A review of the effectiveness of gear modifications to reduce shark bycatch mortality in longlining

Author:
Iris Ziegler, Sharkproject International

Abstract:
IOTC has so far adopted only few shark conservation measures and existing measures focus on banning retention of *Carcharhinus longimanus*, *Rincodon typus*, and all three species of *Alopias*. No measures to reduce at-vessel mortality and post-release mortality have been adopted for longlining fleets at IOTC. While targeted catches will be disincentivized by such bans, an effective overall mortality reduction needs to address bycatch mortality, especially when the sharks that are to be released make up a substantial part of the bycatch of a fishery. While silky sharks are targeted by several artisanal fleets in the Indian Ocean and artisanal fisheries are exempted from the retention ban for Oceanic whitetip sharks, both species get discarded as a regular bycatch by industrial tuna and swordfish fleets, specially by those fleets targeting blue sharks. Scientific studies in the Pacific have recently shown that fishing mortality of both species can be reduced by more than 40% and 30% respectively, when steel leaders are replaced by monofilament leaders and shark lines removed (Bigelow et al. 2021). Therefore, the WCPFC will ban both gear modifications between 20°N and 20°S from 2024 onwards. However, IOTC has failed to agree on a similar conservation measure at its 26th IOTC Commission Meeting.
Reducing bycatch mortality at IOTC is also important for all sharks that get discarded by longline fisheries that do not retain sharks, including but not limited to oceanic whitetip sharks and thresher sharks, but also including silky sharks, mako sharks, and hammerhead sharks. All of them scored high in the ecological risk assessment (Murua et al. 2018), being highly vulnerable to longline interaction combined with high post release mortality when injured during the catch operation. Although little research has been done at IOTC on leader types and other gear modifications suitable to reduce bycatch mortality of sharks in the IOTC, a substantial number of studies have been performed in the Pacific and Atlantic over the last 15 years demonstrating the potential of gear modification to reduce mortality of these and other vulnerable bycatch species, especially when combined with other bycatch avoidance and mitigation measures. Therefore, a substantial number of nations has already banned or are in the process of banning the use of these gear modifications in their fleets.

Introduction

The IOTC Compliance Meeting (IOTC-2023-CoC20_RE) confirms in 2023 that compliance with reporting requirements has further decreased in 2022 to only 65%, the lowest level since 2016. Compliance with reporting of mandatory statistics for sharks (Res 17/05) has also reached an all-time low of 41% and less than 75% compliance was achieved for the conservation measures for oceanic whitetip sharks, for thresher sharks, and for mobulids and manta rays. Only 37% of the reporting of nominal catch and catch efforts for sharks and only 19% of reporting of size frequency data for sharks has been provided. The lack of data has hindered stock assessments in the past and continues preventing meaningful conservation efforts. Non-compliance is not only a serious issue in developing coastal nations, but also applies to several large members states like the European Union, whose fleet has also not been fully compliant with the mandatory reporting requirements on sharks, and this has been a reoccurring situation over the last years.
At the 27th Session of the Indian Ocean Tuna Commission, the Maldives submitted a proposal IOTC-2023-S27-PropR[E] on the conservation of sharks caught in association with fisheries managed by IOTC, which among other shark conservation measures proposed to starting in 2025 to require all CPCs to "*ensure that their long-line vessels do not carry or use wire trace as branch lines or leaders; and branch lines running directly off the longline floats or drop lines, known as shark lines*." The measure intended to reduce bycatch mortality of the most sensitive species, oceanic whitetip sharks, silky sharks, shortfin mako sharks, thresher sharks, and hammerhead sharks in the IOTC when caught as a bycatch in longlines and discarded. Due to the existing retention bans for oceanic whitetip sharks IOTC Resolution 13/06 and thresher sharks *IOTC Resolution 12/09* all incidentally caught animals of those species have to be released as unharmed as possible or discarded dead; however, the IOTC Scientific Committee noted in 2021 that haul-back mortality of critically endangered whitetip sharks is 50%. As stated by Tolotti et al in 2015 "*Banning is not enough*" retention bans must be accompanied by high

enough observer coverage to ensure compliance and data collection, "*as well as the adoption of measures that can reduce the fishing mortality of sharks by avoiding their catch and increasing their survival after release*". However, to date no additional measures have been introduced to enforce compliance with the retention bans, to reduce mortality or to improve post release survival. While hammerhead sharks, silky sharks, and mako sharks can still be retained their stock status is also highly uncertain and the IOTC Scientific Committee in 2021 advised that the Commission should take a cautious approach to the conservation of shortfin mako sharks and silky sharks by implementing management actions that reduce fishing mortality. Both are recognized in the Ecological Risk Assessment (ERA) for their high vulnerability to overfishing (Murua et al 2018) due to their biology and the high spatial overlap with fishing activities. The new conservation measure could potentially have stepped-up shark conservation in the Indian Ocean as it had also suggested to introduce 'Fins Naturally Attached', improve reporting at species level for all gear types, and to intensify research in improved gear selectivity, bycatch avoidance, and mortality reduction measures. Also, the development of management measures with catch limits and catch allocations for commercially targeted species, such as blue sharks would have been part of the measure. During the Commission meeting this proposal received co-sponsorship from a growing number of CPCs, including Bangladesh, the European Union, Indonesia, Madagascar, Pakistan, Somalia, and South Africa and was also supported by many other CPCs.

