Undetected silky sharks (*Carcharhinus falciformis*) in the wells of the tropical tuna purse–seine fleet from the Indian Ocean

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Introduction

Discarding, the act of throwing unwanted catch overboard, represents a significant challenge to fisheries management around the world. Recent estimates suggest that up to 25% of the global fish catch is discarded annually, making it one of the most pressing issues in fisheries management (Tsagarakis et al., 2017). This phenomenon is particularly relevant in the context of the tropical purse seine fishery.

In order to better understand the state of the fisheries, it is vitally important to have good by-catch estimates, both by scientific entities and through on-board observation programs and port capture protocols, as well as by the statements of the Electronic Onboard Logbooks (Ardill et al., 2011, Gilman et al., 2017, Juan Jordá et al., 2022). According to Gilman et al. (2017) the global tuna fleet discarded around 265,279 tons of catch, which represented 5.3% of the total world catch from fisheries for that year. Most of this discarding (64%) was carried out by longline vessels, while the remainder (36%) was attributed to the purse seine fishery. Less than 0.01% came from tuna trolling and trap fishing (Gilman et al., 2017). In the Indian Ocean tropical tuna purse seine fisheries, setting on free schools results in the lowest levels of bycatch, while producing more than 80% of the highest value of yellowfin tuna (*Thunnus albacares*) and bigeye tunas (*Thunnus obesus*). In contrast, sets on associated floating object schools results in almost five times the amount of bycatch, with skipjack (*Katsuwonus pelamis*) constituting almost 70% of the target catch (Ardill et al., 2011).

Cartilaginous fish, with their slow growth and late sexual maturity, are among the vertebrate species most threatened by different types of fishing (Dulvy et al. 2021). According to recent estimates, from 1093 species of cartilaginous fish, 99.6% (1082) are threatened by overfishing in industrial fisheries, mainly due to unintentional capture or bycatch. Overfishing is the main threat to 391 species and is the only threat to two thirds of cartilaginous fish species (Dulvy et al., 2021). However, although bycatch data are scarce, it is estimated that about 50% of the world's reported catches of elasmobranchs are targeted (Wosnick et al. 2022).

The silky shark (*Carcharhinus falciformis*) has moved from the “Low Risk” category on the IUCN Red List of threatened species in 2000 to “Near Threatened” in 2009 and to “Vulnerable” in 2017 (Rigby et al., 2021). In less than two decades the populations have declined significantly, mostly due to fishing for the Asian market (Dulvy et al. 2008) and to a lesser extent as a result of bycatch in other fisheries (Wosnick et al. 2022). The silky shark is the most common shark species that appears in the tuna purse seine fishery, although in turn, this fishery represents the least impact on the associated populations compared to other fisheries (Ardill et al., 2011). According to Poisson et al. (2014), who carried out a study on French vessels in which they observed that the mortality rate of silky sharks in purse seine fishing is 81%, reaching 85% for those individuals brought on board in nets (Poisson et al. 2014).

The Spanish tuna purse seine fleet has been fishing since the 1980s in the waters of the Indian Ocean (Báez et al. 2020). It focuses on three target species of tropical tunas: skipjack, yellowfin and bigeye tuna (Delgado de Molina et al., 2007, Báez et al., 2022). It is one of the largest fleets in the world with a catch of 154,702 tons of these species, compared to the 382,992 tons of global caught by tuna fisheries in 2021. This represents 40.39% of the tropical tuna fishery in this ocean (IOTC-2022-WPTT24, 2022).

Since the beginning of the fishery, technological advances and the need to explore new ways of finding tuna have produced important changes to the fishery. The development of Fish Aggregating Devices (FADs) since the 1990s has been an important revolution. Most sets made by the Spanish fleet currently involve the use of these floating objects (Fonteneau et al., 2000, Fonteneau et al., 2013, Báez et al., 2022). These devices are deployed by ships and geolocated with satellite buoys that have the ability to make rough estimates of the amount of fish aggregated on each object using echo sounders, the use of which has been widespread since the turn of the century (Dagorn et al., 2013, Gilman et al., 2017).

Due to the variable time they spend at sea, floating objects also aggregate other species without commercial interest for tuna fishing in most cases. Groups of sensitive species (sharks, rays and manta rays and sea turtles) are returned to the sea as soon as possible from the main deck or from the fishing deck to avoid their accidental death (Delgado de Molina et al. 2007, García & Herrera, 2018). In the case of other species and groups of species, such as dolphin-fish (*Coryphaena* spp.), rainbow runner (*Elagatis bipinnulata*), several species of carangids (*Caranx* sp.), bullet and frigate tuna (*Auxis* spp.), triggerfish (*Canthidermis maculata*) or wahoo (*Acanthocybium solandri*), these are released or retained on board depending on their commercial interest or for consumption purposes (Ardill et al., 2011). Sometimes their numbers are too large or too small to be detected, and a fraction of them accidentally ends in the wells, where they are stored together with the main catch. Most of the landings take place in the Seychelles. It is the stevedores who are generally in charge of removing part of these species from the ship, either for personal consumption or to sell to small local businesses. In other cases, by-catch with commercial interest is separated and transferred to merchant vessels to be transferred to other markets.

