Study of the migratory pattern and habitat of the silky shark (*Carchahinus falciformis*) in the Indian Ocean

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1. INTRODUCTION

The Echebastar Sustainability group has identified the need to improve knowledge of the biology of the silky shark (*Carcharhinus falciformis*) in the Indian Ocean in order to adapt the mitigation measures already implemented and identify new options to reduce fishing mortality. Also, to provide scientific information to improve the management of this species in the Indian Ocean.

Due to increasing fishing pressure, the abundance of silky sharks has decreased markedly over the last half century (Pacoureau et al., 2020). This species is listed as vulnerable by the IUCN Red List of Endangered Species. In the Indian Ocean, previous Ecological Risk Assessments (ERAs) identified the silky shark among the species most at risk of vulnerability to longline and purse seine nets (Murua et al., 2012; 2018). A preliminary stock assessment was carried out in 2018 (Ortiz de Urbina et al., 2018), using a time series of reconstructed catches, but the results of the assessment were extremely uncertain and also the status of the stock of silky sharks in the Indian Ocean it is considered uncertain (IOTC, 2020). This species is the fourth most important shark species in the Indian Ocean tuna fisheries (23,000 tons caught per year, 10% of the total shark catches) (García and Herrera, 2018). The gillnet and longline are the main contributors to the catch of silky sharks (57% and 42%, respectively), while the purse-seine fishery is responsible for 1.3% (García and Herrera, 2018). Due to their aggregation behaviour around FADs and the overlap of juvenile silky shark habitat with the tropical tuna purse-seine fishery, silky sharks are common in FAD sets and this species is the most important shark species bycatch for tropical tuna seiners (Gilman 2011, García and Herrera, 2018; Hutchinson et al., 2019, Ruiz et al., 2018).

In order to reduce shark mortality, EU and Seychelles purse-seine vessels have adopted best practices for the safe handling and release of sharks accidentally brought on board (Poisson et al., 2014; Grande et al., 2019; Maufroy et al., 2020; Zolett and Swimmer, 2019), and to this end some vessels have adapted the upper deck or lower deck by installing wildlife-specific release devices (i.e. hoppers, catch release conveyor incidental). If best release practices are combined with other mitigation measures, both active and passive (i.e., use of non-entanglement FADs, implementation of fishing strategies to avoid bycatch such as avoiding sets on small schools; releasing sharks from the net), shark mortality could be reduced by 60-65% (Restrepo et al., 2016, 2019).

Thus, to carry out the implementation of these mitigation measures, evaluate their effectiveness and detect new measures that could reduce fishing mortality, it is necessary to expand knowledge about the biology of the species, and in particular the study of its behaviour around the FADs, both horizontal and vertical migrations and habitat. The analysis of this information will allow the detection of windows (time and space) where the probability of capture is lower and to be able to reduce its catch per set.

Due to the high cost of satellite archival POP-UP tags (e.g., $2,000-4,000 per tag), experiments on post-release behaviour and migration pattern of silky sharks are sparse and often unreported. They are based on small sample sizes.

Therefore, to advance in the implementation of mitigation measures, it is necessary to carry out an analysis of the behaviour of silky sharks and carry out tagging with MiniPATs tags, which collect information that allows estimating the daily position and depth, allowing the evaluation of movements. of individuals. The information collected will be useful to analyse in detail the horizontal and vertical migrations of the silky shark. In addition, the data obtained from the marking are necessary to validate the habitat models or to construct new models based in this information. In this way, it will be possible to evaluate the overlap of the fishing activity with the distribution area of the silky shark and detect the possibility of implementing alternative measures that allow reducing fishing mortality in this species.

Therefore, this study aims to investigate the behaviour and migratory pattern (horizontal and vertical migrations), carry out the study of the habitat, and evaluate the post-releasing survival.

