SCIENTIFIC COMMITTEE
TWENTY-SECOND REGULAR SESSION
11-19 August 2026
Apia, Samoa (Hybrid)

POST-RELEASE SURVIVAL OF SHARKS CAPTURED IN THE WESTERN AND CENTRAL PACIFIC PURSE SEINE FISHERY: IMPLICATIONS FOR BYCATCH MANAGEMENT AND CONSERVATION

WCPFC-SC22-2026-EB-IP12
12 July 2026

Submitted by Murua, H., Grande, M., Moreno, G., Murua, J., and Restrepo, V.

Post-Release Survival of Sharks Captured in the Western and Central Pacific Purse Seine Fishery: Implications for Bycatch Management and Conservation

H. Murua, M. Grande, G. Moreno, J. Murua, and V. Restrepo

Abstract

Bycatch of sharks in tropical tuna purse seine fisheries remains a major conservation concern because many species exhibit low productivity and are particularly vulnerable to fishing mortality. This study evaluated the effectiveness of updated best handling and release practices for improving the post-release survival of sharks incidentally captured aboard commercial purse seiners operating in the Western and Central Pacific Ocean. A total of 780 elasmobranchs, primarily silky sharks (*Carcharhinus falciformis*, *n* = 702) and oceanic whitetip sharks (*C.s longimanus*, *n* = 49), were observed during two fishing trips conducted on vessels employing different fishing strategies. Shark condition at release was assessed using a vitality index, blood lactate concentrations, and satellite pop-up archival transmitting (PSAT) tags. Twenty-four sharks were equipped with survivorship PSATs and four additional individuals with miniPAT tags. Blood lactate concentrations increased significantly with declining vitality in silky sharks, supporting the use of vitality assessments as indicators of capture stress. Of the 22 tagged silky sharks, 20 (90.9%) survived for at least 10 days following release, demonstrating that sharks released in good condition using updated handling practices can survive the capture process. However, more than half of all sharks assessed (53%) were classified as being in poor or very poor condition at release, indicating that a large proportion of mortality occurs before deck handling. Extrapolation of tagging results by vitality category suggested that approximately half of the overall bycatch population survived following release, although estimates incorporating blood lactate data were lower. Theses results should be interpreted with cautious because of limitations in sampling in which the tagging did not cover all vitality states in a representative way. These findings demonstrate that best handling practices can substantially improve shark post-release survival, while highlighting that further reductions in fishing mortality will depend on minimizing capture stress and releasing sharks as early as possible during purse seine operations.

Introduction

Bycatch mortality is one of the principal impacts of fisheries on marine ecosystems, particularly for endangered, threatened and protected (ETP) species showing marked population declines in recent years. Due to their life histories traits such as slow growth, late maturation, and low fecundity resulting in low reproductive potential, marine megafauna such as sea turtles, sharks or mobulid rays are among the most vulnerable groups to anthropogenic effects with low resilience to fishing activity (Dulvy et al., 2021; Juan-Jorda et al., 2022).

Tunas support some of the largest and most valuable artisanal and industrial fisheries worldwide (FAO, 2022; ISSF, 2026). The global catch of albacore, bigeye, bluefin, skipjack, and yellowfin, the major commercial oceanic tunas, in 2024 was 5.8 million tonnes. Among the major commercial tunas, the tropical tuna fisheries account for 95% of the catches in weight and tropical tuna purse seine fisheries catch 66 % of the total catch of tunas, approximately 37% associated, 26 % unassociated, and 3% dolphin set) (ISSF, 2026). Although tuna populations are in general managed sustainably, 97% of the catch comes from healthy stocks and 100% catches comes from stock not experiencing overfishing (ISSF, 2026), their fisheries also have impacts on non-target species that are unintentionally caught (Dagorn et al., 2013). Sharks and rays and sea-turtles are among those incidentally caught species (Juan-Jorda et al., 2022; Bourjea et al., 2014; Croll et al., 2016), which need to be monitored, impacts mitigated, and populations assessed and managed for their long-term conservation (Gilman et al., 2023).

Considering the decline of their populations (Pacoureau et al., 2021, Juan-Jorda et al., 2022), several shark and all Mobula ray species have been recently included in Appendix II of the Convention on International Trade in Endangered Species (CITES, 2022). In addition, many of these species, including the oceanic whitetip shark (*C. longimanus*), scalloped hammerhead shark (*Sphyrna lewini*), and giant manta ray (*Mobula birostris*), are classified as threatened or endangered on the IUCN Red List and are listed under the Convention on Migratory Species (CMS), reflecting global recognition of their conservation concern. These international listings emphasize the need for coordinated measures to reduce fisheries interactions and associated mortality across their range, promoting their long-term conservation.

For some of the megafauna bycatch species of purse seiners there are already well-defined protocols that are effective at releasing alive most of the animals such as methods employed to release dolphins (e.g., backdown maneuver, use of divers, etc. specified by Agreement on the International Dolphin Conservation Program (AIDCP) protocols; Hall and Roman, 2013) or whale sharks (e.g., release over the net's corkline, Escalle et al., 2016). For sea turtles, research has shown that most survive if they are released promptly and following best practices (Hall and Roman, 2013; Bourjea et al., 2014; Zollet and Swimmer, 2019).

However, for elasmobranch species best handling and release protocols were developed over 10 years ago (Poisson et al., 2012) and have not been updated until recently (Hutchinson et al., 2024; Murua et al., 2024a). In the past, onboard handling practices resulted in high levels of post-release mortality for this group (Hall and Roman, 2013). For elasmobranchs, tagging studies showed an overall estimate of 15-20% survival for encircled sharks brought onboard, when good practices (Poisson et al., 2012) were applied to release them (Poisson et al. 2014, Eddy et al. 2016, Hutchinson et al. 2015, Restrepo et al. 2017). This can be increased to around 45% if updated handling and safe release best practices are applied and efficient bycatch release devices (BRDs) are employed (Onandia et al., 2021; Grande et al., 2022; Murua et al., 2024b). The survival rate in these studies corresponded to the combination of two factors: (i) 30-60% of the sharks arriving on the deck were alive, and (ii) 50-70% of these live sharks released from the deck could survive if they were released promptly following best practices. Therefore, the use of new (BRDs) as well as best practices on handling and safe release are required so that the currently poor elasmobranch survival rates on purse seine vessels can substantially improve (Murua et al., 2025b).

The present study aims to investigate the post-release survivorship (PRS) of sharks caught in tuna purse seiners operating in the Pacific Ocean when released using updated safe handling and release best practices for sharks. The methodology employed combined the use of pop-up satellite archival tags (PSATs), blood lactate sampling and a vitality index based on the condition of sharks at release. Additional factors that may influence release condition and survivorship, including physiological stress indicators, release methods, and operational and environmental variables, will also be evaluated to estimate post-release mortality.