However, at the end of the 27th Commission Meeting not even Revision 3 of the proposal IOTC-2023-S27-PropR, suggesting that the fisheries can select whether to use shark lines OR to use wire traces, could be agreed on unanimously by all CPCs, as some CPPCs complained that no scientific advice from the IOTC Scientific Committee existed for such a measure and that there was no scientific evidence demonstrating a ban of shark lines and wire traces could to be effective in reducing bycatch mortality of IOTC vulnerable species.

Therefore, the Maldives decided not to go forward with a further revision of the proposal but instead withdrew the proposal and asked that a request be included in the report of the 27th Commission Meeting, that the "*relevant Working Parties and IOTC Scientific Committee, at its 26th session, [..] review the latest science and best practices in other oceans and, in collaboration with the Compliance Committee as appropriate, provide advice to the Commission at S28 on technical and mitigation measures to strengthen the conservation of sharks. In particular advice on vulnerable species such as oceanic whitetip sharks, whale sharks and thresher sharks, and how to reduce the impact of tuna fisheries, including the following:*

- *the use of wire trace as branch lines or leaders and the use of branch lines running directly off the longline floats or drop lines, known as shark lines."*

This paper reviews the more recent literature for evidence of these measures having been evaluated elsewhere to be effective and introduced at national or RFMO level.

Discussion

Shark populations have collapsed globally and especially the populations of oceanic shark species have seen massive declines due the industrial fishing pressure over the last 50 years, with many stocks today either already being overfished or having an unknow stock status and oceanic shark populations having been reduced by more than 70% of their preindustrial biomass. (Pacoureau et al. 2021)

Due to their low fecundity and late sexual maturity and the absence of effective management in international waters these populations have been overexploited by the international fin trade since the 1970s and more recently also by the meat trade, which has evolved over the last decade. (Poseidon et al. 2022). To stop this dramatic situation, effective fisheries regulations to reduce catches to sustainable levels must be introduced and endangered species specifically protected. Measures to effectively reduce bycatch mortality supported by bycatch mitigation technologies, best practices for handling and release, and "*effective marine protected areas that can provide species with refuge from fishing throughout a meaningful fraction of their range"* are essential to establish (Dulvy et al. 2021).

Although retentions bans have been agreed upon for a few shark species in all of the tuna RFMOs after having been listed on the Convention on Migratory Species (CMS) Annex I, as applicable to *Carcharhinus longimanus* and *Rincodon typus*, little or no additional measures have been implemented

to ensure compliance or reduce bycatch mortality and these animals continue to be caught as a bycatch in the gillnet, purse seine and longline fisheries.
Other shark species, although also rated as vulnerable, endangered, or even critically endangered by the IUCN and all now listed on CITES App II, have different levels of protection in the different RFMOs. For endangered *Isurus oxyrinchus* first management measures have recently been adopted by ICCAT with a retention ban in the North Atlantic and an allocated TAC in the South Atlantic, while no catch limits exist for the species in other RFMOs. (Rec 2021/09 and Rec 2022/11). Vulnerable *Carcharhinus falciformis* is subject to a retention ban in WCPFC, and ICCAT has at least suggested an interim bycatch limit of 20% of total catch in weight per fishing trip for vessels not targeting sharks and to limit the number of juveniles to 20% of the total silky shark catch in numbers (IATTC Resolution C-23-08). However, no management measure exists at all for silky sharks at IOTC although silky sharks are actively targeted by artisanal fleets and a regular bycatch in all gear types. Critically endangered hammerhead sharks can be landed without limits in all RFMOs except ICCAT. Thresher sharks are only subject to a retention ban at IOTC and at ICCAT (Rec 09/07 *Alopias superciliosus* only) but not in the two RFMOs in the Pacific.

