Bycatch management in IOTC Fisheries

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Executive Summary

Over the past decade, the IOTC has adopted a number of Conservation and Management Measures (CMMs), supporting the conservation of vulnerable species interacting with IOTC fisheries as bycatch. The adoption of a CMM represents the first step in management, however, it is vital to subsequently evaluate the effectiveness of these following implementation. The main overall aim of the bycatch CMMs is to minimise the fishery impacts on the species of concern, while the specific objectives are typically three-fold, involving; (i) a direct reduction in mortality (often in the form of a retention ban or modification of gear/practices to reduce harmful interactions), (ii) improvements to data quality and (iii) research-related objectives.

Mortality reduction

Despite the lack of objectives for bycatch management in the IOTC Agreement, the IOTC has adopted a number of CMMs specifically developed for the management of non-target species, predominantly centred on non-retention with some avoidance and mitigation measures. For a non-retention measure to be effective in achieving a substantial reduction in mortality, discard survival rates must be high, i.e., low levels of at-vessel mortality (AVM) and post-release mortality (PRM) are required. Compliance levels must be relatively good and any fisheries that are exempt from the measures should not comprise a large component of the fishery for that species. This report attempts to estimate the likely level of mortality reduction achieved by the IOTC retention bans for bycatch species based on the information currently available.

A literature review was undertaken to collate estimates of AVM, PRM and the proportion of landings taken by the artisanal fisheries. While AVM (0.12; 0.11 – 0.13 95% CI) and PRM (0.09; 0.02 – 0.17 95% CI) estimates are generally low for oceanic whitetip shark, the estimated overall reduction in mortality due to the retention ban is still fairly low due to the extremely high estimated proportion (59 % - 65 %) of captures by artisanal fisheries (Murua *et al.* 2013; Garcia and Herrera, 2018) which are exempt from the CMM (Res. 13/06). For bigeye thresher shark the retention ban is expected to have even less impact due to higher AVM (0.21; 0.2 – 0.22 95% CI) and PRM (0.24; 0.13 – 0.37 95% CI) rates combined with similarly high proportion of captures by the artisanal fleets (57 % - 64 %). This highlights the importance of considering all the factors contributing to the mortality of a population when evaluating a management measure. There are clear species-specific differences in survival rates which may make retention bans more appropriate for species such as oceanic whitetip, whereas for species with lower survival rates such as bigeye thresher, further work needs to be undertaken to sufficiently mitigate impacts. Nevertheless, when non-compliance and fishery exemptions are also taken into account, the overall estimated reduction in mortality due to non-retention measures for both oceanic whitetip (28-33 %) and bigeye thresher sharks (22-26 %) are low.

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For mobulids, the expected impact of the recently implemented retention ban is more uncertain as an unknown portion of the fleet is exempt, and post-release mortality rates are relatively unknown for these species. For whale sharks, the survival from purse seine interaction appears to be high while the main threat is the gillnet fleets for which no effective mitigation measures have been implemented. Further work to estimate AVM rates and the scale of interactions would help better determine the level of threat. Survival rates of turtles following capture by the purse seine and longline fleets were relatively high, suggesting that the non-retention measure may be more effective than for other taxa, and as the AVM were particularly low, improved handling and release efforts could lead to very high overall survival rates. While the gillnet fisheries present a substantial threat to populations of small cetaceans, the mandatory sub-surface setting of gillnets is predicted to significantly reduce the number of interactions. Given that the AVM of cetaceans is particularly high, mitigation measures that reduce interactions are critical and further research into this area is important.

Retention bans may be effective in that they are very clear, relatively easy to enforce, can generate awareness of the vulnerable status of the species in question and should prevent the development of target fisheries for the species. But results suggest that the current non-retention and other measures may have only a limited impact on overall mortality levels and a number of factors need to be considered to improve effectiveness.

- *Consider the ecological and biological traits of species.* Differences in biological and ecological traits among species may lead to varied consequences when exposed to fishery capture-related stressors (Gallagher et al 2014; (Hutchinson and Bigelow 2019) and so species-specific attributes should be considered in the development of more effective CMMs.
- *Develop approaches to reduce AVM and PRM rates.* Improving the survival of discards is a clear priority for increasing the impact of non-retention measures. Reducing AVM is not straightforward and may be very difficult to achieve, but opportunities for reducing PRM are greater.
- *Retention bans are not adequate stand-alone measures.* Results suggest that retention bans are unlikely to be effective without other, complementary, forms of management (Tolotti et al. 2015). While they may be more complex to investigate and implement, techniques that reduce fisheries interactions in the first place are likely to be the best strategy for protecting highly vulnerable species (Gallagher et al 2014). The development and implementation of mitigation measures must be progressed alongside retention bans.
- *Consider exemptions from CMMs more closely.* Consideration of the likely impact of any exemptions is important, as these may be substantial. Closer review of the types of fisheries that are dependent on the various species and more specific exemptions for those most could have a significant impact on the overall reduction in mortality achieved. Gillnet fisheries, and often longline fisheries, are omitted from many bycatch CMMs which have tended to focus more on the impacts of purse seine fleets, so renewed focus on these fleets is warranted.
- *Performance standards would facilitate more effective review.* The IOTC has adopted a range of measures in relation to the effects of fishing on bycatch species with vague conceptual objectives (Juan-Jordá et al. 2016) but lacking clearly defined operational objectives and associated indicators, or performance standards which they can be evaluated against.
- *A precautionary approach is advisable.* Findings regarding uptake of non-retention management measures at a national level suggests that consideration should be given to factors such as incomplete uptake due to delayed enactment and low enforcement by some CPCs. Given that many of these issues cannot be easily or rapidly addressed and are likely to continue

regardless of the specific type of management approach, it is even more critical that a precautionary approach is taken to accommodate these factors.

Data reporting and research

Each of the CMMs regarding a particular bycatch species of concern seek to improve data collection and reporting and so include some form of data monitoring requirements. Though as these were typically developed in isolation and at different points in time, there is a lack of coherence and numerous inconsistences in data requirements among CMMs. In some cases this has resulted in gaps in data requirements. For turtles, the reporting of total estimated annual interactions of fleets is explicitly required[3], however, for other species such as cetaceans or seabirds there are no requirements for reported interactions to be total enumerations or pre-extrapolated totals[4]. This results in what little discard data are reported to the IOTC for these species groups being of limited use, given that they are not accompanied by effort (IOTC 2015).

In most other cases where there have been gaps in reporting requirements (e.g. where data reporting has been described as non-mandatory) these have generally been addressed through the subsequent adoption of data-related CMMs, primarily 15/01 and 15/02. Nevertheless, the inconsistencies remain, often resulting in some confusion regarding the exact requirements. Improved clarity and consistency when developing future CMMs for bycatch species would likely result in improvements to data reporting. A simple solution to this may be for species-specific CMMs to simply refer to the general data collection and reporting resolutions (15/01 and 15/02, and any subsequent iterations of these) and for these to include the requirement for total estimates of discards.

Species-level reporting is not required for turtles (12/04), mobulids (19/03), cetaceans (13/04)[5], threshers, makos and hammerheads for total annual interaction estimates. Nevertheless, all species are to be identified as far as possible in observer data so the lack of species-level data reporting requirements is not an issue for fleets with good coverage and reporting programmes, but for the fleets with limited observer coverage there may be poor species-level information based on the current resolutions

Overall, the data monitoring and reporting requirements for bycatch species are relatively comprehensive, however, the reality in terms of the data actually reported to IOTC has been extremely poor, and although it is improving in some areas, it remains very limited for bycatch species. Compliance with data monitoring and reporting is low, generally due to limited resources in many of the developing coastal nations which have fleets made up of numerous small-scale vessels, presenting further challenges to monitoring. For species other than the most commonly caught sharks, data reporting is extremely poor, sparse and unstandardised; not conducive to supporting regional level analyses. Non-retention measures render the nominal catch database even less complete which has serious consequences for evaluating the status of the stocks and makes observer data even more crucial.