This study was funded through the Marine Stewardship Council (MSC) Ocean Stewardship Fund, which supports practical, science-based solutions to improve the sustainability of fisheries, reduce environmental impacts, and strengthen effective fisheries management. Specifically, the project was designed to address conditions identified during MSC certification assessments for Performance Indicators (PIs) 2.3.2 (ETP species management) and 2.3.3 (ETP species information) by independently evaluating the effectiveness of updated handling and release protocols in reducing shark bycatch mortality. The findings will also contribute to meeting the requirements of the Western and Central Pacific Fisheries Commission (WCPFC) Conservation and Management Measures (CMMs) 2022-04 and 2019-05 by providing independently verified information on the post-release fate of sharks. Collectively, the results are expected to support the refinement of evidence-based handling and release guidelines for purse seine fisheries, improve estimates of post-release mortality, and contribute to the conservation and management of threatened, endangered, and protected elasmobranch species.

Material and Methods

Study vessels and fishing operations

Elasmobranch bycatch and handling and release practices were documented during two fishing trips conducted aboard commercial tropical tuna large-scale purse seiners operating in the Pacific Ocean. The first fishing trip was carried out aboard a 71-m Philippine-flagged purse seiner (820 t fish hold capacity) targeting free-swimming tuna schools in the waters surrounding Papua New Guinea using helicopter-assisted fish detection.

The second fishing trip was conducted aboard an 89-m U.S.-flagged purse seiner (1,420 t fish hold capacity) operating in the western and eastern Pacific Ocean, primarily targeting tuna associated with drifting Fish Aggregating Devices (dFADs).

An onboard a scientific observer monitored purse-seine fishing operations throughout both campaigns, recording the handling, processing, and release of incidentally captured elasmobranchs. Observations included all stages from net retrieval to release and focused on operational procedures expected to influence post-release survival, including handling techniques, release methods, use of BRDs (e.g., both vessels had a hopper), the brail number at which each individual was brought onboard, crew participation, and the duration of time spent on deck prior to release.

Safe handling and release practices

Handling and release procedures were recorded through direct onboard observations during all fishing operations. For each elasmobranch encounter, the observer documented the mitigation measures employed by the crew, if equipment was used during handling and release, and any operational procedures considered likely to influence physical injury, physiological stress, air exposure, and consequently the condition of individuals at release. The observer also documented handling procedures expected to increase injury or stress, including lifting sharks by the gills or tail, forceful contact with the deck, prolonged retention on deck or within the fish well before release, and other operational practices potentially compromising post-release survival. These observations were used to identify opportunities for improving bycatch mitigation procedures, including the implementation of dedicated release ramps and other handling devices designed to facilitate rapid and safe release of incidentally captured elasmobranchs.

Common practices observed aboard both vessels included the early detection of sharks entangled in the purse-seine net during hauling, followed by temporary stoppage of net retrieval to allow their disentanglement and release whenever feasible. Sharks recovered during brailing on deck were transported using stretchers whenever possible or handled manually by supporting the body behind the pectoral fins, thereby avoiding lifting individuals by the head, gills, or tail. Large individuals were released using cranes equipped with cargo nets or lifting slings to reduce physical trauma during handling. In addition, crew members assisted scientific personnel during the handling and release of tagged sharks using stretchers.

Additional mitigation measures were implemented aboard the US-flagged vessel. These included the use of a hopper to facilitate the release of bycatch, installation of a sorting grid above the unloading hatch to prevent mobulid rays from entering the lower deck, with a deck crane to assist with the release of large mobulid rays in the hopper.

Field research aboard Purse Seiners

The first fishing trip was conducted aboard a Philippine-flagged purse seine vessel operating in the waters surrounding Papua New Guinea on the Western Pacific Ocean, from 17 December 2025 to 7 January 2026 (**Figure 1**). During the fishing trip, a total of 18 sets were performed, all sets were free-swimming tuna schools using helicopter-assisted fish detection.

The second fishing trip was conducted aboard an U.S.-flagged purse seiner operating in the western and eastern Pacific Ocean between 17 January and 12 March 2026 (**Figure 1**). During the fishing trip, a total of 30 sets were performed, all sets were associated to Fish Aggregating Devices (FADs).

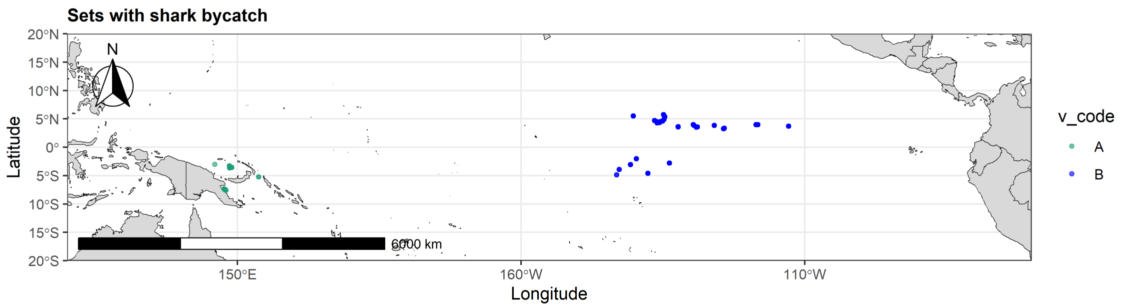

Figure 1. Geographic locations of purse-seine sets in which sharks were incidentally captured during the two fishing trips.

Data collection

During each set with elasmobranch interactions, the following data were recorded for each individual:

- Elasmobranch species
- sex (categorized as female, male, indeterminate, or unknown),
- total length (TL) in cm,
- brail number in which the specimen was brought on-board (i. e., 1^{st}, 2^{nd}, 3^{rd} or > 3^{rd} brail.),
- position in the brail (top, middle, bottom),
- time when the shark was brought on board (time of brailing) and release,
- mode of release, classified as: (i) via brailer, (ii) using light equipment such as stretcher, fabric, sarria or cargo net, (iii) manual release from the deck, (iv) after disentanglement from the hauling net, or (v) via the ramp attached to the hopper.
- vitality index or the condition at release, following the criteria of Heuter and Manire (1994):
  - (i) excellent - very active and energetic, strong signs of life on deck and when release to the water;
  - (ii) good - active and energetic, moderate signs of life on deck and when release to the 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, 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, no revival upon release to water, no swimming movement, sinks.
- behavior after release, noted as: vigorous swimming, slow swimming near the surface, or sinking with minimal movement.

When the number of brail was not recorded, observations were classified as >3 brails;. Being conservative, Individuals with missing vitality assessments were conservatively classified as having “very poor” vitality status.

Blood Sampling and Lactate Measurement

To assess physiological stress, blood samples were collected from the caudal peduncle of 60 individuals (including the tagged sharks): 53 silky sharks (*C. falciformis*), 6 oceanic whitetip sharks (*C. longimanus*), and 1 silvertip shark (*C. albimarginatus*). Samples were taken onboard, and lactate concentrations were measured *in situ* using a portable lactate meter[1] (Lactate Plus, Nova Biomedical).