A retention ban removes the incentive for deliberately targeting those species and thereby is a first step for the conservation of the stock, but irrespective of whether a retention ban exists or not, bycatch of these sharks continues in the fisheries for tuna and swordfish. Therefore, reduction of at-vessel mortality and post-release mortality remain unresolved but urgent tasks that must be achieved for these and other non-retained sharks (Tolotti et al. 2015). Besides some improvements in best handling release practices little has been done to reduce bycatch mortality as most other mitigation measures also potentially affect the catches of target species, as several longlining fleets actively target sharks (Mucientes et al. 2023).
Many of these fisheries have so far shown little willingness to voluntarily adopt bycatch avoidance measures or gear changes that could potentially reduce the catch of the targeted shark species, mostly blue sharks and mako sharks. Although ICCAT has banned retention of shortfin mako in the North Atlantic in 2022 and Spain and Portugal prohibited the introduction of mako from the High Seas in 2021, the total mortality of shortfin mako in both fisheries remained unchanged to previous years at more than 1,000 tonnes as more than 90% of mako sharks were discarded dead by those fleets. The Canadian and US fleets which do not target sharks in their blue shark and swordfish fisheries had released 75% and 60% of the bycaught sharks alive, respectively. (SCRS 2022)

<u>WCPFC taking the Lead in Reducing Bycatch Mortality of Protected Sharks</u>
In 2022 the WCPFC updated its Conservation and Management Measure for sharks CMM 2022-04 including that from 2024 onwards between 20 N and 20 S "*longline fisheries targeting tuna and billfish do not use, or if carrying, must stow wire trace as branch lines or leaders and do not use shark lines or branch lines running directly off of the longline floats or drop lines"* where previously the fisheries were given the choice between the two options. Longline fisheries targeting sharks are required to develop and report their management plans to the Commission.

Although a proposal to introduce a similar ban at IATTC was not adopted during the 101st Commission Meeting in 2023, IATTC had already adopted in 2019 a temporary conservation measure for silky sharks in an attempt to limit silky shark bycatch in tuna longlining fleets, which has been prolonged to 2025 IATTC C-23-08. The conservation measure addresses all longline fleets that capture silky sharks as a bycatch to limit their bycatches to 20% by weight of the total catch and punishes vessels that exceed this limit by requiring them to ban the use of steel leaders for three consecutive months every year. This underlines the widespread knowledge of steel leaders causing higher shark bycatch rates and the specific vulnerability of silky sharks to this gear.

The Western Central Pacific Fishery Commission (WCPFC) has adopted its gear ban to specifically protect vulnerable oceanic whitetip and silky sharks as stated in the Reference Document for Review of CMM 2019-04 "*SC18 noted the updated projections on the impact of banning shark lines, wire leaders, or both and estimates of catchability and probability of post release mortalities on oceanic whitetip sharks (under Project 1011) using observer data on gear configurations by flag for 110,154 longline sets. The biomass of oceanic whitetip sharks is projected to increase if either catch reductions or mitigation methods such as prohibiting both wire leaders and shark lines in the area 20° S to 20° N*

are adopted and implemented. If no action is taken, the stock biomass is projected to remain at a very depleted level".
The recommendation was based on results of a project that had developed an interaction model for oceanic whitetip sharks and silky sharks with longline gear, evaluating the mortality reduction of the removal of shark lines and the transition from branch-lines with wire leaders to monofilament leaders, (Bigelow et al. 2021) thereby building upon an earlier study (Harley et al. 2015) on the catchability and survival as well as the spatial distribution of the two species. In their 2015 analysis they had already warned that "*Given the high levels of fishing mortality experienced by these two species, it is unlikely that the options under the shark CMM (2014-05) of either banning shark lines or wire traces will result in sufficient reductions in fishing mortality. Strengthening this measure may be necessary*."

For the project observer data from more than 110,000 sets between 2010 and 2018 were analyzed for modelling data from 14 fishing nations in WCPFC and for each set evaluating the type of hook (circle hook, J-hook, tuna hook), the type of leader used (monofilament or wire) and whether shark lines were used or not. Preferences for gear configuration vary from fishing nation to fishing nation, but the whole range of configurations was present for the study, ranging from nations like Japan who fish almost exclusively on tuna hooks while the USA and most Pacific Island use circle hooks instead. Most others used a mix of either tuna and circle hooks or J-hooks and circle hooks. Shark lines were only still used by PNG for the evaluated time, whereas most other nations used wire leaders for most of the sets, especially the Pacific Island nations, Korea, and USA. Only PNG used exclusively monofilament leaders. Therefor the study is representative for all gear combinations although fishing nations had to select using either shark lines of wire leaders in line with CMM 2014-05.
The outcome showed improved survival rates from a ban of shark lines alone to be only 2.6% and 5.4% for silky shark and oceanic whitetip shark, respectively, which is lower than previously estimated by Harley et al. (2015). The authors this to the reduced use of shark lines in recent years. The higher contribution to mortality reduction from a ban of wire traces compared to earlier study results is believed to result from better gear identification in the long distant water fleets. (Bigelow et al. 2021).
The overall outcome of the study showed substantial reductions in fishing mortality for both shark species possible from shifting to the proposed gear modifications.