Priority areas for data improvements

General

- Data mining to reconstruct historical catch data as recommended by the SC in 2019 (IOTC 2019b).

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[3] *"The data shall include the level of logbook or observer coverage and an estimation of total mortality of marine turtles incidentally caught in their fisheries". IOTC Res. 12/04*

[4] As required by reporting Form_1DI

[5] species identifications are to be reported to the flag state, not to IOTC (Res. 13/04)

- Improve species identification through methods including regional training workshops and the development of alternative tools to assist identification such as genetic analyses, machine learning approaches and artificial intelligence as recommended by the SC in 2019 (IOTC 2019b).
- Reduce inconsistency among bycatch CMMs by removing data requirements, instead referencing Res. 15/01, 15/02 and 11/04.
- Improve species-level reporting through the addition of species to Res. 15/01, specifically separation of the makos, thresher and hammerhead sharks as well as for mobulids, turtles and cetaceans (while also leaving the aggregate grouping codes available) could improve data for assessments. This was discussed at the SC in 2018 following the report by Clarke (2018).
- Improve awareness and clarity regarding discard reporting requirements. Simplification of discard information may be preferable to obtain increased accuracy over precision.
- Support the collection of biological information and encourage CPCs to collect basic information on size frequencies and conversion factors as part of routine operations (Clarke, (2018).

Observer data

- Support the development of observer programmes, prioritising fleets identified as most important in terms of gaps in bycatch information (i.e. the major gillnet fleets).
- Expand observer coverage in existing programmes which have been making good progress but are still very small scale.
- Refine the categories of smaller vessels (< 24 m) further to increase bycatch information, as proposed by the WPDCS in 2019. The re-classification of vessels into categories so that those 20 – 24 m, which are often semi-industrial, are subject to greater onboard monitoring requirements may result in substantial data gains and increased understanding of the impacts of these fleets.
- Support alternative means of data collection. There has been substantial discussion by the SC around alternative means of collecting observer quality data which has centred around (i) Electronic Monitoring, (ii) crew-based/self-sampling data collection and (iii) port sampling (IOTC 2019a). While a number of initiatives are taking place, a feasibility study would support the determination of appropriate standards across these programmes.
- Improve ROS data reporting to IOTC. Of the ROS data reported to the IOTC, 32 % have not been included in the database due to the unstandardised nature of the information (IOTC 2020).
- Begin preliminary analyses of the existing published information. While the observer information published to-date remains in a preliminary state as the scheme progresses, CPC scientists should begin to use this in a preliminary way. This will progress the process of identifying errors, anomalies and gaps and will catalyse discussions about further improvements by CPC data providers and the Secretariat.

Research

Different bycatch taxa have received varied levels of attention by the IOTC, often due to the amount of data available at the time, and limited time available to provide advice, given the broad remit of the WPEB. In general, shark species have received more attention than other taxa, with the clear focus being species for which there is a sufficient level of information to undertake an integrated stock assessment. Risk assessments to compare relative threats across different gear types have been conducted for the remaining shark species and turtles, while mobulids and cetaceans have had considerably less attention until very recently.

Priority areas for research on sharks were reviewed. These included: stock structure determination, evaluation of PRM rates through tagging, improving biological and ecological information, developing mitigation measures, improving CPUE estimates through cross-fleet collaborative work, reconstructing historic catch series ahead of assessments and developing reference points.

It has been suggested that cetaceans have received disproportionately little consideration by the IOTC in previous years compared with other bycatch taxa, given the scale of the threats (Kiszka et al. 2017; Elliott 2020; IWC 2019). Further collaboration between the IWC and IOTC will help support research efforts, with the primary focus being an ocean-wide ERA covering all of the major tuna fleets (WPEB 2020).

While research efforts on turtles have focussed on ERAs assessing relative risk by gear type (Nel et al. 2013; Williams et al. 2018), the WPEB (WPEB 2018) agreed that these should be improved to quantify the cumulative impacts of multiple fisheries and report the vulnerability status against recognised biological reference points (e.g. B_{MSY}, F_{MSY}) (e.g. EASI-Fish, Griffiths et al. 2018). Little progress has been made on mitigation measures for turtles in the Indian Ocean, despite a recommendation by the SC for a workshop to evaluate these which should be prioritised once resources become available. Studies on PRM of turtles in the Indian Ocean are also relatively sparse, so this remains a priority area of work for the WPEB (WPEB 2020).

Ecosystem considerations

While bycatch CMMs and associated research have often taken a single species approach to management, bycatch reduction efforts clearly need to apply multi-taxa approaches, focussing on cumulative impacts to avoid simply transferring the problem to another species group and address both the species- and ecosystem-level effects of bycatch (Lewison et al. 2014). The gillnet fisheries in the Indian Ocean emerge from this review as a cross-cutting issue across all bycatch taxa. The prevalence of gillnet fisheries and associated high risks for sensitive species (Gillett 2011), the expanding fleet size, extensive length of nets, long soak times (Moazzam and Khan, 2019), extremely poor information, limited observer coverage, limited existing management measures and contravention of measures that are in place (Khan 2020) combine to form a very serious threat to bycatch. The IOTC has recently started to attempt to address these issues through a ban on the use of large scale (>2.5 km) driftnets on the high seas (Res.17/07), the mandatory sub-surface (2 m) setting of gillnets (Res.19/01), and the optional phasing out of gillnets or conversion to other gear types, and increase in observer coverage, or field sampling, to 10 % (Res.19/01). Preliminary results suggest that the modification to sub-surface gillnetting appears to be effective in dramatically reducing bycatch rates across a range of taxa including cetaceans, turtles and some sharks, however, the results are still preliminary and undergoing fuller evaluation to explore issues such as potential effects on other species including mobulids and whale sharks, and changes in species composition of shark catches (Moazzam 2019). The lengthy (4 years) timescale for implementation agreed by the Commission suggests there may also potentially be some resistance to the practice which needs exploring further. The idea of phasing out of gillnets over the longer term and replacement with alternative fishing gear methods has been suggested may be the only real long-term solution (Brownell et al. 2019), however, for the IOTC a combination of approaches may prove more successful in achieving both socio-economic and ecological objectives.

While the importance of social and economic considerations is explicitly acknowledged for target species management and discussions surrounding quota allocations and have led to increased focus on these issues in recent years[6], they are also likely to be particularly pertinent for bycatch species. Industrial vessels are often associated with issues such as high grading and discarding of unwanted catch, whereas small-scale fleets are well known for their high utilisation of catches, to the point that there is often considered to be very little actual 'bycatch', but rather it constitutes a multispecies fishery. This is, nevertheless, still a cause for concern when fishing is at a level which is considered to be unsustainable for particular populations, of which marine megafauna are particularly susceptible. Yet it means that the economic and social burden of a bycatch CMM may fall disproportionately on developing coastal nations with small-scale fisheries[7] and therefore needs due deliberation and discussion as part of the management process so that optimal solutions across a range of criteria (not only ecological) may be sought (e.g. payments for ecosystem services as compensation; subsidies for alternative gear).

In light of UN Sustainable Development Goal 2 regarding food security[8], retention bans may be considered as the antithesis of this as it promotes the discarding of dead, as well as live, individuals. This perceived notion of wastefulness has been identified by some coastal CPC fishers and can result in a reluctance to adhere to bans (Rice 2017). The social and economic considerations are complex and have primarily been dealt with through exemptions to-date. While the initial rationale for these exemptions seems obvious, in practice the broad-brush nature of implementation means the management measures are probably not able to achieve the level of reduction in mortality required for recovery of impacted populations and to achieve sustainability of the stocks[9]. To this end, social and economic factors must be considered in the long-term as well as the short-term.

The inconsistency in the nature of exemptions applied among the various CMMs is further indicative of the limited analysis that has gone into these aspects. Finer-scale identification of the most vulnerable groups who need to be made exempt from legislation while ensuring that the more capable majority adhere to them may enable the measures to have a meaningful impact on stock recoveries, and ultimately, sustainable livelihoods. This concept has been introduced for mobulids in Res. 19/03[10], so it will be interesting to see how this eventuates and, if successful, whether a similar approach can be applied to other species.