Tag programming and tagging

Satellite pop-up archival transmitting tags, both survivorship (sPAT) and miniPATs (Wildlife Computers, Inc.), were programmed for detachment 60 and 180 days post-deployment respectively. sPATs were programmed to record maximum and minimum daily depths and temperatures as well as depth at 10-minute intervals during the final four days of deployment.

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

sPAT and miniPAT release was also triggered if a tag exceeded 1,400-1,700 meters or remained at a constant depth for more than three consecutive days.

In total 24 sharks were equipped with sPATs (22 silky sharks, 1 oceanic whitetip and 1 silvertip shark), and 3 oceanic whitetip sharks and 1 sicklefin devil ray (*M. tarapacana*) were tagged using a miniPAT. In all cases, tags were attached using a 10 cm monofilament tether encased in an alimentary-grade silicone tubing to prevent friction. A Domeier-style anchor was used for tag attachment to sharks and rays. To ensure proper insertion of the tag, a 2 cm incision was made at the base of the dorsal fin using a sterilized scalpel. All tagging equipment (tether, anchor, and scalpel) was treated with 5% povidone-iodine (Betadine Antiseptic Cream) to minimize the risk of infection.

Post-Release Survival Assessment

Post-release survival was inferred from depth telemetry data transmitted by the sPATs and miniPAT and the time elapsed from tagging to detachment. Sharks were classified as survivors if their movement data indicated normal diel vertical migration and active horizontal displacement for at least 10 consecutive days post-release, following criteria established by Hutchinson et al. (2015). Mortality was inferred when tags reported depth anomalies (e.g., constant depth over several days or extreme depth breaches) prior to premature detachment.

For satellite tagged individuals, a survival rate was assigned to each vitality index category. Later, the survivorship percentages by vitality index category were applied to predict the total survivorship for all silky sharks caught in the trip. In addition, for silky sharks that were both tagged and had blood samples taken, a Wilcoxon rank sum test was used to evaluate differences in lactate between survivors and dead sharks as determined from the PSAT data. This analysis also included three dead individuals that were blood sampled but not tagged. The logistic regression model was used 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 the rest of sharks that were blood sampled but not tagged, using a 50% probability threshold from the survivorship curve (Hutchinson et al., 2015). The fitted values were then used to estimate a lactate survival threshold. This lactate threshold was applied to predict survival rates by vitality index and then to predict overall survivorship for all sharks captured during the fishing trip.

Results

Sharks Bycaught and Release

A total of 780 elasmobranchs were incidentally captured during both trips: 702 silky sharks, 49 oceanic white-tip sharks, 7 hammerheads (Sphyrna spp.), 6 bull sharks (*C. leucas*), 3 thresher sharks (Alopias sp.), 3 silvertip sharks, 3 sicklefin devil ray (*Mobula tara*pacana), and 7 unidentified sharks.

Elasmobranchs	Friesland	Marita88	Total general
Alopias superciliosus	1		1
C. albimarginatus		3	3
C. leucas		6	6
C. longimanus	49		49
Hammershark		6	6

Mobula tarapacana	2	1	3
na		7	7
Silky	639	63	702
Sphyrna zygaena	1		1
Thresher shark		2	2
Total general	**692**	**88**	**780**

The total length of silky sharks ranged from 48 cm to 252 cm (mean ± SD, 144±37.6 cm) and for oceanic white tip sharks, the range was 120-198 cm (mean ± SD, 153.6±17.1 cm) (Figure 2).

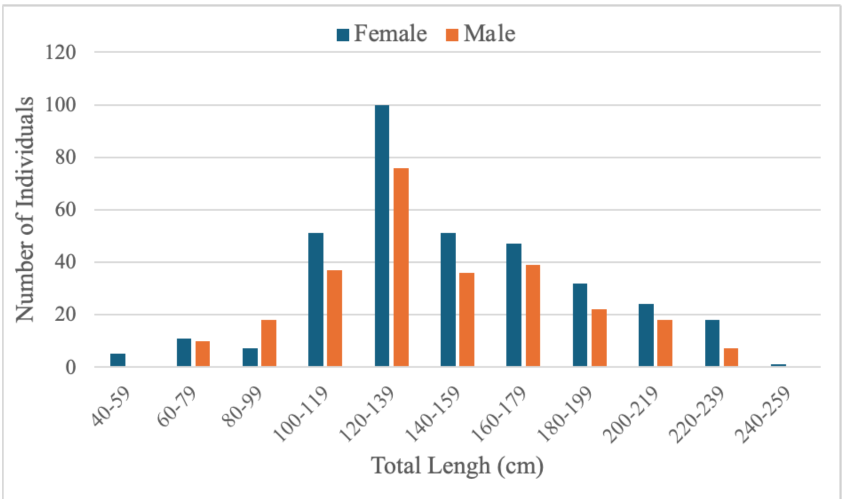

Figure 2.- Size distribution of silky sharks (*C. falciformis*) incidentally captured during both trips.

Most sharks (n=596 or 82.2%) were released from the upper deck using the cargo nets or stretchers with or without hopper depending on the vessel, while the rest of shark species (n=129 or 17.8%) were released manually from the upper deck. In general, the release time did not exceed 2 minutes for all the individuals with information on release time (n = 544, 80%), while this percentage slightly decreased for those individuals assessed as in good condition after release (n = 289, 74%) (Figure 3).

Figure 3.- Releasing time of incidentally caught sharks depending on Vitality Status.

A vitality index was recorded for 554 bycaught sharks, including 515 silky sharks and 29 oceanic white tip sharks (Table 2). At-vessel mortality, defined as either observed mortality or a shark with a “poor” or “very poor” vitality index, was estimated at 53% (n=298) (Table 1). Although we considered the “poor” category as “mortality”, in some cases individuals may survive depending on their condition at release and lactate level. Therefore, our at-vessel mortality estimate should be considered conservative. For silky sharks, the rate was slightly higher at 55% (285 individuals out of 515), while oceanic white tip sharks had a significantly lower at vessel mortality rate of 4% (1 out of 29 individuals).

Table 2.- Number of sharks (total, silky sharks and oceanic white-tip sharks) released by vitality index and brail number in which the specimen was brought on-board.