The monitoring of the fishery by the Regional Fisheries Management Organizations (RFMOs) implies the adaptation and evolution to the new strategies, improving both the scientific estimates of the exploited species and the knowledge of the impact of the fishery on the ecosystem, which it can help improve the management and sustainability of fisheries resources. The general evaluation of the adequacy of past and present monitoring systems is the estimation system called T3 (Tropical Tuna Treatment), an important tool to provide estimates of the specific composition and of the global catches of tropical tunas throughout the historical series. It generates an adjustment or correction of the catches based on the extrapolation of the spatio-temporal samplings to the observed catches (Pallarés & Petit, 1998, Lechauve, 1999, Pianet et al., 2000, Duparc et al., 2018).

We have tested two different hypotheses regarding the presence of *Carcharhinus falciformis* in the wells of the Indian Ocean tropical purse seine fishery during port unloading. The first hypothesis suggests that those individuals are part of an unobserved fraction of bycatch, which would lead to underreporting. The second hypothesis suggests that they are a fraction of bycatch that, despite being observed, accidentally ended up in the wells. The distinction between these hypotheses is significant, as accurately estimating the volume of discards per species is crucial to understanding the magnitude of the problem.

Material and methods.

The present study began in January 2021 in the unloading of Spanish-flagged vessels in Seychelles. From that moment, and still today, it continues to be developed together with the sampling of Tropical Tunas for the Spanish Institute of Oceanography (Pérez San Juan et al., 2021).

Observers data.

The data taken on board the tuna purse seine vessels are due to the National Basic Data Program carried out by the Spanish Institute of Oceanography. The data were taken by Spanish scientific observers, who witnessed and scientifically reported each set with its corresponding catch and associated discard if any.

The trips of the observers correspond to a trip of the tuna seiner, which is the period that elapses from when they leave the port until they have caught a complete load and enter the port again to unload.

For the present work, data from all the trips made by Spanish observers between January 2021 and December 2022 have been taken.

Port sampling data.

The tuna port sampling begins with the arrival of the vessel in port. The coordinator requests the documents of the trip: the fishing logbook and the wells plan, after which he selects the appropriate wells to work during unloading in port. Wells from a single set are prioritized. If they do not exist, the choice of wells is conditioned by the type of set (they must be the same), by the date (there must not be sets with more than 15 days of difference in the same well) and by the geographical area (there must be no more than 5º of latitude and longitude between sets) (Bach et al., 2018).

Once the wells have been selected and knowing the type of fish they contain (<10 kg or >10 kg), the sampling of the well begins. When tuna weighing less than 10 kg appear in the tank, a first subsampling is carried out in which 250 individuals are randomly selected to identify them and measure their fork length (FL). Given the high incidence of skipjack, only 50 of them are measured, the rest are counted and counted for the total count of 250. When the first subsampling is finished, a reasonable amount of time (generally at least one hour) is allowed to begin the second subsampling in order to obtain data from two different strata in the well.

When the weight of each tuna in the well is greater than 10 kg, the sampling is also divided into two sub-samples, by which they are identified and the pre-dorsal length (LD1) of 100 individuals is measured in each round. It is also necessary to wait a reasonable time (30-60 minutes) between rounds to sample all the strata of the well (Bach et al., 2018).

In 2020, a specific Sampling Protocol for the Bycatch Observed in Wells was implemented, according to which the bycatch samplings were carried out during the hour that must be waited between the two rounds of tuna sampling to be carried out.

During unloading, all species that are not tropical tunas are deposited next to the well they came from before being removed by stevedores, so it is easy for the sampling team to determine the origin of each sampled species. Along with the well of origin, we also have the geographical area in which it was fished and the time of year. Each and every one of the bycatch species were measured to their (FL) except for those that appear in large numbers such as *Canthidermis maculatus* or *Decapterus macarellus*, which were simply counted. For sharks, the total length (TL) was taken and the sex of each individual was also noted for all cartilaginous fish (sharks and rays).

Statistical analysis.

Of all the samplings carried out in port in the period 2021-2022 (n= 511), those samplings where a scientific observer on board and a sampling on port coincided were selected (in total n= 306 samplings). In a first step, the Mann-Whitney U Test was used to compare the sample means of the mean sizes of the specimens measured on board by the observers, against the sizes of the silky sharks measured in wells, in case there was any selection by size (Nachar, 2008).