- "*Banning branchline wire leaders has the potential to reduce fishing mortality by 28.2% and 35.8% for silky shark and oceanic whitetip shark, respectively".*
- "*Banning both shark lines and wire leaders has the potential to reduce fishing mortality by 30.8% and 40.5% for silky shark and oceanic whitetip shark, respectively".*

<u>Gear Modifications as an effective Measure to reduce Bycatch Mortality</u>

Gilman et al, in a 2022 global meta-synthesis estimating at vessel mortalities for pelagic longlines, found higher at vessel mortalities for many Carcharhiniform species and *Lamniformes* in the Atlantic than in the Pacific, while they could not find a significant impact from the type of hook used in either of the Oceans. J-hooks and circle hooks were thus rated as equivalent but substantial differences in mortality were found between different species in the same ocean basin. *Carcharhinus falciformis* has a generally higher mortality than *Carcharhinus longimanus* and most other shark species, while only hammerhead sharks had similarly high mortality rates.
The authors conclude that for species with low at vessel mortality and if the sharks are discarded the benefit of improvements in handling and release would have the biggest impact on overall survival rates, whereas catch limits or retention bans and trade bans are useful for sharks with low at vessel mortality if the fisheries retain sharks. Sharks showing high at vessel mortality rates benefit from methods that avoid and reduce the risk of catching them. While no further measures to reduce at vessel mortality are suggested, retention bans are only considered useful if leading to reduced catches.
(Gilman 2022).

Swimmer et al. in 2020 took a different perspective in deciding which measures are most suitable to apply, differentiating between fisheries that target sharks and those that catch sharks only as an unwanted bycatch. For the latter, mitigation measures such as deep sets, reduced soak time, longline gear without wire leaders and hook and bait changes are considered as most effective but should always be selected per species as effects and outcomes may differ between species.

Replacing wire leaders by monofilament leaders was rated as having a high potential to reduce shark bycatch as sharks can 'bite off' and swim away, whereas wire leaders are known to have higher retentions and sharks may stay hooked on these for many hours until the lines are hauled in.
Australia has therefore banned wire leaders in its eastern tuna longline fisheries in 2005 (Swimmer et al. 2020) and Western Australia banned it in all fisheries in 2022. Lack et al. (2009) concluded in the Pacific Island Regional Plan of Action for Sharks that nylon leaders decrease shark bycatch in longline fisheries and increase the survival of escaped sharks, as sharks that managed to free themselves by biting off the lines are expected to be less injured than those hooked on wire leaders. By 2012 the Pacific Island countries and several other countries such as Ecuador, Federated States of Micronesia, New Caledonia, Papua New Guinea, South Africa, Tonga and Republic of the Marshall Islands had banned wire leaders (PEW 2012). Also, the USA has been reported to be in the process of moving from wire leaders to monofilament in 2021 to step up protection of oceanic whitetip sharks in particular (Hutchinson et al. 2021).

Studies by Ward et al. (2008) in Australia, Afonso et al. (2012) in the South Atlantic and Coelho et al. (2013) in the North Atlantic also reported improved survival rates for monofilament leaders versus wire leaders 10 to 15 years ago, with Ward calling this mitigation measure "*highly promising given that it is effective, easy to implement, easy to enforce, requires minimal expenditure, and does not reduce catch rates of targeted species*". Ward also calculated the annual financial wins of such a gear change for the fisheries to be 8,000 US$ because higher tuna catches outweigh the increased costs for gear maintenance. (Ward et al. 2007)

Vega et al. (2009) assessed the blue shark bycatch in swordfish longline fisheries in the eastern South Pacific for two gear configurations, polyamide monofilament mainline and leaders and polyethylene multifilament mainlines with wire leaders. The catch of sharks was higher for the "Spanish system" with the wire leaders, while the Florida style monofilament set had higher tuna and swordfish catches but less sharks. Besides material also the soak time showed an effect on shark catches and larger sharks of more than 200 cm fork length were primarily caught on the Spanish system. The study confirmed the benefits of a switch to monofilament longlines for reducing blue shar bycatch.

Hutchinson et al. assessed in 2021 the post-release mortality rates of discarded *Prionace glauca*, *Alopias superciliosus*, *Carcharhinus longimanus*, *Carcharhinus falciformis* and *Isurus oxyrhincus* in two longline tuna fisheries in the central Pacific Ocean when 224 sharks were tagged by fisheries observers. While many factors appear to be important - such as handling, release techniques, trailing gear length, and shark species - the highest survival rates were found in animals captured on monofilament leaders and released in good condition without trailing fishing gear. The authors highlight that singular factors may not be enough to reduce bycatch mortality and that higher water temperatures may also be contributing to higher mortality rates as sharks get more exhausted and worn out during the catch procedure and prolonged time on the hook when caught in warmer waters. The study also noted that the combination of various factors is decisive for the overall increase in bycatch survival, but that switching from wire leaders to monofilament leaders allows sharks to "bite off "from the gear, "*which may have a larger positive, albeit unmeasurable impact*".

A comparison of at-vessel mortality rates of blue sharks, shortfin mako sharks, silky sharks, bigeye thresher sharks, and smooth hammerhead sharks captured on longlines targeting swordfish in the Indian Ocean and the Atlantic Ocean found much higher at-vessel mortality rates across all species in the Indian Ocean and also attributed this to the higher water temperatures in the Indian Ocean compared to the Atlantic (Coelho et. al 2011).