ALL SHARKS					
# Brail/Vitality Index	**Excelent**	**Good**	**Correct**	**Poor/Very Poor**	**Total**
1	21	30	12	7	70
2	6	21	17	22	66
3	18	14	24	28	84
=>4	7	33	57	241	338
Total	**52**	**98**	**110**	**298**	**558**
%	**9%**	**18%**	**20%**	**53%**	**100%**

SILKY SHARK					
# Brail/Vitality Index	**Excelent**	**Good**	**Correct**	**Poor/Very Poor**	**Total**
1	17	29	12	7	65
2	2	20	17	22	61
3	12	13	22	26	73
=>4	5	26	55	230	316
Total	**36**	**88**	**106**	**285**	**515**
%	**7%**	**17%**	**21%**	**55%**	**100%**

OCEANIC WHITE-TIP SHARK					
# Brail/Vitality Index	**Excelent**	**Good**	**Correct**	**Poor/Very Poor**	**Total**
1	4	1	0	0	5
2	4	1	0	0	5
3	6	1	1	0	8
=>4	2	7	1	1	11
Total	**16**	**10**	**2**	**1**	**29**
%	**55%**	**34%**	**7%**	**4%**	**100%**

Blood lactate levels were measured in 58 individuals (16 tagged individuals): 51 silky sharks, 6 oceanic white tip sharks, and one silvertip shark. Mean lactate concentration levels by species are summarized in Table 3.

Species	# Individuals	Min	Max	Mean (± S.D)
FAL	51	0.6	14.5	7.04±3.31
OCS	6	0.8	13.8	6.40±4.84
ALS	1			8.2

For silky sharks, blood lactate concentrations differed significantly among vitality index categories (Kruskal-Wallis non-parametric test: $H = 13.81$, $p = 0.0032$) (Figure 4), indicating that physiological stress varies according to vitality status of individuals and being highest in moribund individuals.

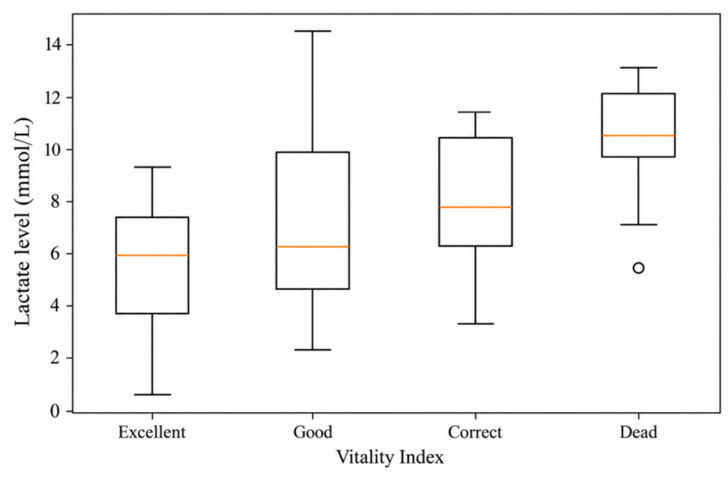

Figure 4.- Lactate levels by vitality index in silky sharks.

Tagged elasmobranchs

28 elasmobranchs were tagged during both trips: 22 silky sharks, 1 oceanic whitetip and 1 silvertip shark with sPATs and 3 oceanic whitetip sharks and 1 sicklefin ray with a miniPAT. In the following sections, only information for the 22 silky sharks is provided.

Table 4 summarizes the information of the 22 silky sharks tagged with sPATs at released. Two tags detached prematurely (tag detachments were programmed for 60 days) before 10 days showing mortality, while 7 were detached between 10 and 30 days and 13 were detached around the 60 days as programmed.

Table 4.- Satellite tagged silky shark information including length, sex, tagging deployment and release data and days at sea after release.

Number	Species	Length (cm)	Sex	Deployment Date	Release Date	Days at Sea
1	FAL	214	Male	21/12/25	10/1/26	20
2	FAL	210	Male	23/12/25	21/2/26	60
3	FAL	174	Female	23/12/25	7/1/26	15
4	FAL	181	Male	23/12/25	16/1/26	24
5	FAL	196	Female	23/12/25	2/1/26	10
6	FAL	215	Female	29/12/25	27/2/26	60
7	FAL	166	Male	31/12/25	1/3/26	60
8	FAL	144	Female	31/12/25	1/3/26	60
9	FAL	177	Female	31/12/25	1/1/26	1
10	FAL	171	Female	31/12/25	7/1/26	7
11	FAL	184	Male	02/01/26	4/3/26	61
12	FAL	142	Female	10/02/26	26/2/26	16
13	FAL	179	Female	10/02/26	12/3/26	30
14	FAL	171	Male	12/02/26	14/4/26	61
15	FAL	186	Male	13/02/26	15/4/26	61
16	FAL	149	Female	18/02/26	6/3/26	16
17	FAL	204	Male	20/02/26	22/4/26	61
18	FAL	204	Male	22/02/26	24/4/26	61
19	FAL	168	Male	24/02/26	13/4/26	48
20	FAL	193	Female	25/02/26	23/4/26	57
21	FAL	150	Female	26/02/26	27/4/26	60
22	FAL	206	Female	01/03/26	20/3/26	19

Tag retention times are shown in Figure 5. From the 22 sharks tagged: (i) two (9.1%) showed immediate post-release mortality, as the tags reached excessive depths before ten days at liberty, indicating the death of the animals, while twenty (90.9%) survived the fishing operation, showing normal behaviour for at least 10 days after release.

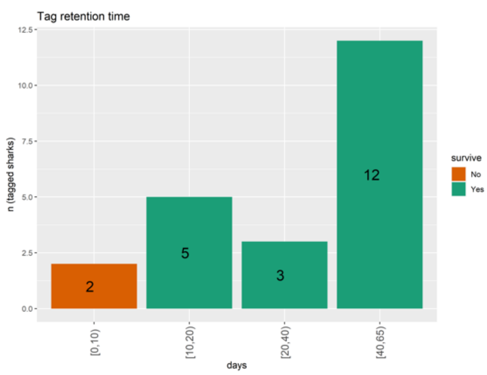

Figure 5.- Days at sea of the 22 silky sharks tagged using sPATs

<u>Post-release survival rate by vitality state of the tagged sharks</u>

Although satellite tagging provides the most reliable method for directly estimating post-release survival, only sharks in sufficiently good condition to withstand the tagging procedure could be selected for tag deployment. Consequently, tagged individuals were not randomly sampled from the bycatch population and did not include sharks released in poor or very poor vitality condition. The survival estimates derived directly from the tagged sharks therefore represent the fate of animals released in relatively good condition rather than the entire bycatch. To estimate post-release survival at the population level, the survival observed for tagged sharks within each vitality category was subsequently combined with the frequency distribution of vitality states recorded for all sharks encountered during the fishing trips. For vitality categories that were not represented among tagged sharks (poor and very poor), survival probabilities reported by Murua et al. (2024c) were used. This approach allowed survivorship to be extrapolated from the tagged subset to the overall bycatch population.

Figure 6 summarizes the number of silky sharks tagged within each vitality category together with their observed post-release fate. Tagged sharks represented only the Excellent, Good and Correct vitality categories because individuals in Poor and Very Poor condition were considered unsuitable candidates for satellite tag deployment.