Approaches to bycatch management

Management by IOTC is generally centred around top-down regulation, typical of regional level management. This has been achieved through input controls such as technology developments including mitigation measures and process standards such as time-area closures and vessel trip or size limits. These can be effective, but they tend to remove incentives for fishery operators to find other ways to reduce bycatch and are often not updated regularly enough as technology developments advance and best practices change. Performance standards, which require vessels to meet a standard, e.g. a bycatch quota or rate, tend to create stronger and more direct incentives (Squires et al. 2021) and so might improve the effectiveness of bycatch management.

Market based measures have also been used by some fleets within the IOTC, such as those involved in FIPs or who have obtained or are pursuing MSC certification. Market-based methods can create strong and effective incentives for bycatch reduction and should be encouraged, however, they are

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[6] E.g. Resolution 18/09

[7] SDG10 commits Member states to "Reduce inequality within and among countries"

[8] SDG2 commits Member states to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture"

[9] SDG12 commits Member states to "Ensure sustainable consumption and production patterns"

[10] *"Mobulid rays surrendered in this manner may not be sold or bartered but may be donated for purposes of domestic human consumption".*

primarily suited to fleets which have a market to a country where a price premium will be gained, often involving an export market. For many of the artisanal fisheries in the IOTC which have predominantly domestic markets this is approach is less feasible and bycatch policy may do better to focus on intrinsic motivation.

Intrinsic motivation includes social and personal norms of conservation and altruism for their own sake rather than the desire for an external reward and may traditionally be in place already in many fisheries. This may be particularly important for small-scale and artisanal fisheries where the practical reality of enforcing regulations is extremely difficult and social customs and norms may have a greater effect on behaviour than bycatch regulation (Gillett 2011). With better communication and awareness raising, vessels may be more motivated to comply with regulations, and even go beyond literal compliance, not only because of the threat of legal sanctions but also because of social pressures. There are some voluntary initiatives already in place in the Indian Ocean providing successful examples of bycatch management, for both small-scale and industrial fleets, potentially paving the way for longer term behavioural changes leading to new social norms.

The idea of intrinsic motivation being important for bycatch management ties in with the emerging consensus that there is a need for greater collaboration with fishers in bycatch management (IWC 2019). Direct involvement of fishers is crucial to the development of approaches to bycatch reduction, utilising their in-depth knowledge of the fisheries in which they operate to develop methods that are appropriate, effective and will be accepted in the long-term (Brownell et al. 2019). Management approaches where fishers have taken an active role in developing and trialling mitigation measures to reduce bycatch have already proven effective in many areas (Lewison et al. 2014). By going beyond simply focussing on top-down direct regulation and utilising a combination of management approaches, the IOTC is more likely to be successful in reducing pressure on bycatch species.

Introduction

The annual catch of tuna and tuna-like species in the Indian Ocean was over 1.8 million tonnes in 2019 (IOTC, 2021) and tuna fisheries, both industrial and small-scale, are of major socioeconomic importance throughout the Indian Ocean (Ardill, Itano and Gillett, 2012). The main fisheries in the region are gillnet (33 %), purse seine (30 %), handline and troll (17 %), longline (10 %) and pole-and-line (6 %)[11].

Gillnet and purse seine fisheries are the most important fisheries in terms of catch volume[11]. Gillnet fisheries have been increasing dramatically over the last few decades from an average annual catch of 176 000 t in the 1980s to 630 000 t in recent years (2010-2019)[11]. This is driven by coastal state fleets including I.R.Iran, India, Indonesia, Pakistan, Sri Lanka and Oman. They tend to target a range of species including skipjack, yellowfin and neritic tunas, billfish, dolphinfish and pelagic sharks. Nets employed are generally very large; lengths of 7 – 12 km have been reported by the Pakistani fleet (Moazzam and Khan, 2019).While gillnets can be very specific for the size range of fish they target and capture by gilling, those used predominantly in the Indian Ocean are made of several net panels with different mesh sizes and using low hanging ratios, resulting in non-selective fishing (MRAG, 2012; Aranda, 2017). This results in a very non-specific gear type in which a huge range of species can be entangled.

Purse seine fisheries have seen high catch volumes similar to those of the gillnet fleets in recent years as the fishery has expanded once more following a period of decline due to piracy in the late 2000s (Chassot *et al.*, 2010). Purse seiners tend to target small yellowfin tuna and skipjack for canning. Vessels may set their nets on free tuna schools, which may be associated with mobulids or potentially small cetaceans, however, they are increasingly setting on FADs, which are generally associated with higher bycatch of small tunas, sharks and turtles (Amandè *et al.*, 2008).

While longline fleets have formed an increasingly smaller proportion of total Indian Ocean fisheries captures in recent years, they are still substantial in terms of the magnitude of shark catches, second only to the gillnet fisheries (IOTC, 2021). There are longline fleets targeting large bigeye tuna and bluefin tuna for sashimi markets, those targeting albacore for canning and others targeting swordfish and blue shark. Longline fisheries are also particularly associated with bycatch of turtles and cetaceans, due to depredation.

Line fisheries, including handline and trolling, have expanded in recent years[11]. These fisheries take a wide variety of tuna species but primarily catch yellowfin, skipjack, seerfishes and kawakawa. While catches are high, following purse seine and gillnet fisheries, the fisheries operate in coastal waters and so interactions with pelagic shark species are thought to be low (IOTC, 2021).

Pole and line fishing fleets primarily target skipjack tuna, but juvenile yellowfin, kawakawa and frigate tunas are also frequently captured; the main bycatch species are rainbow runner and dolphinfish (Miller *et al.*, 2017). These are known to be very selective fisheries in which fish are captured one-by-one, so fishers can clearly see what is being caught. Interactions with

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[11] Reported retained catch of tuna and tuna-like species and associated bycatch species: 2015-2019 [IOTC-2021-WPEB17-DATA03-NC-REV1]

cetaceans and turtles are rare and, in the largest pole and line fishery in the Maldives, shark fishing has been prohibited since 2010 (Miller *et al.*, 2017).

A large proportion of catches taken by tuna fisheries in the Indian Ocean fisheries are taken by what are considered 'artisanal fisheries' in the IOTC database, however, the term has not been clearly defined and inconsistencies have been noted in the use of the concept throughout IOTC CMMs (Cacaud, 2016). The term 'artisanal fishery' has been commonly used, but with different qualifications such as "for subsistence" or 'for the purpose of local consumption" or "operating exclusively in their respective EEZs". This has resulted in a lack of clarity in some cases (e.g. Resolutions 13/04, 13/05 and 13/06) over whether the term artisanal includes large vessels operating within their EEZ.

In a comprehensive review of IOTC terms and definitions, Cacaud (2016) observed that there is no agreed definition of the concept of "artisanal fisheries" at the international level, so advised that all references to the concept are dropped and replaced with the term "coastal fisheries". In 2020, the WPICMM agreed that a revised definition[12] of 'coastal fisheries' should instead be used throughout resolutions which would include artisanal fisheries, but not be limited to them, and would clarify that a fishing activity undertaken by a vessel of 24 m in overall length or above is not coastal fishery, even if it is operating exclusively in the waters under the jurisdiction of the flag State (WPICMM03, 2020). This is important, given that catch data suggest that artisanal fisheries are expanding.

Bycatch species status and threats

Bycatch has been defined by the IOTC Scientific Committee as:

> *"All species, other than the 16 species listed in Annex B of the IOTC Agreement, caught or interacted with by fisheries for tuna and tuna-like species in the IOTC area of competence. A bycatch species includes those non-IOTC species which are (a) retained (byproduct), (b) incidentally taken in a fishery and returned to the sea (discarded); or (c) incidentally affected by interacting with fishing equipment in the fishery, but not taken."*

While interactions with a broad range of species occur, this report focusses on the species: blue shark (*Prionace glauca*), mako sharks (*Isurus* spp.), hammerhead sharks (*Sphyrna spp*.), thresher sharks (*Alopias spp*.), silky sharks (*Carcharhinus falciformis*), oceanic whitetip sharks (*Carcharhinus longimanus*), mobulids (*Mobula spp.),* whale sharks (*Rhincodon typus),* cetaceans and marine turtles.