2. OBJECTIVES

The main objectives of this project are:

i) Assessment of post release survival;

ii) Study of the migratory pattern of the silky shark;

iii) Study of the silky shark habitat and its overlap with the FAD purse-seine fishery;

iv) Assess the contribution of implemented mitigation measures to reduce silky shark mortality and identify complementary measures.

3. MATERIAL AND METHODS

a. Field work

Two samplings have been conducted in the Indian Ocean to tag sharks and recover information on shark biological traits and physiological indicators. Both trips have been conducted in Echebastar´s vessels. The trips lasted from the 22nd of October to the 23rd of November 2020 and from 29th of September to 17th of October of 2021.

The survey area comprises the waters north of Seychelles up to 9ºN latitude and between longitudes 53ºE and 63ºE in the Western Indian Ocean.

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

- sex (female, male, indeterminate or unknown),
- length (cm),
- 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 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 or lateral doors, (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).

To evaluate the post -releasing survival, migratory pattern and habitat sPAT and MiniPAT POP.UP tags were used (Wildlife Computers, Inc.) (Table 1).

Table 1. Characteristics of the tags used in the sampling.

Tag Type	Description of the information provided and set-up
SPAT https://wildlifecomputers.com/our-tags/pop-up-satellite-tags-fish/spat/	- Max and min daily temperature and depth. - Last 4 days: High resolution data of depth (each 10 minutes). - Pop-off: 60 days
MINIPAT https://wildlifecomputers.com/our-tags/pop-up-satellite-tags-fish/minipat/	- High resolution records of depth (each 10 minutes) of Depth, temperature and light (position). - Pop-off: 180 days

To evaluate the concentration of lactate levels, blood samples were taken from the caudal peduncle of silky sharks (Fig. 1) and measured "in situ" using a lactate meter[1] (Lactate plus).

Fig. 1 Blood extraction in a Silky shark

b. 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 they remained alive ≥15 days.

In tagged specimens', difference in survival rate depending on vitality index categories were assessed by Chi-square test. This analysis includes individuals that were not finally tagged due to their poor condition but were considered as dead. The percentage of survivorship by vitality index category was applied to predict survivorships for all sharks bycaught in the trip.

[1] *https://www.laktate.com/producto/lactate-plus/*

Moreover, for silky sharks tagged and blood sampled Wilcoxon rank sum test was used to evaluate differences in lactate between survivors and dead sharks. This analysis also included dead individuals blood sampled but not tagged. A logistic regression model was done to relate survivorship (based on tagging) and lactate concentration estimated from blood samples. This logistic regression model and maximum likelihood estimation were used to predict the probability of survival for sharks with blood analysis taken but were not tagged (using as a survival threshold the 50% of probability of the survivorship curve) (Hutchinson et al., 2015). The fitted values were then used to predict survival rates by fishing operation stage and applied to predict survivorships for all the sharks captured during the fishing trip (Hutchinson et al., 2015).

4. PRELIMINARY RESULTS

a. Tagged animals

A total of 28 sharks were tagged with POP-UP satellite archival tags (24 SPAT[2] and 4 MiniPATs[3]) in the first trip in 41 FAD fishing operations. During this trip 278 silky sharks were captured (101 - 188 cm) (Table 1). In the second trip 248 silky sharks were captured (97 - 198 cm) in 31 FAD fishing operations and 33 sharks were tagged (14 SPAT and 19 MiniPATs) (Wildlife Computers, Inc.) (Fig 2, Table 2).