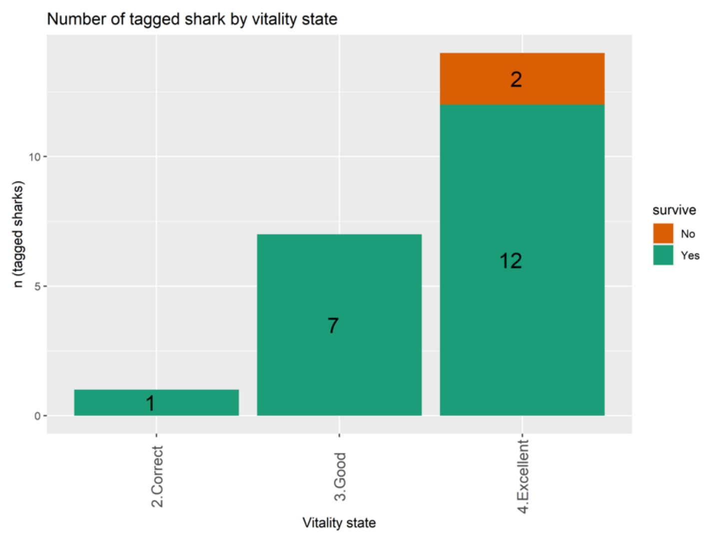

Figure 6. Number of shark tagged by vitality state and survivorship.

The survival rates observed for tagged sharks within each vitality category were combined with the vitality composition of the entire bycatch to estimate overall post-release survival. For the Poor and Very Poor categories, which were not represented among tagged sharks, survival probabilities reported by Murua et al. (2024b) were applied. The resulting survival probabilities by vitality category are shown in Figure 7 and were subsequently used to estimate overall survivorship for each fishing trip (Table 5).

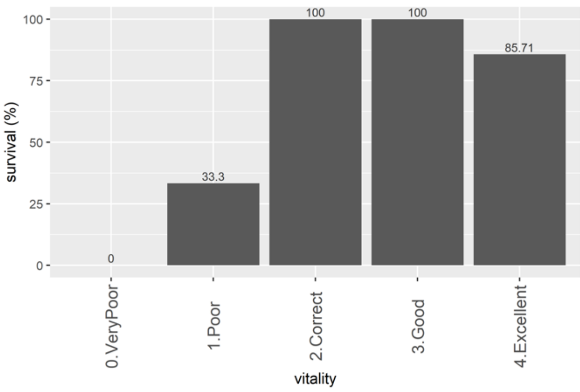

Figure 7.- Shark survival rates by vitality state.

By applying the survival rate by vitality index of the tagged individuals to all sharks in the trip, we predicted an overall survival of 51.2% which ranged from 42.8% to 52.5% depending on the trip (Table 5). As observed in previous studies on tuna purse seiners, post-release mortality increases with a decrease in the vitality state. In addition, as in previous studies mortality shows an increasing trend with the number of brails. All vessels fully implemented best handling practices; therefore, differences in survival rates cannot solely be attributed to the level of best-practice implementation. Other factors, such as vessel operational procedures (e.g. sacking time, brailing time, and brail size), may strongly influence the amount of time sharks remain confined in the sack and, consequently, their probability of survival. In addition, environmental factors such as sea surface temperature (SST) may also affect survival, as higher temperatures are associated with reduced survival probabilities.

Table 5.- Overall survivorship rate based on tagging by vitality index.

Brail	VeryPoor (n)	Poor (n)	Correct (n)	Good (n)	Excellent (n)	Total Survival (n)	Total Survival (%)
1	0.0	0.3	13.0	29.0	14.6	56.9	84.9%
2	0.0	5.7	22.0	25.0	12.0	64.7	53.9%
3	0.0	13.0	97.0	48.0	79.7	237.7	46.2%
TOTAL	**0.0**	**19.0**	**132.0**	**102.0**	**106.3**	**359.3**	**51.2%**

Post-release survival rate based on lactate levels of the tagged sharks

For silky sharks that were both tagged and had blood samples taken, the blood lactate concentrations differed significantly among survivors and dead sharks as determined from the PSAT data ($p<0.005$). We did observe significant differences between the two groups (Fig 8).

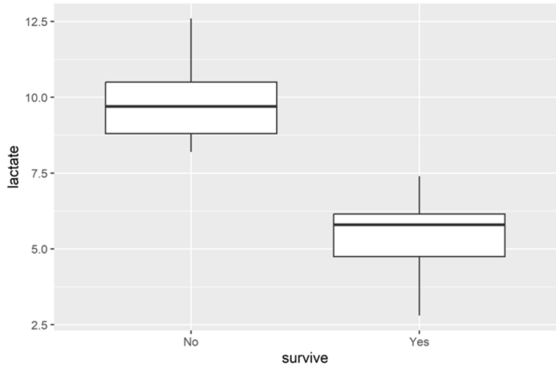

Figure 8. Lactate levels for sharks that survived and did not survive the fishing operation based on tagging.

A logistic regression model was used to relate survivorship (based on tagging) and lactate concentration estimated from blood samples (Figure 9). This logistic regression model and maximum likelihood estimation are usually used to predict the probability of survival for the rest of sharks that were blood sampled but not tagged, using a 50% probability threshold from the survivorship curve (Hutchinson et al., 2015). We assume a survival threshold at 7.81 mmol/L, concentration at which the probability of survival was estimated as p = 0.5 from the survivorship curve (i.e., if [lactate] < 7.81 mmol/L then it was considered a "survivor" and above a "death").

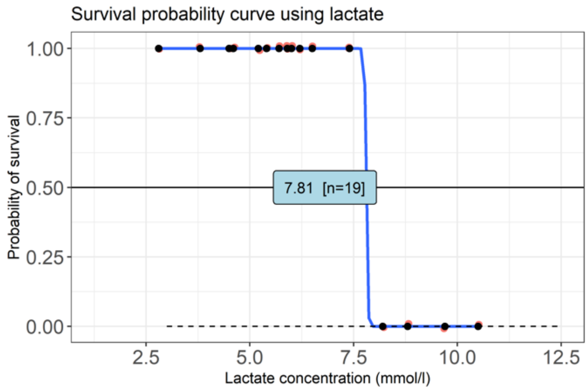

Figure 9. Logistic regression curve showing the predicted probability of post-release survival for silky sharks (*C. falciformis*) as a function of blood lactate concentration. The 50% survival probability threshold was estimated at 7.81 mmol/L.

Based on this blood-sample survival threshold, a survivorship rate was estimated for each vitality state for those sharks that were blood-sampled (Figure 10) and applied to all sharks in the trip to estimate an overall survival. The overall shark survival estimated using this extrapolation was 37.2%, ranging from 28.2% and 36.8% depending on the fishing trip (Table 6).

