falciformis*, the following variables were recorded:

- sex (female, male, indeterminate or unknown),
- total length in cm (TL),
- number of the brail in which the specimen was taken on board (1st, 2nd, 3rd brail and subsequent),
- position in the brail (up, medium, bottom),
- time when the shark was brailed on board and released,
- mode of release: (i) using the brailer, (ii) using light equipment such as stretcher, fabric, *sarria* or cargo net, (iii) using specific equipment such as a hopper, conveyor-belt or ramps, (iv) manually from deck, (v) after disentangling from hauling net;
- vitality index, —i.e., status of the animal at release based on the states proposed by Heuter and Manire (1994):
    - (i) excellent (very active and energetic, strong signs of life on deck and when returned to water);

- (ii) good (active and energetic, moderated signs of life on deck and when returned to water);
- (iii) correct (tired and sluggish, limited signs of life, moderate revival time required when returned to water, slow or atypical swimming away);
- (iv) poor (exhausted, no signs of life, bleeding from gills, jaw or cloaca, long revival time required when returned to water, limited or no swimming observed upon release);
- (v) very poor or death: moribund, no signs of life, excess bleeding from gills, jaw, or cloaca, unable to revive upon return to water, no swimming movement, sinks.

- behavior after release (swim vigorously, swim slowly near the surface, sinks with little movement).

Also, in each interaction, the observer recorded if the handling and release practices applied followed the guidelines defined in the Code of Good Practices (Grande et al., 2019).

A total of 60 sharks were tagged with POP-UP satellite archival tags, of which 37 were SPAT[5] and 23 MiniPATs[6] (Wildlife Computers, Inc.), during two fishing trips and two different stages of the fishing operation: *i)* when releasing the shark on the upper deck or *ii)* when releasing the shark using the bycatch release conveyor belt installed in the lower deck. The tags were attached with a 10 cm long monofilament tether protected with an alimentary silicon tube. A small titanium dart was used for all except 11 individuals which were tagged using a Domeier anchor. A 2 cm incision was done with a scalpel in the dorsal fin base (tether, anchor and scalpel were smeared with Betadine Antiseptic Cream 5% povidone iodine to prevent infections).

2.2. Tag programing

SPAT tags were programmed to be released after 60 days of deployment and set by default to record maximum and minimum daily depths and temperatures, and ten-minute interval depth data for the end of the deployment (i.e. last 4 days). MiniPAT tags were programmed for 180 day release after deployment. If depth exceeded 1,700 m or remained constant for more than 3 days POP-UP tags were also programmed to be released. Daily data recorded with MiniPATs corresponded to temperature and depth, and change in light-level for each UTC day light intensity data point every 600 seconds.

2.3. Post-release survival analysis

For each tagged shark a fate was given (dead or alive) based on the depth records transmitted by the SPATs or MiniPATs and the time elapsed from tagging to detachment date. Sharks were considered to survive the fishing operation if tags showed a normal behaviour of daily depth/horizonal migration above 15 days, which was considered as an indication that they remained alive.

In tagged specimens, differences in survival rate, estimating using pop-up tagging information, depending on vitality index categories were assessed by Chi-square test. A survival rate was attributed

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[5] *https://wildlifecomputers.com/our-tags/pop-up-satellite-tags-fish/spat/*
[6] *https://wildlifecomputers.com/our-tags/pop-up-satellite-tags-fish/minipat/*

to each of the vitality index categories. The percentage of survivorship by vitality index category was applied to predict the survivorship for all sharks bycaught in each trip.

3. Results

3.1. Shark bycaught and released

Vitality index was obtained for all the silky sharks caught in both trips (Table 2). During 2020 and 2021, 526 silky sharks (*C. falciformis*) (278 and 248 sharks, respectively) were incidentally caught during 71 FAD set operations (41 and 30 FAD set operations, respectively). Sharks were handled and released applying best practices (Grande et al., 2019):

- 10.8% (n=57) were entangled in the net when hauling (i.e., sharks entangled in the purse seine net during 'haul back' and removed by the fishermen as the net emerged from the water; thus, these sharks were lifted on board before sacking up and brailing),
- and 89.2% were brailed and released: from which 26.6% were caught in the first brail (n=140), 26.4% in the second brail (n=139) and 36.1% in the third or subsequent brails (n=190).

Silky shark at vessel mortality, defined as observed mortality by the observer or sharks with very poor vitality index, was of 34.8% in the two trips (n=183). Data by trip is included in Table 2.

Table 2. Number of sharks released by status and fishing operation stage released (i.e., entangled in the net or brailed).