Sharks

Table 1 provides a summary of the current status of shark species interacting with Indian Ocean tuna fisheries in terms of the relative resilience ranking in the most recent Ecological Risk Assessment (ERA) (Murua *et al.*, 2018), its IUCN threat status, whether it is listed by CITES in its Appendix II, and the current IOTC management advice.

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[12] Coastal fisheries: *"Any fishery, including artisanal fisheries, where the fishing activity is undertaken by a vessel that is not required to be registered on the IOTC Record of Authorised Vessels, targets or catches tuna and tuna-like species and operates exclusively in the waters under the jurisdiction of the flag State, but does not include any vessel of 24 metres in length overall or above operating exclusively in the waters under the jurisdiction of the flag State"*(WPICMM03, 2020).

Blue shark *(Prionace glauca)*

The blue shark *(Prionace glauca)* is the most common shark in pelagic oceanic waters throughout the tropical and temperate oceans worldwide. Blue sharks live until at least 25 years, mature at 4–6 years, and have 25–50 pups every year. Because of these life history characteristics, they are considered to be the most productive of all the pelagic shark species. Blue sharks have been targeted historically by semi-industrial and artisanal fisheries and caught as bycatch in industrial fisheries, but in recent years a targeted industrial longline fishery has developed due to its high commercial value.

An ecological risk assessment (ERA) conducted for the Indian Ocean by the WPEB and SC in 2018 consisted of a semi-quantitative risk assessment analysis to evaluate the resilience of shark species to the impact of a given fishery by combining the biological productivity of the species and its susceptibility to each fishing gear type. Blue sharks received a fairly high vulnerability ranking (No. 6) in the ERA rank for longline gear because although it was estimated to be the most productive shark species, it was also characterised by very high susceptibility to longline gear. Blue shark was estimated as not being vulnerable to purse seine gear (Murua *et al.*, 2018). The current IUCN threat status of ‘‘near threatened” applies to blue sharks globally.

The blue shark was last assessed in 2017, using four assessment models which all produced similar results suggesting the stock is currently not overfished nor subject to overfishing, but with a trajectory towards overfishing. Based on model projections, the management advice is to reduce catches by 10 % to increase the probability of maintaining the spawning biomass at a level above B_{MSY}. Catches are currently (2019) well below the estimated MSY (IOTC, 2020b).

Mako sharks *(Isurus spp.)*

The shortfin mako (*Isurus oxyrinchus*) is widely distributed in tropical and warm temperate waters and is one of the fastest swimming shark species. Shortfin mako has a lifespan of approximately 30 years, reaches maturity at 18–21 years, and has relativity few offspring (<25 pups every two or three years). These life history traits make it vulnerable to overfishing. Shortfin mako sharks are often targeted by some semi-industrial, artisanal and recreational fisheries and are a bycatch of industrial fisheries. The main fishing gear are the longline targeting swordfish, longline targeting sharks, fresh longline and gillnet fisheries. *I . oxyrinchus* is one of the most commonly caught sharks species in gillnet fisheries, reportedly making up 46% of the shark catch for the Pakistani fleet (Shahid et al., 2016).

In the shark ERA, shortfin makos received the highest vulnerability ranking (No. 1) for longline gear given its low productivity and high susceptibility to longline gear, however, they are thought to be less vulnerable to purse seines and gillnets (Murua *et al.*, 2018). While a stock assessment was undertaken in 2020, no conclusion was reached on a status due to a variety of issues including model misspecification; the low credibility of nominal catch data; the selection of biological parameters used in the model; and the inability of the aggregated biomass dynamic model to reconcile the significant time delay (around 8 years) between fishing and the effect on future recruitment (IOTC, 2020b). Various CPUE indicators exist but show conflicting trends. The current IUCN threat status of ‘Endangered’ applies to shortfin mako sharks globally and it has been placed on CITES Appendix II.

The longfin mako (*Isurus paucus*) has a worldwide distribution in tropical and warm temperate waters. The species is caught globally as target and bycatch in pelagic commercial and small-scale longline, purse seine, and gillnet fisheries that operate throughout its range, though less frequently than the shortfin mako. It is likely less vulnerable to shallow set pelagic longline gear than the shortfin mako, because of its deeper depth distribution. The longfin mako is of serious conservation concern due to its apparent rarity, large maximum size, low fecundity, and continued, poorly-documented take in intensive fisheries (Rigby, 2019). In the shark ERA, longfin makos received a vulnerability ranking of 7 for longline and gillnets and 4 for purse seine fisheries, because of the higher susceptibility to that gear (Murua *et al.*, 2018). The current IUCN threat status of ‘‘Endangered’ applies to shortfin mako sharks globally and it has been placed on CITES Appendix II.

Hammerhead sharks *(Sphyrna spp.)*

The scalloped hammerhead shark (*Sphyrna lewini*) is a widely distributed pelagic coastal and semi-oceanic species, common in warm temperate and tropical waters. The maximum age for scalloped hammerheads in the Atlantic is estimated to be over 30 years, maturity is reached at about 15 years and they have relatively few (<31) pups every year, making them particularly vulnerable to overfishing (IOTC, 2020b). There is no stock assessment for the Indian Ocean, and one CPUE series (South African gillnet), which suggests a decline (Rigby, Dulvy, *et al.*, 2019). In some areas, the scalloped hammerhead shark forms large resident populations, while in other areas large schools of small-sized sharks are known to make long seasonal migrations. Their aggregating behaviour makes large schools highly vulnerable to fishing and therefore high CPUEs maybe recorded even when stocks are severely depleted (Baum et al. 2007). The main fishing gears used are the ringnet, gillnet, coastal and fresh longlines. They are reported to make up 5% of the shark catch in gillnet fisheries (Shahid et al., 2016). Scalloped hammerhead shark received a low vulnerability ranking in the ERA rank for longline and purse seine gear, but has a higher susceptibility to gillnet fisheries (6) (Murua *et al.*, 2018). The current IUCN threat status of ‘Critically Endangered’ applies to scalloped hammerhead shark globally and it has been placed on CITES Appendix II.

The smooth hammerhead (*Sphyrna zygaena*) is a coastal and semi-oceanic pelagic shark, wide-ranging in tropical and warm temperate seas to depths of at least 200 m. The smooth hammerhead is caught globally as target and bycatch in coastal and pelagic commercial and small-scale longline, purse seine, and gillnet fisheries (Rigby, 2020). The only CPUE indicator that exists for smooth hammerhead sharks, Sphyrna zygaena, caught in South Africa’s KwaZulu-Natal bather protection programme which indicated no significant trend over time (Dicken et al., 2018). In the ERA, smooth hammerhead was ranked second for gillnet fisheries due to its high susceptibility to this gear type (Murua et al., 2018). This corresponds to estimates suggesting that the majority of hammerhead interactions are with the gillnet fisheries (Garcia and Herrera, 2018). The current IUCN threat status of ‘‘Vulnerable” applies to smooth hammerhead shark globally and it has been placed on CITES Appendix II.

The great hammerhead (*Sphyrna mokarran*) is a large (to 610 cm total length) coastal and semi-oceanic pelagic shark, wide-ranging in tropical and warm temperate seas to depths of 300 m. It is caught globally as target and bycatch in coastal and pelagic large- and small-scale longline, purse seine, and gillnet fisheries, and is often retained for the fins. It has a long lifespan of up to 44 years and only breeds once every two years, which combined with high bycatch mortality, makes it susceptible to depletion (Rigby, Barreto, Carlson, *et al.*, 2019b). The Great Hammerhead appears to have undergone steep declines in the Indian Ocean and the global population is estimated to have undergone reductions of 50.9–62.4% (Rigby, Barreto, Carlson, *et al.*, 2019b). In the ERA, great hammerheads had a medium vulnerability ranking for longline and purse seine fisheries, and very low for gillnet fisheries (Murua et al., 2018). The current IUCN threat status of ‘‘Critically Endangered” applies to great hammerhead shark globally and it has been placed on CITES Appendix II.