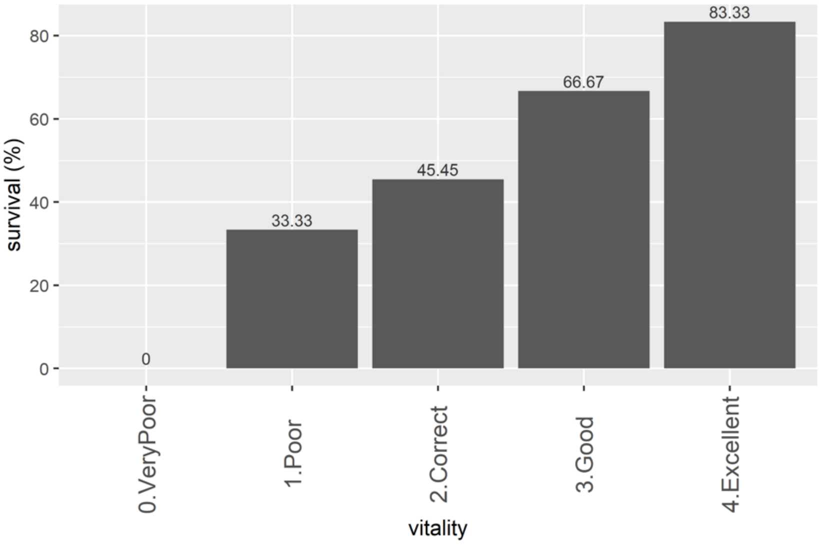

Figure 10.- Estimated post-release survival rates of silky sharks by vitality state, based on the blood lactate survival threshold derived from tagged individuals.

Table 6.- Overall survivorship rate estimated from blood lactate and tagging data by vitality index, combining results from both research trips.

Brail	VeryPoor (n)	Poor (n)	Correct (n)	Good (n)	Excellent (n)	Total Survival (n)	Total Survival (%)
1	0.0	0.3	5.9	20.0	17.5	43.7	60.8%
2	0.0	7.0	11.4	17.3	16.7	52.4	34.9%
3	0.0	13.7	48.2	38.7	94.2	194.7	34.8%
TOTAL	**0.0**	**21.0**	**65.4**	**76.0**	**128.3**	**290.8**	**37.2%**

Discussion

This study provides valuable insights into the application of updated bycatch release devices (BRDs) and best handling practices designed to enhance the post-release survivorship of sharks incidentally caught in tropical tuna purse seine fisheries. The integration of a hopper, combined with established safe-handling protocols, substantially improved operational practices aboard both fishing vessels. The applied best practices enabled rapid and safe releases, with approximately 80% of sharks released within two minutes. This minimization of air exposure and handling stress, two critical factors influencing elasmobranch survival (Stewart et al., 2024), concomitantly reduced handling effort and risk for crew members.

At-vessel mortality estimates (53%) were similar to those obtained by Onandia et al. (2021), Grande et al. (2022), and Murua et al., (2025b) and lower than the research conducted by Poisson et al. (2014), Eddy et al. (2016), and Hutchinson et al. (2015), which observed a higher mortality at haul-back. Inter-trip variability in fishing mortality is expected, as post-release survival in elasmobranchs can be influenced by multiple interacting operational and environmental factors. However, advances in the last decade regarding better handling and release practices and improved training of crew members (Murua et al., 2023) may have contributed to the higher survival rates in recent studies.

Satellite-tagging results provide direct evidence that sharks released alive following updated handling practices can survive the fishing event. Of the 22 silky sharks fitted with survivorship PSATs, 20 (90.9%) survived for at least 10 days after release, with most tags remaining attached until the programmed release date. These results represent high post-release survival for silky sharks released from purse seine fisheries. However, tagged sharks were intentionally selected among individuals in sufficient condition to withstand tagging, and no sharks in poor or very poor vitality condition were tagged. Consequently, the observed survival rate should not be interpreted as representative of the overall bycatch population.

To overcome this limitation, survivorship was extrapolated to all sharks using two complementary approaches. The first combined the observed survival of tagged sharks with vitality index categories, producing an estimated overall survival of approximately 51% across all sharks. This estimate is substantially lower than the survival of tagged sharks because over half of all captured sharks (53%) were classified as poor or very poor at release. These results emphasize that while survival among sharks released in good condition is high, the overall survival of the bycatch population remains constrained by the large proportion of sharks arriving on deck in compromised state, which is likely connected to the overcrowding and low mobility conditions experienced by sharks and the rest of the catch inside the net's sack.

The second approach incorporated physiological information by combining blood lactate concentrations with tagging-derived survival. This analysis yielded a lower overall survival estimate (approximately 37%), suggesting that external vitality assessments alone may overestimate survival in some individuals. Blood lactate integrates cumulative physiological stress experienced during capture and handling and therefore provides an independent measure of sublethal stress that is not always detectable through visual assessment. The lower survival predicted by lactate indicates that some sharks classified as having acceptable vitality may nevertheless experience internal metabolic stress sufficient to reduce post-release survival. Nevertherless these results should be considered with cautious as the tagging was centred in animals in best condition and some vitality states were under sampled (i.e. from very poor to correct).

Vitality indices and lactate levels provided additional evidence of the benefits of rapid, low-stress release methods. Silky sharks exhibited a significant relationship between lactate concentration and vitality, indicating that physiological stress increased progressively as vitality declined. Likewise, lactate concentrations differed significantly between sharks that survived and those that died according to PSAT data, supporting lactate as a useful predictor of post-release fate. These findings agree with previous studies demonstrating that blood lactate is an effective indicator of capture stress in pelagic sharks (Hutchinson et al., 2015; Grande et al., 2022). These indicators are crucial in the context of quick release protocols as they can improve our confidence in survivorship estimates.

Taken together, the three approaches illustrate a continuum of survivorship estimation. Satellite tags provide the most reliable estimate for sharks that can be tagged, vitality indices allow extrapolation to the wider bycatch population, and blood lactate provides an independent physiological validation that refines these estimates. Rather than representing conflicting results, the three methods are complementary and together provide a more robust assessment of post-release mortality than any single method alone.

Although all vessels implemented updated handling protocols, estimated survival differed among fishing trips and vessels. These differences are unlikely to result solely from compliance with best handling practices and instead suggest that operational characteristics, including sacking duration, brailing speed, brail size, crowding within the bunt, and the order in which sharks are removed from the net, strongly influence shark condition at release. Similarly, environmental factors such as sea surface temperature may further exacerbate physiological stress and reduce survival. Consequently, maximizing post-release survival requires not only appropriate handling once sharks reach the deck but also operational measures that minimize capture duration before sharks are brought aboard.

The demonstrated improvements in shark survivorship are essential to the broader objective of enhancing the sustainability of shark populations. Sharks are particularly vulnerable to overexploitation and incidental capture because their life-history traits—slow growth, delayed maturity, and low fecundity—limit population productivity and recovery potential (Juan-Jorda et al., 2022. Reducing post-release mortality is therefore a critical step toward mitigating fishery impacts and promoting the recovery and resilience of depleted populations.