The possible causal effect of having observed at least one individual of silky shark in a particular well during the sampling, as dependent variables, was analyzed by using the total catch from a fishing operation (abbreviated as "catch"), the well with its corresponding weight (abbreviated as "well"), number of silky shark observed on board (abbreviated as "sharks observed"), number of silky sharks estimated by the scientific observe during the fishing operation (abbreviated as "sharks estimated"), as independent variables.

Thereby, a logistic binary stepwise forward/backward regression was performed to test whether the probability of observing at least one individual of silky shark in wells in relation to the independent variables.

Model coefficients were assessed by means of an Omnibus test and the goodness-of-fit between expected and observed proportions of by-catch events along ten classes of probability values and evaluated using the Hosmer and Lemeshow test (which also follows a Chi-square distribution; low p-0.05 would indicate lack of fit of the model) (Hosmer and Lemeshow, 2000). The Omnibus test examines whether there are significant differences between the -2LL (less than twice the natural logarithm of the likelihood) of the initial step, and the -2LL of the model, using a Chi-squared test with one degree of freedom. On the other hand, the Hosmer and Lemeshow test compares the observed and expected frequencies of each value of the binomial variable according to their probability.

In addition, the discrimination capacity of the model (tradeoff between sensitivity and specificity) was evaluated with the receiving operating characteristic (ROC) curve. Furthermore, the area under the ROC curve (AUC) provides a scalar value representing the expected discrimination capacity of the model. The relative importance of each variable within the model was assessed using the Wald test (Hosmer and Lemeshow, 2000).

Results.

A total of 1,002 sharks were observed and sampled in the wells of Spanish tuna vessels during 2021 and 2022 (Fig. 1). Of them, 51% were male and 49% female. Three individuals were not sexed (Fig. 2).

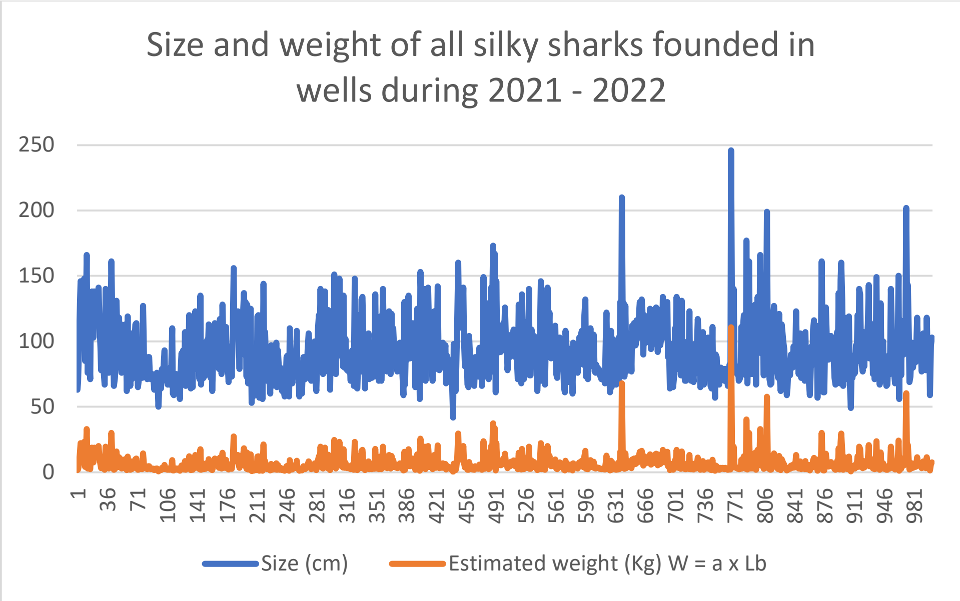


FIG 1: Size and weight of silky sharks found during the period of the present study.