Thresher sharks (*Alopias* spp.)

Bigeye thresher shark (*Alopias superciliosus*) is found in pelagic coastal and oceanic waters throughout the tropical and temperate oceans worldwide. In the tropical Indian Ocean, the greatest abundance of bigeye thresher shark occurs at depths of 50 to 300 m, in temperatures ranging from 8 to 25°C. It is a solitary species, however it is often caught in the same areas and habitats as pelagic thresher sharks. Because of their life history characteristics, they are relatively long lived (+20 years), mature at 3–9 years, and have very few offspring (~2 pups) every year, the bigeye thresher shark has the lowest intrinsic rebound potential of the thresher sharks and is vulnerable to overfishing (IOTC, 2020b). Bigeye thresher shark are often targeted by some recreational, semi-industrial and artisanal fisheries and are a bycatch of industrial pelagic longline tuna and swordfish fisheries. Bigeye thresher shark received a high vulnerability ranking in the ERA rank for longline gear and lower for purse seine and gillnet fisheries (Murua et al., 2018). The current IUCN threat status of ‘‘Vulnerable” applies to the bigeye thresher shark globally and it has been placed on CITES Appendix II.

The pelagic thresher shark (*Alopias pelagicus*) is commonly found in pelagic coastal and oceanic waters throughout the tropical Indo-Pacific. The pelagic thresher is thought to be a highly migratory, epipelagic, solitary species found in surface waters to depths of 300m It aggregates around seamounts and continental slopes (Compagno 2001). Pelagic thresher sharks are relatively long lived (+ 20 years), reach maturity at 8–9 years, and have very few offspring (2 pups every year). The main fishing gear for the pelagic thresher shark is gillnets, where it is one of the most commonly caught shark species, comprising approximately 25% of the catch (Shahid et al., 2016). In contrast with the bigeye thresher shark, pelagic thresher shark was considered to have a low vulnerability to longline gear and a higher vulnerability ranking for purse seine and gillnet fisheries (Murua et al., 2018). The current IUCN threat status of ‘Endangered’ applies to the pelagic thresher shark globally and it has been placed on CITES Appendix II.

The common thresher (*Alopias vulpinus*) is a coastal and semi-oceanic pelagic shark found globally in tropical and temperate waters that occurs from the surface down to depths of 650 m (Rigby, Barreto, Fernando, et al., 2019). It is a long-lived species (38 years), yet with slightly larger litters than other threshers (2–6 pups) every year, so consequently has a higher rate of population increase than the pelagic and bigeye thresher sharks. The species is caught as target and bycatch in pelagic and coastal commercial and small-scale longline, purse seine, and gillnet fisheries, while the majority of catch is taken as bycatch of industrial pelagic fleets in high-seas waters (Camhi et al. 2008). In the ERA, the common thresher was allocated a medium vulnerability ranking for longline and purse seine fleets, and a relatively low vulnerability to gillnets, partly due to the lower post-capture mortality since the retention ban came into force[13] (Murua et al., 2018). The current IUCN threat status of 'Vulnerable' applies to the common thresher shark globally and it has been placed on CITES Appendix II.

Silky sharks *(Carcharhinus falciformis)*

The silky shark (*Carcharhinus falciformis*) is one of the most abundant large shark species inhabiting tropical and subtropical oceanic waters throughout the world. Silky sharks are relatively long lived (over 20 years), mature relatively late (at 6–15 years), and have medium fecundity (<20 pups every two years). Small silky sharks are also commonly associated with schools of tuna, particularly under floating objects while large silky sharks associate with free-swimming tuna schools. Silky shark is often targeted by some semi-industrial, artisanal and recreational fisheries and is a bycatch of industrial gillnet, pelagic longline and purse seine fisheries. It is the fourth most important shark bycatch species, contributing >10 % of total shark mortality in the Indian Ocean (Garcia and Herrera, 2018). It is still targeted by the Sri Lankan gillnet-longline fishery, is the most common shark species caught in Indonesian longline fisheries (Simeon *et al.*, 2018) and also frequently caught in Pakistani gillnet fisheries, comprising 25 % of all sharks caught (Shahid et al., 2015).

The ERA indicated that silky shark is ranked highly for all gear, due to its low productivity and high susceptibility to all gear types (Murua et al 2018). A preliminary stock assessment was run in 2018 but was extremely uncertain, however, and so the population status of silky sharks in the Indian Ocean is considered unknown (IOTC, 2019e). Despite the lack of data, there is some anecdotal evidence suggesting that silky shark abundance has undergone a five-fold decrease in catch rates between 1980 and 2005[14]. The current IUCN threat status of 'Vulnerable' applies to the silky shark globally and it has been placed on CITES Appendix II.

Oceanic whitetip shark *(Carcharhinus longimanus*)

The oceanic whitetip shark (*Carcharhinus longimanus*) was once one of the most common large sharks found globally in warm oceanic waters, though is now perceived to be rare in some regions. They are relatively long lived, mature at 4–5 years, have relatively few offspring and a biennial reproductive cycle (1-15 pups every two years) and is likely vulnerable to overfishing. The species has a high catchability due to its preference for surface waters and its inquisitive nature, and it is commonly caught by gillnet, longline and purse seine fisheries (Rigby, Barreto, Carlson, *et al.*, 2019a; IOTC, 2020b).

Oceanic whitetip shark received a medium vulnerability ranking in the ERA for longline, purse seine and gillnet fisheries, due to their lower post-capture mortality following the retention ban[15] and implementation of safe release practices in many purse seine fleets (Murua et al 2018).

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[13] IOTC Res. 12/09 On the conservation of thresher sharks (family Alopiidae) caught in association with fisheries in the IOTC Area of Competence

[14] Silky shark stock status summary supporting information: https://www.iotc.org/node/3379

[15] IOTC Res. 13/06 On a scientific and management framework on the Conservation of shark species caught in association with IOTC managed fisheries

While data are limited and no stock assessment has been carried out for the Indian Ocean, the available standardised CPUE indices from longline fleets of Japan and EU,Spain suggest a decline and a study of oceanic abundance around FADs concluded that the abundance has declined in recent years (2000-2015) compared with historic years (1986-1999) (Tolotti et al., 2016). The global population is estimated to have undergone a reduction of >98% (Rigby, Barreto, Carlson, et al., 2019a). The current IUCN threat status of 'Critically Endangered' applies to the oceanic whitetip globally and it has been placed on CITES Appendix II.

Mobulids (*Mobula* spp.)

Mobulids (manta and devil rays) are slow growing, with long maturation times and extremely low fecundity (~0.5 pups year^{-1}) (Couturier *et al.*, 2012). As a result, they rank among the least productive all elasmobranchs and are not considered to be able to support sustainable targeted fisheries of any type (Dulvy et al., 2014). While individuals are often solitary or travelling in small groups, most species have also been observed gathering in schools ranging in size from a few to hundreds of individuals (Anderson, Adam and Goes, 2011; Couturier et al., 2012).

Manta and devil rays have been threatened globally throughout their range by surface gill net, longline, purse seine and directed harpoon fisheries in which they have been caught as a targeted species or as incidental catch (White et al., 2006; Shahid et al., 2018). Though there is anecdotal evidence that successful conservation campaigns may be reducing demand for gill plates in conjunction with stronger government policies on wildlife trade in China (Lawson et al., 2017) and they are also protected through a number of international agreements, including CMS Appendices I and II, CITES Appendix II and IOTC Res. 19/03[16] which introduced a retention ban for all but subsistence fisheries.

Nevertheless, the vast majority of mobulid captures are actually a result of unintentional bycatch due to the similarity in the distributions of mobulids with tuna and tuna-like fisheries across epipelagic tropical habitats in regions of high productivity and so mobulids are caught in virtually every fishing gear type (Croll *et al.*, 2016; Shahid *et al.*, 2018; Stewart *et al.*, 2018).