Additionally, the training initiatives, including the skipper and train-the-trainer workshops, represent an effective strategy for scaling best practices across fleets. Building knowledge and operational familiarity with safe handling and release best practices favours voluntary uptake and ensures more consistent and widespread application, which is key for meaningful reductions in bycatch mortality at the fishery-wide level. Since 2009, ISSF has organized and hosted more than 135 Skippers Workshops at major ports on five continents (Murua et al., 2023; 2025a). These collaborative initiatives have already contributed to widespread adoption of non-entangling FADs and improved handling techniques, illustrating how co-development with fishers can accelerate implementation of conservation measures.

Nevertheless, the present results also demonstrate that improvements in deck handling alone cannot fully mitigate purse seine impacts. More than half of the sharks assessed exhibited poor or very poor vitality by the time they reached the deck, indicating that a substantial proportion of mortality occurs before handling and release procedures begin. Consequently, safe release practices should be viewed as the final component of a broader mitigation hierarchy (Gilman et al., 2023), in which avoidance of shark interactions, early release from the net, and operational measures that shorten confinement time collectively contribute to reducing fishing mortality. This approach includes implementing avoidance strategies prior to net setting, as well as mitigation measures before sharks are brought aboard, such as releasing individuals while still in the net, to more effectively reduce bycatch mortality (Restrepo et al., 2019).

Moreover, evaluating survival rates of vulnerable released fauna in purse seine fisheries will help guide management decisions, as simply banning retention onboard will not be an effective strategy in the case of purse seine vessels where a high proportion of individuals do not survive after release under current practices (Tolotti *et al.*, 2015). The present study estimating post-release mortality using a combination of electronic tagging, vitality assessments, and physiological indicators, provides fisheries managers with improved estimates of fishing mortality for stock assessment and ecological risk analyses.

Despite these encouraging results, several limitations should be acknowledged. First, the number of tagged sharks remains relatively small, particularly within the lower vitality categories, requiring extrapolation from previous studies for sharks classified as poor or very poor. Second, the number of blood samples was limited, and the reliability of some lactate measurements, particularly during the second trip, may have been compromised. This restricted our ability to model interactions among physiological stress, operational variables, and environmental conditions. Therefore, survivorship estimates based on tagging and blood lactate by vitality index should be interpreted with caution. Expanding physiological sampling and tagging across a wider range of vessels, fishing strategies, and environmental conditions will improve the precision of future post-release mortality estimates and facilitate the development of predictive survival models applicable to tropical tuna purse seine fisheries.

In conclusion, our results demonstrate that effective best handling and release practices, have the potential to substantially improve the post-release survival of sharks in tropical tuna purse seine fisheries arriving on deck in a correct state. Satellite-tag observations confirmed high survival among sharks released in good condition, while extrapolations based on vitality assessments suggested that approximately half of the overall bycatch population may survive following release.. Collectively, the results indicate that best handling and release practices can substantially reduce post-release mortality, but also highlight that minimizing capture stress and reducing mortality before sharks reach the deck remain the greatest challenges and opportunities for further conservation gains. Continued refinement of fishing gear and operations for impact mitigation, together with widespread implementation of best practices, effective bycatch release devices, and crew training, will be essential to further reduce shark mortality and support long-term sustainability outcomes in the tropical tuna purse seine fisheries.

Acknowledgement

We extend our sincere appreciation to Frabelle and Friesland Fishing companies for allowing us conducting the research cruise at their vessels as well as to the captains, skippers and crews of the Marita 88 and Friesland F. V. whose involvement was integral to the success of this project. We also would like to thank the PNG-FIA and Trimarine for their help and support of this project. This project is supported through funding from the Marine Stewardship Council (MSC) Ocean Stewardship Fund. The views expressed herein are those of the author(s) and do not necessarily represent the official positions or policies of MSC.

References

Bourjea, J.Ô., 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. https://doi.org/10.1016/j.biocon.2014.06.020

CITES (2022). Nineteenth meeting of the Conference of the Parties. Panama City, Panama, 14 - 25 November 2022..

Croll, D.A., Dewar, H., Dulvy, N.K., Fernando, D., Francis, M.P., Galván-Magaña, F., et al. (2016). Vulnerabilities and fisheries impacts: the uncertain future of manta and devil rays. Aquatic Conservation: Marine and Freshwater Ecosystems 26(3), 562—575.

Curnick DJ, Andrzejaczek S, Jacoby DMP, Coffey DM, Carlisle AB, Chapple TK, Ferretti F, Schallert RJ, White T, Block BA, Koldewey HJ and Collen B. 2020. Behavior and Ecology of Silky Sharks Around the Chagos Archipelago and Evidence of Indian Ocean Wide Movement. Front. Mar. Sci. 7:596619. doi: 10.3389/fmars.2020.596619

Dagorn, L., Holland, K.N., Restrepo, V., and Moreno, G. (2013). 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 and Fisheries 14(3), 391-415.

Dulvy N.K., N. Pacoureau, C.L. Rigby, R.A. Pollom, R.W. Jabado, D.A. Ebert, B. Finucci, C. M. Pollock, J. Cheok, K.B. Herman, C.S. Sherman, J. M. Lawson, R.H.L. Walls, P. Charvet, D. Fernando, G.M. Ralph, J.H. Matsushiba, C. Hilton-Taylor, S.V. Fordham, C.A. Simpfendorfer. 2021. Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. Curr Biol 2021; 31 :4773–4787.e8. https:// doi.org/ 10.1016/ j.cub.20 21.08.062

Eddy, C., Brill, R., Bernal, D., 2016. Rates of at-vessel mortality and post-release survival of pelagic sharks captured with tuna purse seines around drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. Fish. Res. 174, 109–117. https://doi.org/10.1016/j.fishres.2015.09.008

Escalle, L., Murua, H., Amande, J.M., Arregui, I., Chavance, P., Delgado de Molina, A., Gaertner, D., Fraile, I., Filmalter, J.D., Santiago, J., Forget, F., Arrizabalaga, H., Dagorn, L., Merigot, B., 2016. Post-capture survival of whale sharks encircled in tuna purse-seine nets: tagging and safe release methods. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 782–789. https://doi.org/10.1002/aqc.2662

FAO (2022). The State of World Fisheries and Aquaculture 2022. Sustainability in action. Rome. https://www.fao.org/documents/card/en/c/cc0461en

Gilman, E., Chaloupka, M., Booth, H., Hall, M., Murua, H., Wilson, J., 2023. Bycatch-neutral fisheries through a sequential mitigation hierarchy. Mar. Policy 150, 105522. https://doi.org/https://doi.org/10.1016/j.marpol.2023.105522

Grande M., I. Onandia, J. M. Galaz, J. Uranga, N. Lezama-Ochoa, J. Murua, J. Ruiz, I. Arregui, H. Murua, J. Santiago. (2022). Assessment on accidentally captured silky shark post-release survival in the Indian Ocean tuna purse seine fishery. IOTC-2022-WGFAD03-09. https://iotc.org/documents/WGFAD/03/09ç

Hall, M.A., and Roman, M. (2013). Bycatch and non-tuna catch in the tropical tuna purse seine fisheries of the world. FAO fisheries and aquaculture technical paper 568 FAO, Rome. www.fao.org/3/a-i2743e.pdf

Hutchinson, M.R., Itano, D.G., Muir, J.A., Holland, K.N., 2015. Post-release survival of juvenile silky sharks captured in a tropical tuna purse seine fishery. Mar. Ecol. Prog. Ser. 521, 143–154. https://doi.org/10.3354/meps11073.