Afonso et al. (2012) observed significant differences in shark catches between wire leaders and monofilament leaders only for J hooks, explaining this by the higher probability of sharks being able to bite off if gut hooked versus being jaw hooked. 97% of bite offs occurred on monofilament leaders.

The Impact of Circle Hooks, J-Hooks, Japanese Tuna Hooks, and Large Circle Hooks on Mortality

The use of different hook types, mostly J-hooks and circle hooks, to either reduce shark bycatch or bycatch mortality has been subject to numerous, controversial outcomes in several studies over time. Swimmer et al. (2020) summarize those studies, with results ranging from reduced blue shark catches in the Pacific on circle hooks, to increased silky shark and oceanic whitetip shark bycatch in the Atlantic

compared to J-hooks or tuna hooks. Even for the same species, shortfin mako, outcomes ranged anywhere from less, equal, to more sharks being caught on circle hooks in comparison to J-hooks. Studies had also been performed to assess the impact of circle hook size on different sharks with, again, mixed outcomes. Most of these studies did however show that at-vessel mortality was lower and post-release survival rates higher for circle hooks than the other hook types for a range of different shark species, including night sharks, blue sharks, silky sharks, oceanic whitetip sharks, and porbeagle. Sharks are more frequently hooked in the jaw than gut by circle hooks and are thus subject to less injuries and have a better chance of survival.

Campana et al. (2016) reported the at-vessel mortality rate of shortfin mako in the Northeast Atlantic swordfish fishery using circle hooks to be 26.2% and post-release mortality of healthy makos to account for 30% after release.

French et al. (2015) showed high survivorship for shortfin mako shark in South Australian waters when caught on monofilament leaders and circle hooks.
A more recent study by Bowlby et al. (2022), however, associated circle hooks with longer recovery times for shortfin mako sharks after having been released.
In a meta-analysis Clarke et al (2014) also found that six out of eight studies that had evaluated hooking location, confirmed that sharks captured on circle hooks were more frequently hooked in the mouth or jaw rather than internally. However, they evaluated this not only as beneficial in reducing injury and mortality but also as a drawback as jaw hooked sharks have less chances to free themselves by biting through the nylon leader.

Diaz et al. (2020) evaluated observer data in the U.S. pelagic longline fleet and the effect of circle hooks and J-hooks in combination with water temperature, soak time and animal size, and found that use of circle hooks resulted in reduced at-vessel mortality for shortfin mako in the swordfish fishery, both in the Pacific and in the Atlantic. They emphasize that the impact of gear changes must be addressed as part of an ecosystem-based approach, since the use of circle hooks also reduces mortality of other bycatch species, such as sea turtles.

Carbonara et al. (2022) found circular hooks not to affect the quantitative bycatch of blue sharks in Mediterranean fisheries, but found the bycaught animals to be in better condition "*which can have a significant impact on post-release mortality*".

Newer studies highlight the benefits of so-called "large circle hooks", which are fishing hooks with the point turned perpendicularly back to the shank to form a generally circular or oval shape, and the point of the hook is not offset more than 10 degrees. Use of such hooks was found to reduce mortality of shark bycatch such as endangered shortfin mako in the Atlantic (Reinhardt et al. 2017) and may hold further potential when combining them with monofilament leaders.

Evaluating the impact of other bycatch avoidance and mortality reduction measures

In 2022, the IATTC staff conducted a detailed investigation of four shark species that had previously been rated as "most vulnerable" out of 32 species assessed in a vulnerability assessment (Griffith et al. 2022) and then prioritized for further research using the Ecological Assessment of the Sustainable Impacts of Fisheries (EASI-Fish) assessment. Silky shark, and the three species of hammerhead sharks (*Sphyrna lewini, Sphyrna mokarran Sphyrna zygaena*) were thus prioritized.

Silky and hammerhead sharks are frequently caught as a target or as a bycatch by both industrial and artisanal fisheries in the Eastern Pacific. Therefore, the effect of different conservation measure scenarios, either as stand alone or in combination, were evaluated for their potential to shift the status of these species to "least vulnerable". Fishing closures and specifically a closure of industrial longlining throughout the complete Eastern Pacific for 120 or 180 days were rated as most effective in reducing mortality for all four species, as these fisheries have the biggest overlap with the distribution of the four species of sharks and time closures of fisheries would therefore most significantly avoid shark catches and thus shark mortality. Besides a retention ban for juveniles of less than 100 cm total length or a complete retention ban for all sharks, a ban of wire leaders (wire traces) was considered to greatly reduce at-vessel mortality but might be offset by the high post-release mortality of these species. However, no combined measures to evaluate the benefits of reduced at-vessel mortality with additional measures to reduce post-release mortality were specifically evaluated. (Griffith et al. 2023)

The Impact of Release Practices on post release Survival

While gear modifications and setting practices such as soak time can help to reduce at-vessel mortality, it is important to complement these measures by optimized handling practices when hauling in and releasing unwanted shark bycatch, to reduce post-release mortality that can occur over at time of more than 360 days after release as this study showed (Hutchinson et al. 2021).