Mortality from industrial purse seine fisheries has been thought to pose one of the most significant threats to mobulids globally (Ward-Paige, Davis and Worm, 2013; Croll et al., 2016; Stewart et al., 2018). Romanov (2002) estimated that between 253 and 539 mobulids were caught by purse seiners in the western Indian Ocean each year (1985 - 1994), while more recent estimates are higher; 1936 mobulids per year (1981-2008) (Croll et al., 2016), or 1832 individuals per year (2003 - 2009) (Amande *et al.*, 2012). Mobulid interactions with FAD sets are extremely low, while sets on free schools have higher but still very sporadic mobulid catch rates (Romanov, 2002; Hall and Roman, 2013).

Drifting gillnet fisheries also pose a significant threat to mobulids. In Sri Lanka, the mobulid bycatch from gillnet fisheries targeting skipjack tuna (Katsuwonus pelamis), yellowfin tuna (Thunnus albacares) and billfish are particularly large, with estimated total landings exceeding 56 000 individuals in 2011 (Fernando and Stevens, 2011). Similarly in Indonesia, the drifting

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[16] Resolution 19/03 *On the conservation of mobulid rays caught in association with IOTC fisheries*

gillnet fisheries targeting skipjack have recorded substantial bycatch of mobulid rays (White et al., 2006).

Information on mobulid interactions with longline fleets has been more limited, however, a recent analysis of regional level observer information demonstrated some high interactions (~100 mobulids caught in a single trip) concluding that longliners can interact with mobulids at a large scale and may be of the same scale or greater than for the purse seine fishery (Martin, 2020a).

Whale shark *(Rhincodon typus)*

Relatively little is known about the life history and ecology of the whale shark, *Rhincodon typus*, but it has a *k*-selected life history and may not reach sexual maturity until possibly 30 years (Li, Wang and Norman, 2012) indicating low productivity and limited potential for recovery in the case of overexploitation. The large proportion of time spent in epipelagic waters searching for planktonic prey makes Rhincodon typus particularly vulnerable to mortality from surface activities such as bycatch in net fisheries and vessel traffic collisions (Pierce and Norman, 2016; Harvey-Carroll *et al.*, 2021).

Whale shark populations are thought to be in decline in many areas, including Mozambique and the Maldives (Reeve-Arnold et al., 2019; Harvey-Carroll et al., 2021), with an estimated overall decline of 63% in the Indo-Pacific over the last 75 years (three generations) (Pierce and Norman, 2016). It is currently listed as Endangered by the IUCN at its last assessment in 2016 (Pierce and Norman, 2016), and is included in CITES Appendix II), in CMS Appendix II, in UNCLOS Annex 1 (Highly Migratory Species) and the Convention on Biological Diversity.

There has been increasing demand for whale shark fins and flesh in some Southeast Asian countries since the 1990s and recent surveys indicate that that the fins are demanding high prices which has led to localised increases in fishery landings in the eastern Indian Ocean (Li, Wang and Norman, 2012; Pierce and Norman, 2016). Targeted artisanal fisheries for whale sharks have existed in a number of countries, e.g. Indonesia, the Philippines, Iran, Maldives, India and Pakistan (Pierce and Norman, 2016). A targeted commercial fishery existed in Gujarat, India, until whale sharks became legally protected in 2011, though some bycatch still occurs, with 79 landings reported from 2001 to 2011 (Akhilesh et al. 2013). A small opportunistic fishery is active in Oman and small-scale harpoon and entanglement fisheries have taken place in several other countries such as Iran and Pakistan, though there are no recent landings data (Pierce and Norman, 2016). In the Maldives, the fishery for whale sharks was closed in 1995 with the introduction of national bans, however, occasional hunting is thought to persist (Riley, Harman and Rees, 2009).

In southern China, large-scale commercial take of whale sharks was thought to still be increasing in 2012. The targeting of whale sharks is prohibited in China where they are considered a second-class national protected animal which are illegal to hunt without a special permit, however, compliance has been observed to be weak and there is seldom any kind of enforcement (Li, Wang and Norman, 2012). While capture is more often as a result of bycatch in net fisheries rather than direct targeting, they are still reportedly routinely captured and retained when sighted due to the high price they command (Li, Wang and Norman, 2012). Moreover, there is also evidence of illegal trade given the continued presence of whale shark fins in Hong Kong markets despite the lack of permit records in the CITES Wildlife Trade Database (Pierce and Norman, 2016).

Nevertheless, despite the persistence of some of these artisanal targeted fisheries, and the large-scale fisheries in southern China, the primary threat to whale shark populations is believed to be their interactions with tuna purse seine and gillnet fisheries as bycatch (Pierce & Norman 2016). Tuna are known to aggregate around marine megafauna such as whale sharks and cetaceans (Romanov, 2002) which assists in the detection of schools by tuna purse-seine vessels operating in the Indian Ocean. These may be encircled intentionally or accidentally, if not visible at the time of setting (Murua et al., 2013). For gillnets, reports from India suggest that specifically avoiding entangling whale sharks in fishing nets is seen as virtually impossible (Akhilesh et al., 2013).

Cetaceans

Most populations of large whales have been protected from targeted commercial whaling through the Indian Ocean Sanctuary implemented by the IWC in 1979, which appears to have been effective for many species, given that many formerly depleted marine mammal populations have been shown to be recovering (Magera *et al.*, 2013). Nevertheless, many of the world’s smaller cetaceans are currently in danger of extinction and bycatch remains one of the most significant threats (Brownell et al., 2019; IWC, 2019). A number of international global environmental accords (e.g. Convention on Migratory Species (CMS), Convention on Biological Diversity (CBD), International Whaling Commission (IWC)), as well as numerous fisheries agreements oblige States to provide protection for cetacean species known to interact with IOTC fisheries.

Gillnet fisheries

Gillnet fisheries are considered to be the primary source of cetacean mortality in the Indian Ocean and are considered to be a major cause for concern (Kiszka *et al.*, 2009, 2017; Anderson, 2014; Garcia and Herrera, 2018; IWC, 2019; Anderson *et al.*, 2020; WPEB, 2020). Small cetaceans swim into gillnets, sometimes for the purposes of depredation, and become entangled in the mesh. The high prevalence of drifting gillnets in the Indian Ocean means that this results in substantial mortality. A recent review by Anderson et al., (2020) estimated cetacean bycatch for gillnet fleets in the Indian Ocean, suggesting catches peaked at around 100 000 cetaceans yr^{-1} between 2004 and 2006 and have since declined to around 80 000. While subject to large uncertainty due to the extremely limited data available, these estimates are compatible with previous figures (Anderson, 2014; Garcia and Herrera, 2018).

The threat of gillnets to cetaceans has been widely acknowledged. An expert workshop convened by the IWC in 2019 concluded that there was a need to focus on gillnets as the fishing gear likely to be responsible for the most significant bycatch of cetaceans in the Indian Ocean region (IWC, 2019). In a recent global review of cetacean bycatch, the IOTC was classified as a ‘high risk’ tRFMO on the basis of its more prevalent use of gillnets compared to other RFMOs (Elliott, 2020).

Across India, the species most commonly caught as bycatch by in mechanised vessels using gillnets are spinner dolphins, finless porpoises (*Neophocaena phocaenoides*), Indian Ocean humpback dolphins (*Sousa plumbea*), Bryde’s (*Balaenoptera edeni*) and blue whales (*Balaenoptera musculus*) (Yousef et al. 2009; Kuppusamy, 2019). In the semi-industrial gillnet fisheries of Pakistan, cetacean bycatch includes Indo-pacific bottlenose dolphins (*Tursiops truncatus*), common dolphins (*Dephinus delphis*), spinner dolphins (*Stenella longirostris*), Risso's dolphins, humpback whales (*Megaptera novaeangliae*) and several deep-diving whale species (Shahid *et al.*, 2016; IWC, 2019). Along coastlines such as Kenya, Tanzania and Madagascar in the western Indian Ocean, the most common bycatch species are the Indo-pacific humpback and bottlenose dolphins (Kiszka et al., 2017).