Hutchinson, M. R., J. Lopez, and A. Aires-da-Silva. 2024. Best Handling And Release Practice Guidelines For Sharks In Iattc Fisheries. IATTC SAC-15-11.

IATTC. 2024. IATTC Resolution 24-05 for the protection and sustainable management of sharks. IATTC Resolution 2024-05.

ISSF. 2026. Status of the world fisheries for tuna. ISSF Technical Report 2026-01. International Seafood Sustainability Foundation, Pittsburgh, PA, USA

Juan-Jordá, M.J., Murua, H., Arrizabalaga, H., Merino, G., Pacoureau, N., Dulvy, N.K., 2022. Seventy years of tunas, billfishes, and sharks as sentinels of global ocean health. Science (80-.). 378, eabj0211. https://doi.org/10.1126/science.abj0211

Murua, J., Moreno, G., Dagorn, L., Itano, D., Hall, M., Murua, H., Restrepo, V., 2023. Improving sustainable practices in tuna purse seine fish aggregating device (FAD) fisheries worldwide through continued collaboration with fishers. Front. Mar. Sci. 10. https://doi.org/10.3389/fmars.2023.1074340.

Murua, J., Ferarios, J.M., Grande, M., Ruiz, J., Onandia, I., Zudaire, I., Krug, I., Salgado, A., Santiago, J. 2024. Best Practice Guidelines for handling and release of bycatch species in tuna purse seiners. AZTI.

Murua, J, Ferarios, J.M., Grande, M. Nagore, C., Salgado, A., Lopez, J., Hutchinson, M., Moreno, G., Murua, H., Santiago, J. 2024. Silky shark post-release survival evaluation in tropical tuna purse seiners using hoppers with ramps. WCPFC-SC20-2024/EB-IP-21.

Murua J., Maitane Grande, Gala Moreno, Hilario Murua, Nagore Cuevas, Jose M Ferarios, Alexander Salgado, Victor Restrepo, Josu Santiago. 2025a. Codeveloping on deck conservation technology with tropical tuna purse seine fishers to mitigate elasmobranch bycatch, ICES Journal of Marine Science, Volume 82, Issue 5, May 2025, fsaf057, https://doi.org/10.1093/icesjms/fsaf057

Murua, H., Moreno, G., Murua, J., Grande, M., Restrepo, V. 2025b. Trialing shark bycatch release devices on board purse seiners in the Pacific Ocean to enhance shark survival. WCPFC-SC21-2025/EB-IP-12.

Onandia, I., Grande, M., Galaz, J.M., Uranga, J., Lezama-Ochoa, N., Murua, J., Ruiz, J., Arregui, I., Murua, H, Santiago, J. 2021. New assessment on accidentally captured silky shark post-release survival in the Indian Ocean tuna purse seine fishery. IOTC-2021-WPEB(17(DP)-13_rev1. https://iotc.org/documents/WPEB/1701/13

Pacoureau, N., Rigby, C.L., Kyne, P.M., Sherley, R.B., Winker, H., Carlson, J.K., Fordham, S. V., Barreto, R., Fernando, D., Francis, M.P., Jabado, R.W., Herman, K.B., Liu, K.M., Marshall, A.D., Pollom, R.A., Romanov, E. V., Simpfendorfer, C.A., Yin, J.S., Kindsvater, H.K., Dulvy, N.K., 2021. Half a century of global decline in oceanic sharks and rays. Nature 589, 567–571. https://doi.org/10.1038/s41586-020-03173-9.

Poisson et al., 2012 Poisson, F., Vernet, A.L., Séret, B., Dagorn, L. 2012. Good practices to reduce the mortality of sharks and rays caught incidentally by the tropical tuna purse seiners. EU FP7 project #210496 MADE, Deliverable 7.2. 30p.

Poisson, F., Séret, B., Vernet, A.-L., Goujon, M., Dagorn, L., 2014. Collaborative research: Development of a manual on elasmobranch handling and release best practices in tropical tuna purse-seine fisheries. Mar. Policy 44, 312–320. https://doi.org/https://doi.org/10.1016/j.marpol.2013.09.025

Restrepo, V., Dagorn, L., Itano D., Justel-Rubio and A., Forget F. and G. Moreno (2017). A Summary of Bycatch Issues and ISSF Mitigation Initiatives To-Date in Purse Seine Fisheries, with emphasis on FADs. lSSF Technical Report 2017-06. International Seafood Sustainability Foundation, Washington, D.C., USA.

Restrepo, V., L. Dagorn, G. Moreno, J. Murua, F. Forget, and A. Justel. 2019. Report of the International Workshop on Mitigating Environmental Impacts of Tropical Tuna Purse Seine Fisheries. Rome, Italy, 12-13 March, 2019. ISSF Technical Report 2019-08. International Seafood Sustainability Foundation, Washington, D.C., USA.

Stewart J.D., Melissa R. Cronin, Erick Largacha, Nerea Lezama-Ochoa, Jon Lopez, Martin Hall, Melanie Hutchinson, Emma G. Jones, Malcolm Francis, Maitane Grande, Jefferson Murua, Vanessa Rojo, Salvador J. Jorgensen. 2024. Get them off the deck: straightforward interventions increase post-release survival rates on manta and devil rays in tuna purse seine fisheries. ICES J Mar Sci 2024; 79 :1015. https://doi.org/ 10.1016/ j.biocon.2024.110794

Tolotti M., J. D. Filmalter, P. Bach, P. Travassos, B. Seret, L. Dagorn. 2015. Banning is not enough: The complexities of oceanic shark management by tuna regional fisheries management organizations. Global Ecology and Conservation, Vol. 4: 1-7. https://doi.org/10.1016/j.gecco.2015.05.003.

WCPFC 2024. CMM 2024-05 - Conservation and Management Measure for Sharks. WCPFC CMM 2024-05.

Zollet E.A., Swimmer, Y., 2019. Safe handling practices to increase post-capture survival of cetaceans, sea turtles, seabirds, sharks, and billfish in tuna fisheries. Endanger. Species Res. 38, 115–125.