Juvenile animals are generally known to be more susceptible to exposure to stress and often show higher post mortality rates, as found by Bowlby et al. (2021) for porbeagle with juveniles being more susceptible to harm than adults. The authors of this study also found that leaving porbeagle and mako sharks in the water improves their chance of survival.

Leaving sharks in the water and removing as much trailing gear as possible by either using a dehooker or cutting the line as close as possible to the animal and thereby reducing the trailing gear to less than 1 m had the best survival outcomes over a study period of 1 year, with almost a 40% increase in survival of both shortfin mako and silky sharks in studies in Hawai'ian fisheries. (Hutchinson et al. 2021) The length of trailing gear left on the shark may have increasing effects over time, with increasing risks of entanglement, impeding hunting and escape, and increasing energy consumption (Hutchinson et al. 2021). This study found blue sharks to be "*highly susceptible to mortality post-release and had the lowest post-release survival rate (62%) of the 5 species*". Blue sharks also had the lowest longtime survival of only 18% after 360 days out of all five assessed shark species. In other literature blue sharks are generally assessed to have low at vessel mortality and post release mortality. Gilman et al. (2022) had classified blue sharks among the species with lowest at vessel mortality and found that Carcharhiniform species in the Atlantic had 2.9 times higher at vessel mortality than in the Pacific, whereas Campana et al. (2009) had stated a post release mortality of only 19% for discarded blue sharks after seven days and an overall mortality of 35% in the Canadian swordfish fishery in the North Atlantic. This demonstrates that both at vessel and post release mortality are influence by many factors, some of which are fishery specific, or ocean specific, and apparently species specific, but survival can still benefit from gear modifications and improved handling practices at release.

A similar study on shortfin mako and silky shark also found that survival rates were higher when trailing gear was minimized in relation to the size of the animal, i.e. the smaller the shark the shorter the remaining line should be (Francis et al. 2019). This study evaluated mostly fisheries with circle hooks but no details were provided on the materials for branchlines and leaders. However, the estimated survival from tagged sharks of 100 cm or more fork length was about 85% for both species at 60 days. Survival was much higher for uninjured sharks than for those that had been injured during the hooking and release process. The post-release survival rates of uninjured sharks were, however, substantially higher than survival rates recorded for silky sharks in other studies and the low survival rates estimated by Gilman et al. (2022), who found silky sharks to have the highest at-vessel and post-release mortality. Survival rates for shortfin mako even exceeded, e.g., the high survival rates of 77.2% determined for mako for ICCAT (Miller et al. 2019).
The calculated overall survival rates including data from WCPFC fisheries observers for all three stages of fishery interaction were estimated to be 48.6% and 52.3% for mako and silky shark, respectively, demonstrating that gear configurations causing less injuries in combination with best release handling practices, can improve survival rates of released sharks substantially. These study outcomes confirm the value of retention bans as a conservation measure even for more vulnerable species like silky sharks.

Measures for Avoiding Shark Bycatch

Cosandey-Godin. A. and A. Morgan (2011) published a summary of shark bycatch mitigation measures and while there are more than 10 years between this overview and more recent studies, the empirically confirmed measures recommended are still mostly the same today: use circle hooks, ban wire leaders, reduce soak times and ensure release handling procedures are done in a way to minimize additional stress or potential injuries for the animals.
Avoiding shark bycatch in the first place might be achieved by avoiding warmer water temperatures and shallow hooks. The latter was also observed by Tolotti et al. in 2015. Oceanic whitetip bycatch in the Southwest and equatorial Atlantic was significantly reduced when setting deeper than 100 m and avoiding waters in the water column above 20°C.

The use of different bait may also impact the extent of shark bycatch, with squid often referred to as resulting in higher bycatch rates while shark bycatch is lower when finfish is used as a bait. However, as summarized by both Ward et al. in 2008 and Swimmer et al. in 2020, results have been conflicting, with squid bait increasing shark bycatch in one study over mackerel bait, but mackerel bait increasing shark bycatch in another.

Mucientes et al. (2023) confirmed high fishing mortality rates for blue sharks and shortfin mako around the Azores and the majority of animals caught were juveniles that have not reached sexual maturity. While juvenile blue sharks have better chances of survival than shortfin makos if released, the authors are alarmed by the high catch rates and recommend maintaining the retention ban for shortfin mako in the North Atlantic and the Total Allowable Catch limit for blue sharks, but also recommend improved monitoring of shark catches. They suggest that "*decision-makers and managers should propose and implement strategies aimed at reducing the spatial overlap of threatened sharks and fishing*" by establishing closed areas to reduce interaction with these sharks.