Year	Release stage	Very Poor	Poor	Correct	Good	Excellent	TOTAL
2020	Entangled	0	2	8 *(3)*	15	16 *(5)*	41 *(8)*
	1st brail	12	12 *(1)*	27 *(5)*	12 *(2)*	0	63 *(8)*
	2nd brail	31	26 *(2)*	17 *(4)*	4 *(1)*	0	78 *(7)*
	3er brail or later	66 *(1)*	21 *(3)*	9 *(1)*	0	0	96 *(5)*
	TOTAL	**109 *(1)***	**61 *(5)***	**61 *(13)***	**31 *(3)***	**16 *(5)***	**278** *(28)*
2021	Entangled	0	2 *(1)*	1 *(1)*	6 *(5)*	7 *(6)*	16 *(13)*
	1st brail	7	19	38 *(8)*	10 *(4)*	3	77 *(12)*
	2nd brail	18	17	24 *(2)*	2 *(2)*	0	61 *(4)*
	3er brail or later	49	41 *(2)*	4 *(1)*	0	0	94 *(3)*
	TOTAL	**74**	**79 *(3)***	**67 *(12)***	**18 *(11)***	**10 *(6)***	**248 *(32)***

( ) number of tagged sharks

From the 60 sharks (97-198 cm TL) tagged (28 and 32 sharks during, 2020 and 2021 respectively) with satellite tags (37 MiniPATs and 23 SPATs) (Fig.1 and Table 2), 14 sharks (seven sharks in each of the trips) showed immediate mortality within the first 24 hours after release (i.e., depth of more than 1,700 m or constant depth for at least three days) attributed to post-release mortality events. During, 2020 one of the tags popped off prematurely after 9 days at sea with no apparent clear reason (i.e., due to the pin breaking or tag detaching) but was considered as a death event based on the last horizontal and vertical behavior records. During 2021, one tag remained attached for 4 days showing a too deep behavior which reflect shark mortality. In addition, during this second trial two of the deployed tags did not respond and were not considered for the post-release survival analysis. Forty-two tags remained attached for more than 15 days (20 or 71% and 22 or 73% tags deployed during 2020 and 2021, respectively).

3.2. Post-release survival based on the vitality index

Significant differences were detected in survivorship among vitality index categories (p-value < 0.01). The percentage of tagged sharks that survived according to the vitality index was 100% for those released in excellent conditions, 90.9% for those in good conditions, 68% for sharks in correct condition, 33.3% for sharks in poor condition and 0% for very poor or dead condition. Applying the survival rate by vitality index of the tagged individuals to the vitality scores determined by the observer in each of the trips, we predicted an overall survival rate of silky sharks accidentally captured of 38.13% in 2020 and 39.62% in 2021 (Table. 3).

Table 3. Number of sharks by fishing stage and vitality index category. The predicted survival (%) is given for each category and trip.

Zone	Dead (0)	Poor (1)	Fair (2)	Good (3)	Excellent (4)	Total	Estimated survival N	Estimated survival %
Tangled	0	2	8	15	16	41	**35**	**87.17**
1st_brail	12	12	27	12	0	63	**33**	**52.81**
2nd_brail	31	26	17	4	0	78	**23**	**30.59**
3rd_brail	66	21	9	0	0	96	**13**	**13.67**
(all)	109	61	61	31	16	278	**105**	**38.13**
Pred. survival (%)	*0*	*33.33*	*68*	*90.91*	*100*			
Survivors	**0**	**20**	**41**	**28**	**16**			

Zone	Dead (0)	Poor (1)	Fair (2)	Good (3)	Excellent (4)	Total	Estimated survival N	Estimated survival %
Tangled	0	2	1	6	7	16	**13**	**86.25**
1st_brail	7	19	38	10	3	77	**44**	**57.48**
2nd_brail	18	17	24	2	0	61	**23**	**39.02**
3rd_brail	49	41	4	0	0	94	**16**	**17.44**
(all)	74	79	67	18	10	248	**98**	**39.62**
Pred. survival (%)	*0*	*33.33*	*68*	*90.91*	*100*			
Survivors	**0**	**26**	**46**	**16**	**10**			

4. Conclusions and Recommendations

Post-release survival rates of sharks in the Indian Ocean released from purse seine vessels, in which best handling and release practices were implemented and a lower deck conveyor belt installed, were estimated by satellite POP-UP archival tagging during two fishing trips in ECHEBASTAR´s vessels. When the percentage of survivorship by vitality index stage was applied to predict survivorship for all sharks in their respective trips, 38.13% and 39.62% % survivorship was estimated during 2020 and 2021 trips, respectively. As observed in previous studies on tuna purse seine vessels, the post-release mortality is at its lowest when sharks are in good shape while still swimming in the net before sacking up. Mortality starts to raise from the moment the sac is formed and incrementally with the number of brails. The vitality index observed simultaneously decreased with brail number. The overall survivorship during the two trips was higher than the survivorship estimated in previous shark release studies in purse seine vessels (Poisson et al. 2014b, Hutchinson et al., 2015, Filmalter et al., 2015b, Eddy et al., 2016). The difference could rely on the fishing operation itself, the time elapsed from the catch to release, and the application of improved handling and release practices. Since the application of best release practice programs several years ago fishers have been improving their shark releasing skills. Importantly, also the adaptation of the lower deck by installing the bycatch release conveyor belt could have reduced the shark release time for individuals accidentally arriving at this part of the vessel. Hence, having a positive influence on the reduction of at vessel mortality.

These findings suggest that if best handling and release practices are applied and effective fauna handling/release devices are incorporated on board, a significant increase in post-release survival of sharks could be obtained in tuna purse seine vessels. Therefore, this leaves room for shark survival increase through improvement of best practices and bycatch release devices employed in purse seine vessels.

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