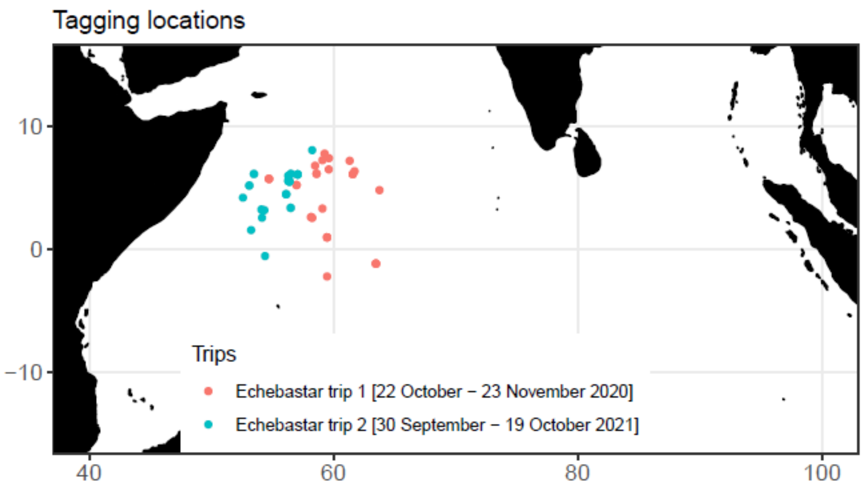


Fig 2. Tagging locations by study phase

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

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

Table 2. Number of sharks tagged, and type of POP-UP tags used by trip

Study Phase	Start date	End date	nSPAT	nMINIPAT
1	22/10/2020	23/11/2020	24	4
2	29/09/2021	17/10/2021	14	19

b. Days after release

During the first trip, 7 sharks (25% of tagged sharks) showed immediate mortality within the first 24 hours after release (depth of more than 1,700 m or constant depth for at least three days) attributed to post-release mortality events. One of the tags popped off prematurely after 9 days at sea with no apparent clear reason (i.e., due to the pin broken or tag detach) but was considered as a death event based on the last horizontal and vertical behavior. Twenty tags remained attached for more than 15 days, which was considered to represent surviving sharks (71.4%). All the tags attached have reported transmission (Fig 3).

During the second trip, 2 tags failed, and 8 tags (25% of the tags used in the trip with a correct functioning) popped off within the first 5 days after being released, indicating a post-release mortality. The rest of the tags have remained attached to the animals during more than 15 days (23 tags or 74% of the tags used in the trip with a correct functioning), indicative that the animals survive the fishing operation (Fig 3).

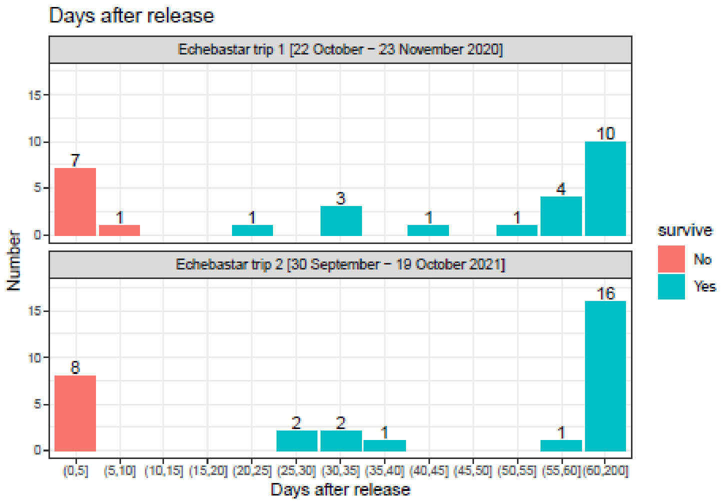
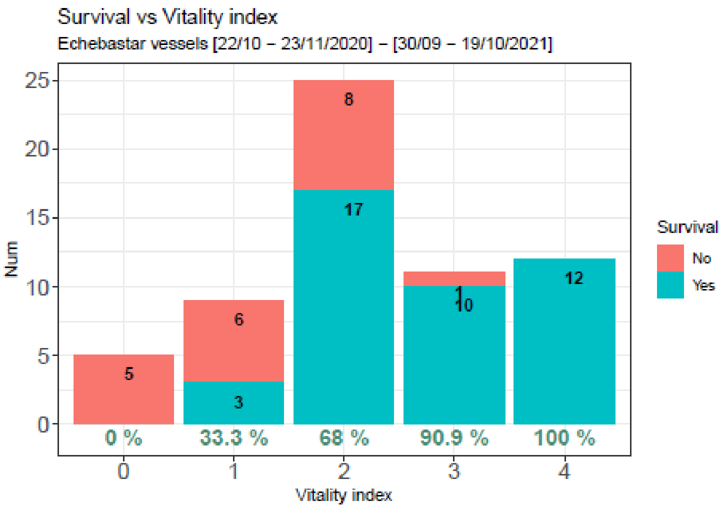