Summary and Evaluation of existing Gaps in Shark Conservation

Coelho et al (2019) provided an extensive overview on the status of shark conservation in the Atlantic and further investigations needed in their report for *Improving scientific advice for the conservation and management of oceanic sharks and rays: Final report – Study,* which they had prepared for the EU Commission. When evaluating the available measures for reducing at vessel mortality and post release mortality they rated the effectiveness of a prohibition of wire leaders and using monofilament instead to result in reduced numbers of shark catches but higher catch rates for tuna and billfish. The use of circle hooks instead of J-hooks was expected to reduce post release mortality of sharks by reducing "*deephooking*" whereas circle hooks are mostly associated with jaw hooking. They also refer to the reduced impacts of circle hooks on sea turtles. Fishermen are quoted to complain about increased efforts for baiting circle hooks.
They conclude that "*wire leader bans have been demonstrated as beneficial for many shark species. However, such measure may have economical impacts on the* catches. [….] *Leader materials should also be investigated taking into account the effects of the hook types used, as those interactions are still unknown.*" Therefore, such studies should be initiated investigating the impact and interactions between hook type and leader material on shark retention, at vessel mortality and post release mortality of sharks in the longline fisheries.
In addition, the authors recommend that more conservation and management measures at RFMOs should be based on "*spatial/temporal closures of fishing for areas with high density of both mature females and juveniles of the most susceptible species*", while noting that these areas have mostly not yet been identified.

Gillman et al. (2023) assessed the state of implementation of National Plans of Action for Sharks (NPOAs) and evaluated the effectiveness of the 55 adopted NPOAs as a conservation tool to reduce the bycatch of Chondrichthyes. Shockingly enough only 12% of sharks, rays and chimaeras landed were caught by nations that have an up to date NPOA, while all other catch nations had either none at all or an outdated NPOA. And among the 22 assessed shark fishing nations responsible for 1% or more of the globally reported landings each, Iran, Nigeria Spain, Portugal, and France, had not adopted or drafted a NPOA. Although the European Union has adopted its plan of action in 2009, it had failed to review and update it since then. The United Nations international plan of action for the conservation and management of sharks recommends to do a performance assessment of national and regional plans of action at least every 4 years.
16 bycatch mitigation approaches are listed to avoid or reduce bycatch, reduce mortality, or offset of catches and their use in the 55 existing NPOAs assessed, showing that 7 of them included a ban of wire leaders for pelagic longline fisheries to allow animals to escape and to reduce at vessel and post release mortality.
However, the authors also found that none of the existing NPOAs had a "*specific and measurable outcome objective"* or includes a harvest strategy for chondrichthyan stocks caught as bycatch, and only 7.5% of all NPOAs have "*specific, measurable and timebound*" objectives. The authors' analysis concludes that if NPOAs have "*neither specific objectives nor strategies, the plans have limited operational utility*."

Conclusion

Inconsistencies of data in different studies should not be taken as an indicator that a bycatch measure such as banning wire traces and shark lines is not effective, but rather as a sign that there are many factors involved especially in view of the huge variability of gear modifications existing throughout the oceans. A similar conclusion has also been taken by Reinhardt et al. (2017) noting that "*contradictory results underscore the multi-facetted nature of bycatch mitigation, where it is often unclear if benefits relative to one component of the capture process are outweighed by detriments to another".*

Depending on vessel size, target species, fishing area and sometimes even historic preferences, different combinations of hooks, leaders, and branch lines in combination with differences in soak time, set time, setting depth, bait, and last but not least release handling procedures, to name only a few of the many variants, the effect of wire leaders versus monofilaments may not be as apparent in one fishery or study as in another.

Given that 1) analysis of a huge WCPFC observer dataset - which included date from many fishing nations and a wide range of gear combinations over many years - revealed that replacing steel leaders with monofilament and removing shark likes resulted in a 40% reduction in fishing mortality of a critically endangered shark species which has been over exploited in all oceans including the Indian Ocean, and 2) given that the stock status of oceanic whitetip sharks is "unknown" (IOTC SC 2022), there is ample reason to adopt a similar measure at IOTC as proposed during the 2023 Commission Meeting. Even more so considering mortality for another vulnerable shark species, silky sharks, was also found to decrease by more than 30% from such changes (Bigelow et al. 2021). A combined ban of shark lines and wire leaders therefore has substantial conservation potential for pelagic sharks, while not resulting in a decrease of tuna catches, and actually providing an overall cost benefit for the fisheries. (Ward et al. 2008).

Most successful bycatch mitigation measures have been proposed to be those, "*that (1) minimize bycatch with limited or no impact on target species catch, (2) have been proven through at-sea experimental research, (3) are practical, affordable, and easy to use, and (4) do not risk the safety of the fishing vessel crew or the bycaught animals*". (Swimmer et al. 2020). All of these apply to a ban of wire traces and shark lines in tuna fisheries, with the potential of reducing both at-vessel mortality of bycatch and overall shark catches, including shortfin mako, hammerheads and blue sharks by providing increased chances of survival for those sharks that can free themselves.