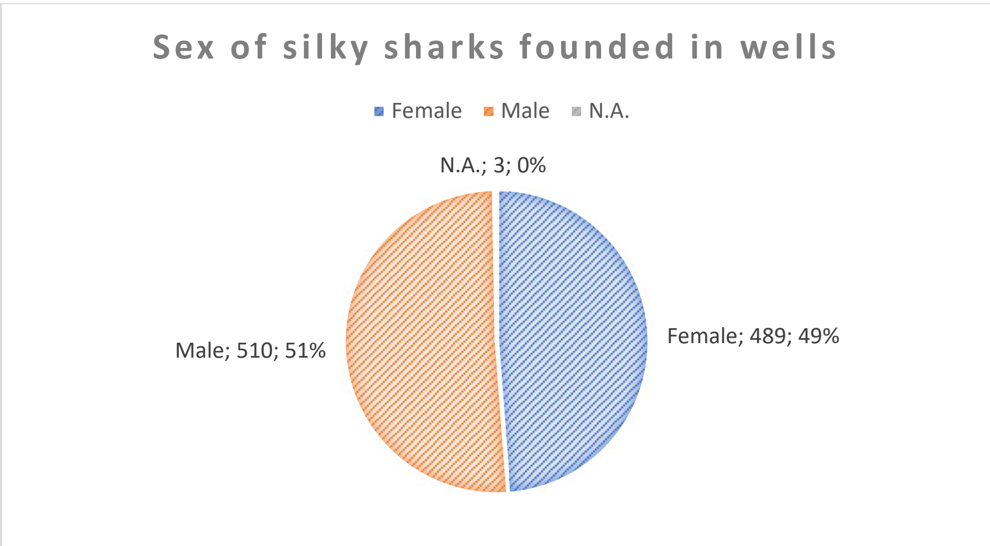


FIG 2: Sex of all silky sharks sampled in the present study.

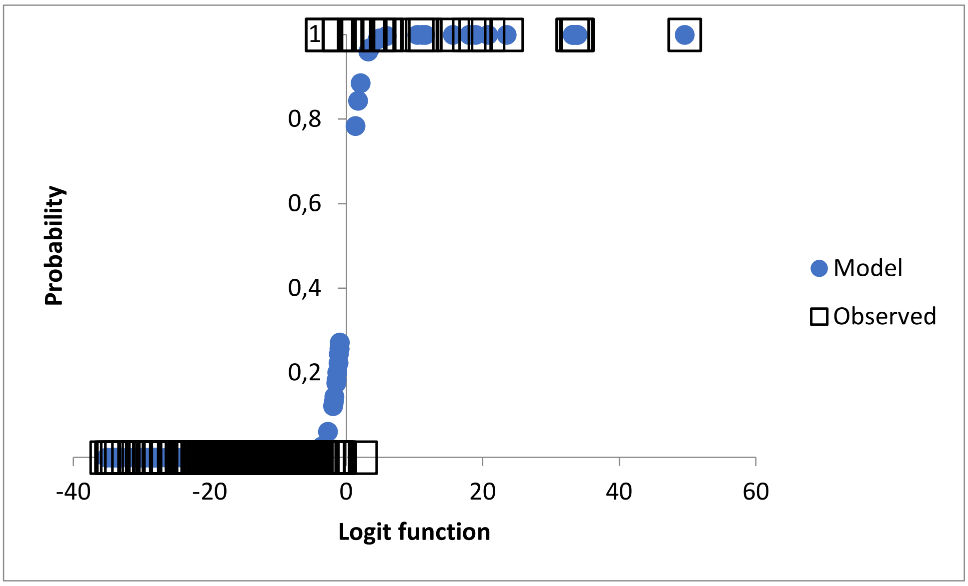
We observed significant differences between the mean size of silky sharks measured by observers (mean 113,92 cm) versus wells (mean 85.74 cm), Mann-Whitney U= 1012,000; No.=242; P<0.001.

A statistically significant logistic model was obtained for the probability of observing at least one individual of silky shark in particular wells during the sampling, according to the logit function:

$$Logit:\ y = -3.575 + Catch*0.215 + Wells*-0.175$$

The model's goodness of fit was significant according to the Omnibus test (Omnibus test = 153.792; df = 2; P < 0.001;

Hosmer and Lemeshow test = 2.413, df = 8, P = 0.966), and its discrimination capacity was outstanding (AUC = 0.99).



According to this model, we can affirm that the greater the catch and the less volume there is in the wells, the greater the probability of finding sharks in port. This implies that there is a fraction of silky sharks that is not observed by observers or by the crew.

Discussion.

This study shows that there is a catch component not sampled or estimated during the catch that accidentally ends up in the wells, increasing the mortality rate of specimens during the fishing activity, and that could be undetected.

There is an impact on silky shark populations by purse seine vessels.

The main weakness of the present study is that there is a potential bias in large sets, since smaller wells are more likely to observe silky sharks. Therefore, new methods need to be developed to estimate this volume of misreported catches, as well as to mitigate the impact of the purse seine fishery on Indian Ocean silky shark populations.

It is essential to develop systems that improve the estimates of the populations of undetected species that end up stowed in the wells, and if possible minimize their presence. The installation of hoppers on tuna vessels could lead to significant improvements in the presence of accessory species in the wells (Wosnick et al., 2022). With this system, the net is deposited in the hopper and all species of no commercial interest are quickly thrown overboard by the crew.

Based on this observation, we believe that it would be beneficial to increase the number of physical observers on board. According to Briand et al. (2018), EMS is a useful tool but it is not developed to make adequate estimates of bycatch, especially in the case of sharks, billfish and other species of high commercial interest. (Briand et al. 2018). EMS should complement the work of scientific observers, not replace it.

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