The level of threat of the Indian Ocean gillnet fisheries to cetaceans has been compared to the eastern tropical Pacific Ocean dolphin purse seine fishery and commercial whaling in terms of magnitude, but has so far been much lower profile in terms of public awareness and corresponding management action (Anderson et al., 2020). While few effective solutions to the problem of bycatch of small cetaceans currently exist (Brownell et al., 2019; IWC, 2019), gillnet fishing in the Indian Ocean remains as potentially "the largest unresolved contemporary cetacean conservation and management issue" (Anderson et al., 2020).

Pelagic longline fisheries

Incidental catches of cetaceans in pelagic longline fisheries is relatively rare, involving entanglement in lines or more commonly, due to depredation by toothed whales, where hooked fish or bait are taken from the line (Kiszka et al., 2009). Cetaceans may become hooked or entangled during depredation, or may die or be injured as a result of methods used by fishers to prevent depredation and gear damage (Gilman, 2011; Rabearisoa, Bach and Marsac, 2015). The species involved are generally large delphinids such as the short-finned pilot whale (*Globicephala macrorhynchus)*, Risso's dolphin (*Grampus griseus)*, false killer whales (*Pseudorca crassidens) and* killer whales (*Orcinus orca*) (Kiszka *et al.*, 2017). Overall levels of interaction from the longline fisheries are reported to be relatively low; Garcia & Herrera (2018) estimated that longline fleets in the Indian Ocean accounted for only 0.2% of total cetacean mortality (~350 individuals annually).

Purse seine fisheries

There have been an increasing number of studies in recent years suggesting that cetacean bycatch rates are low in industrial purse seine fisheries in the Indian Ocean (Escalle *et al.*, 2015; Ruiz Gondra *et al.*, 2017; Garcia and Herrera, 2018; Ruiz *et al.*, 2018). Historically, purse seine vessels have considered whales to be good indicators of the presence of tuna schools and have often intentionally set on large baleen whales (Romanov, 2002; Murua *et al.*, 2013; Escalle *et al.*, 2015). Species include Bryde's whale (*Balenoptera edeni)*, fin whale (*B. physalus)*, sei whale (*B. borealis)*, and humpback whale (*Megaptera novaeangliae)* (Escalle *et al.*, 2015; Ruiz *et al.*, 2018). Whales associated with tunas were generally reported to be found in groups of 2-3 whales, sometimes reaching up to 8 individuals (Romanov, 2002). The encircling of cetaceans has been prohibited by the EU since 2007, and by the IOTC since 2013, but cetaceans are not always sighted prior to the commencement of the set and so may be encircled accidentally.

The practice of using dolphins to detect schools and setting on dolphin-associated tuna schools is very common in the eastern tropical Pacific, and tuna-dolphin associations (mostly spotted dolphins *Stenella attenuata* and spinner dolphins *Stenella longrostris*) have similarly been observed in the western Indian Ocean (Hall, 1998; Anderson, 2014; WPEB, 2020). Yet dolphin-associated sets appear to be made relatively rarely (<10 yr^{-1}) in the Indian Ocean, relatively few interactions with delphinids have been reported, and those that are have been linked to very high survival rates (Escalle et al., 2015). Reported interactions include the delphinids (S*tenella* spp., common dolphin *Delphinus delphis*, common bottlenose dolphin *Tursiops truncatus*, rough-toothed dolphin *Steno bredanensis*, short-finned pilot whale

Globicephala macrorhynchus, false killer whale *Pseudorca crassidens*, melon-headed whale *Peponocephala electra*, and killer whale *Orcinus orca)* (Escalle *et al.*, 2015). The extent of earlier interactions of purse seiners with delphinids has been contested (Anderson, 2014; Kiszka *et al.*, 2017; Kiszka, Talwar, *et al.*, 2018), however, EU purse seiners have had close to 100 % observer coverage since 2016 and interactions are regularly reported to the IOTC (Ruiz *et al.*, 2018).

Most dolphins do not associate with FADs and so are not caught in FAD sets, although interactions with FAD sets have been reported from the western Pacific and Atlantic (Molony, 2005; Ruiz Gondra *et al.*, 2017).Nevertheless, rough-toothed dolphins are known to associate with drifting objects and may be particularly impacted by FAD entanglement and FAD sets (Anderson, 2014). The transition towards less entangling FADs (IOTC Res, 19/02) should address this aspect, however legacy FADs are likely to remain in circulation for a while.

Handline and pole and line fisheries

Many coastal handline fisheries target large yellowfin tuna, detected through their association with dolphins (mainly spotted and spinner dolphins) (Anderson, 2014). They appear to interact regularly with small coastal species of delphinids such as around Mayotte and Reunion, causing injuries or mortalities, the scale of which is unknown (Kiszka et al., 2009).

While the Maldivian pole and line fishery is considered to have a very low impact through its main fishing operations which involve taking fish individually, bait fishing operations use lights to attract small fish and there have been reports of Indo-pacific bottlenose dolphins (*Tursiops aduncus*) taking these fish, although the extent of this and threat level is unknown (Anderson, 2014).

Marine turtles

There are six species of marine turtle found in the Indian Ocean, listed in Table 2. The IUCN threat status of many of these species is high, at least for part of their population. The species are protected by a number of international conventions, including the CMS and the CBD.

While no stock assessments have taken place for marine turtles due to data limitations, risk assessments have been undertaken (Nel et al., 2013; Williams et al., 2018). Gillnet fisheries are thought to have the greatest population-level impact on the mortality of marine turtles (Wallace et al., 2013), with catches estimated to be an order of magnitude greater than the purse seine and longline fisheries (Nel et al., 2013). More recent estimates suggest longline fisheries are as important as gillnet fisheries in term of the contribution to marine turtle bycatch (Garcia and Herrera, 2018), but purse seine fisheries interactions are thought to be much lower (Nel et al., 2013; Garcia and Herrera, 2018). Nevertheless, no sea turtle sub-populations were classified as low vulnerability to longline, purse seine or gillnet fisheries – all were classified as either medium or high vulnerability (Williams et al., 2018). Within these fisheries, the species identified to be most vulnerable to fishing were green turtles, loggerhead turtles and hawksbill turtles, particularly in the Arabian Sea and Bay of Bengal (Williams et al., 2018).

IOTC Bycatch CMMs

Over the past decade, the IOTC has adopted a number of Conservation and Management Measures (CMMs), as 'Resolutions' supporting the conservation of vulnerable species interacting with IOTC fisheries as bycatch. The adoption of a management measure represents the first step in management, however, it is vital to subsequently evaluate the effectiveness of these following implementation. It has been agreed in international fora that any such evaluation needs to focus on what has been achieved rather than what has been adopted, consider uncertainty and work to reduce it over time, and formulate management measures to improve data quality (Anon, 2019). This report seeks to address some of these issues through a review and analysis of the available information to date. Table 3 provides a list of the main IOTC CMMs related to the bycatch species included in this review. The overall goal of the bycatch CMMs is to minimise the fishery impacts on the species of concern, while the specific objectives are typically three-fold, involving; (i) a direct reduction in mortality (usually in the form of a retention ban or modification of gear/practices to reduce harmful interactions), (ii) improvements to data quality and (iii) research-related objectives (Table 4).

CMM effectiveness in reducing mortality

The thresher sharks, oceanic whitetip shark, mobulids, whale shark, turtles and cetaceans are all subject to non-retention measures. Ideally, the effectiveness of CMMs in reducing mortality on bycatch species would be investigated through monitoring bycatch rates and population level analyses evaluating recovery by species. In reality, the data for many of these species are too sparse and limited to attempt to assess the effectiveness of CMMs in this way. Nevertheless, the section below reviews the data that are available to evaluate the current situation.

For a non-retention measure to be effective in achieving a substantial reduction in mortality, discard survival rates must be high, i.e., low levels of at-vessel mortality (AVM) and post-release mortality (PRM) are required. Compliance levels must be relatively good and any fisheries that are exempt from the measures should not comprise a large component of the fishery for that species. This report attempts to estimate the likely level of mortality reduction achieved by the IOTC retention bans for bycatch species through a review of the information available. This involved a literature review to collate estimates of AVM and PRM as well as the proportion of landings taken by the artisanal fisheries and information on CPC compliance.