Only shark fisheries, i.e. those fisheries that actively target sharks but still prefer using the nicer semantics of "bycatch" would see decreased catches (Coelho et al. 2019). However, this economic drawback for those fisheries should be acceptable in view of urgent conservation needs for vulnerable shark species in IOTC.

However, the review also demonstrates the importance of achieving both <u>reduced at-vessel mortality AND improved survival rates post release</u> by ensuring the animals remain uninjured and are not overly exhausted at the time the lines are hauled in, and that they are then exposed to as little stress as possible during the release while rapidly and non-invasively removing as much of the gear as possible.

Reducing soak times, stepping up release handling practices by releasing sharks while still in the water, and cutting the lines as closely to the hook as possible to reduce trailing gear are all important measures, but they require sharks to be alive and vital when hauled in.

Best of all would be avoiding catching them in the first place by introducing bait changes, adjusting setting depths, and evaluating spatial or time closures for areas and/or times of higher shark interactions. However, while the most effective (Griffith et al. 2023), the latter is also the most difficult to achieve without closing the complete fishery and causing substantial socio-economic impact on the fisheries. Therefore, focusing on mortality reduction measures for at minimum those sharks that are not retained by the fishery is a first step forward.

In this direction, additional investigations of the interaction between hook types and leader types and their combined impact on mortality might be important to evaluate as proposed by Clarke et al. in 2014 and by Coelho et al. in 2019, who had suggested a systematic study on this interaction on catch rates, at vessel mortality and post release mortality.

Sharks are facing a global crisis, with 32.6% of all evaluated species of *Chondrichthyes* being classified as threatened with extinction. At the time of the first global assessment in 2014, less than 10 years ago, this statement applied to only 24% of species (Dulvy et al. 2021). Even more dramatic is the status of oceanic sharks, three quarters of which are already threatened with extinction (Pacoureau et al. 2020). We are running out of time and should waste no more of it before implementing gear modifications that have demonstrated effectiveness in reducing shark bycatch mortality, even if such studies have been performed in other ocean basins and not yet in the Indian Ocean.

Recommendations

We should refrain from repeatedly requesting more data and more research as a prerequisite for action, but instead start acting and promptly implement measures that have empirically demonstrated to improve survival, while continuing or initiating additional research.
This might also be the best approach to fully evaluate the benefits of large circle hooks versus tuna and/or J-hooks, noting that clear definitions for each of the hook types might be a first step (Clarke et al. 2014) to help differentiate between the effects observed for conventional circle hooks and large circle hooks, as most of the literature concluding to see no difference between J-hooks and circle hooks does not specify the size and shape of the circle hooks used in the study. Large circle hooks are well recognised for reducing bycatch and mortality of sea turtles in the North Atlantic (Swimmer et al. 2017). While systematic studies evaluating the benefits of hook types in combination with leader materials and the use of shark lines are certainly needed in all oceans, the available data from WCPFC provide sufficient scientific evidence of at least wire leaders and shark lines to be banned in all oceans, while initiating these studies to evaluate the combined benefits of hook types and especially large circle hooks in an ecosystem-based approach.

We therefore urge the Scientific Committee to advise the Commission to ban shark lines and wire leaders and to combine this ban with additional bycatch avoidance and mortality reduction measures as were proposed by the Maldives and many other CPCs during the last Commission Meeting.

We should also stop using the term “bycatch” as an excuse to avoid implementing effective and species-specific management measures for shark stocks that experience targeted exploitation by fishing operations. Wosnick et al (2022) estimated that “*about 50% of reported global catches of elasmobranchs are from bycatch*” which implicitly means that the other 50% are actively targeted, but still not actively managed.
As Gilman et al (2023) concluded that NPOAs should include harvest strategies and “*specific measurable objectives*” if meant to be effective in reducing and mitigating shark bycatch, this certainly should have to apply when shark populations are actively targeted by fisheries.
Directed management measures are needed for all targeted stocks, such as blue sharks, shortfin mako sharks, silky sharks, and hammerhead sharks. By establishing reference points and limit points for a comprehensive harvest strategy with total mortality limits, fully allocated quotas, and pre-agreed plans to prevent overfishing and to rebuild overfished stocks, we can start moving towards an ecosystem-based approach that addresses fishing mortality of all vulnerable Chondrichthyes species in the IOTC area of competence. All of this could be combined in a regional plan of action for sharks for IOTC that has specific, measurable and timebound objectives for the conservation and management of sharks as proposed by Gilman et al. (2023) and also discussed by Juan-Jorda et al. (2022).

Finally, we need much better reporting of bycaught and discarded sharks down to the species level and including data on release status, which can only be achieved by increased observer coverage and a high percentage of independent observation of all fishing activities by combining human observers with electronic monitoring systems. Artisanal fisheries should be included, too and electronic monitoring systems should be made available to them at no cost to facilitate reporting for those fisheries.

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