Fig 3. Number of sharks by day range after release for each fishing trip

c. 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 (Fig. 4)



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 4).

Table 4. Number of sharks and survivals by vitality index stage and brail and the estimated survival for each 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**			

d. Post-release survival based in lactate levels

The overall survival estimated using lactate level threshold was of 30.94% and 61.29% of in the first and second trip, respectively (Table 5).

Table 5. Number of sharks for which the lactate was measured by brail and the predicted survival for each fishing trip with a lactate level threshold of < 7.61.

Post-release survival of juvenile silky sharks

	Lactate<7.6	N measured	Pred. survival (%)	Total	Survivors
Tangled	10	15	**66.67**	41	**27**
1st brail	4	14	**28.57**	63	**18**
2nd brail	3	8	**37.50**	78	**29**
3rd brail	1	8	**12.50**	96	**12**
(all)	18	45	**30.94**	278	**86**

	Lactate<7.6	N measured	Pred. survival (%)	Total	Survivors
Tangled	17	17	**100.00**	16	**16**
1st brail	21	26	**80.77**	77	**62**
2nd brail	11	14	**78.57**	61	**48**
3rd brail	6	22	**27.27**	94	**26**
(all)	55	79	**61.29**	248	**152**

e. Migratory pattern and habitat

During the month of May (2022) the information of all the tags with a correct functioning has been received (2 tags have failed). The study on habitat and migratory pattern is being conducted during the second semester of 2022, first exploring the migratory pattern.

6. PRELIMINARY CONCLUSIONS

Post-release survival rate of sharks released from purse seiners, in which best handling and release practices are implemented, is estimated by satellite POP-UP archival tagging and lactate blood levels. When the percentage of survivorship by vitality index stage was applied to predict survivorships for all sharks, a 38.13% and 39.62% survivorship was estimated for sharks bycaught and released during the first and second trip, respectively. When lactate level threshold was estimated for survivorship and used to predict survival rates, we obtained a 30.94% and 61.29% of overall survival in the first and second trip, respectively. Due to the objectives of the project (that is, monitoring the migratory patterns and habitat of sharks), sampling of lactate during the second trip was biased towards individuals in better conditions, more suitable for tagging with satellite tags with which daily geolocation is obtained. Therefore, the overall survival rate derived from lactate level should be considered as an overestimate in the case of the second trip.

As observed in previous works on tuna purse seiners, the post-release mortality is at its lowest when sharks are in good shape and when they are swimming in the net. Mortality starts to increase from the moment the sac is formed and with the number of brails which concomitantly decreases the vitality index observed. In this study the at vessel mortality observed (40%) was lower and overall shark survivorship higher than the ratios estimated in previous works. The difference could rely on the fishing operation itself and the time elapsed from the catch to release (which can be influenced for example by set size, brail size or environmental conditions) or shark biological characteristics (e.g. size, age). In addition, the experience gained by the crew over time since the application of best releasing practices several years ago and the adaptation of the deck by the installation of the bycatch release conveyor belt could have a positive influence to reduce the at vessel mortality.

These findings suggest that if best handling and release practices are applied and fauna handling/release devices are incorporated on board, a significant increase in post-release survival of sharks could be obtained on tuna purse seiners.

The data obtained in this tagging campaign will be used to further study the biology of silky sharks by exploring their habitat use and investigating migratory patterns of this species, which could help in the design and development of future alternative mitigation approaches. This work will be carried out during the second semester of 2022.

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