Sharks

Sharks with a retention ban: compliance with CMMs

This first assumption when adopting and implementing a CMM is that it will be enacted and enforced. This section reviews reported nominal (retained) catches for sharks with a retention ban over the relevant time period alongside information from the corresponding compliance reports.

Resolution 13/06 On a scientific and management framework on the conservation of shark species caught in association with IOTC managed fisheries

A retention ban on oceanic whitetip sharks (*Carcharhinus longimanus*) was adopted by the Commission in 2013 and so the first full calendar year for which it came into effect was 2014. Nominal catches from the IOTC database were reviewed for retained catches of oceanic whitetip before and after the adoption of Res. 13/06 (Table 5). The Resolution is applicable to all flagged vessels on the IOTC Record of Authorised Vessels, which are those authorised to fish for tuna or tuna-like species managed by the IOTC on the high seas with the exception of artisanal fisheries operating exclusively in their respective Exclusive Economic Zone (EEZ) for the purpose of local consumption, and India, due to the objection.

Figure 1 shows the reported retained captures of oceanic whitetip since 1986. The trend in reported landings is historically dominated by a single fleet (Sri Lanka) in which the shark fishery expanded until 1999 and subsequently declined. Catches have been more variable since 2010 but indicate that the capture and retention of oceanic whitetip sharks is still occurring, predominantly by the gillnet and line fisheries, albeit at very low levels in 2017 and 2018. Retention since 2014 has been reported predominantly by gillnets and small-scale line fisheries, however, there are still some reported captures by the industrial fleets (Figure 2). The main industrial fleet still reporting some retention of oceanic whitetip sharks is I.R.Iran, while the other industrial fleets have reported catches to a much lesser extent. While Comoros has reported high catches since implementation of the ban, this is an artisanal fishery and so is exempt from the measure. On review of national legislation, it is apparent that it has taken a few years for some CPCs to incorporate Res. 13/06 into domestic law and two countries are only now incorporating it into legislation, 7 years later, demonstrating a considerable time lag between adoption and implementation of a measure (*Table 6*).

Resolution 12/09 On the conservation of thresher sharks (family Alopiidae) caught in association with fisheries in the IOTC Area of Competence

In 2010, a retention ban came into force for all three species of thresher shark which interact with IOTC fisheries (*Alopias* spp.) in the form of IOTC Resolution 10/12, which was subsequently superseded by Res. 12/09. The Resolution is applicable to all flagged vessels on the IOTC Record of Authorised Vessels (RAV), which are those authorised to fish for tuna or tuna-like species managed by the IOTC on the high seas. While no specific exemption has been noted for artisanal fisheries, this is implicit given that there is no requirement for vessels ≤ 24 m operating exclusively in their EEZ to be registered on the RAV.

Since 2011, the first full year following the first iteration of the retention ban, Indonesia, Pakistan, Madagascar, and to a lesser extent, India, Maldives, EU-Portugal, EU-Reunion, Seychelles, South Africa and Tanzania have all reported retained catches of thresher sharks (Table 7). Figure 3 shows the trend in retained catches of thresher sharks since 1990, showing an increase in reported catches until 2012, since when catches have remained fairly stable, fluctuating around 4.5 – 5.5 1000 t. Catches have only dropped markedly in the last year of the series, 2018, however, there was a reduction in shark catches across most species between 2017 and 2018 which is considered to be likely due to reporting issues by several CPCs (India, Indonesia and Mozambique) rather than reflecting an actual decline in catch (WPEB, 2020). This apparent discrepancy in catches reported by Indonesia in 2018 is also reflected in Table 7 which indicates a reported decline in catches of thresher sharks by ~1000 t compared with previous years.

Catches of thresher sharks have been reported predominantly by the small-scale line and gillnet fisheries (Figure 3). Catches of thresher sharks reported by the industrial fisheries are very low with the vast majority of instances reported by artisanal fisheries (Table 7). Very few individuals have been identified to species level, particularly in recent years. Where they have been identified to species level, the majority were common threshers from the 1990s to the early 2000s, whereas more recently there were more pelagic threshers.

While the retention of thresher sharks is currently banned nationally by all reporting CPCs, for some of these countries the international agreement has taken a number of years to be incorporated into national legislation. Only a minority of the reporting CPCs had enacted and enforced a ban by 2011, the year after the Resolution came into force, in its first iteration, Res. 10/12 (Table 8). Nevertheless, reported catches of thresher sharks by Indonesia, Pakistan and Madagascar did not change following the implementation of national legislation in 2012, 2016 and 2014 respectively, presumably because these were predominantly caught by artisanal fisheries (Table 7) (Figure 4).

Factors affecting retained catches of prohibited species

Possible reasons for reported retained catches following a ban include incorrect reporting of oceanic whitetip and thresher sharks as nominal catches rather than as discards, however, there is little incentive to do this and so errors in the reporting of retention status are more likely to be the other way round. Non-compliance and lack of enforcement may also be an issue, potentially due to low awareness among fishers and fisheries governing institutions.

Ongoing capture and retention of oceanic whitetip sharks was also previously identified during an IOTC-CITES workshop in 2017 (Rice, 2017a). Discussions held in that workshop indicated it was suspected that it is not only artisanal fisheries operating for the purpose of subsistence and that some commerce in meat and fins is likely to occur as there is substantial undocumented regional trade. Potential reasons included lack of awareness and a reluctance to discard sharks that were already dead at haul back, as this was perceived as wasteful given that sharks are still an important part of many fisheries. Breach of fisheries regulations was also viewed as a relatively minor problem in some CPCs compared with other national concerns. Rice (2017a) concluded that the number reported as retained nominal catch is likely due to a delay in the adoption and of national bans on retention, however, it is clear from reviewing the information on national legislation that some catches of both oceanic whitetip and thresher sharks are still occurring despite national bans. Nevertheless, catch levels of oceanic whitetip are relatively low and while they are higher for thresher sharks, this is almost entirely by the artisanal fleets. Based on direct reports it appears that there has been some non-compliance since implementation of the Resolutions, and this obviously does not include any retained captures that are unreported.

Sharks with a retention ban: fisheries exemptions

Although artisanal fisheries are exempt from these retention bans, they are important fisheries in the Indian Ocean, responsible for 60% of captures of the same pelagic stocks (IOTC, 2019d). Given that the nominal catch data reported for IOTC shark species are considered to be grossly incomplete (WPEB, 2020), the proportion of captures of a given species taken by the industrial and artisanal fleets were calculated based on the fleet-specific catch estimates of Murua *et al.* (2013) and Garcia and Herrera (2018). Murua et al. (2013) covered 17 fleet categories and estimated average catches of sharks for the period 2000-2011, while Garcia and Herrera (2018) covered 53 fleets, estimating catches for the time period 2014-2016. Mapping of fleet classifications used in each of the studies to those used in the IOTC nominal catch database was undertaken in order to allocated the catches of each fleet and species to the categories ‘artisanal’ or ‘industrial’. While the total estimates of species captures were quite different across the two studies the estimated proportions taken by artisanal and industrial fisheries were more similar. Murua et al. 2013 estimated total artisanal fleet captures as 58.6 % for oceanic whitetip shark and 56.9 % of bigeye thresher sharks; estimations were not available for the other thresher shark species. Garcia and Herrera (2018) estimated artisanal captures as 64.6% and 63.6 % for oceanic whitetip and thresher sharks respectively.

Sharks with a retention ban: survival of discards

While retention is banned, capture is still permitted and this alone can have serious consequences potentially resulting in mortality, whether the final outcome is retention or not (Tolotti, Filmalter, *et al.*, 2015). Where sharks are targeted by industrial fisheries, banning may have a substantial impact, however, sharks that are relatively productive and support targeted industrial fisheries (e.g. blue shark) are more likely to be considered for management measures that do not involve a total retention ban, but instead aim to achieve a sustainable level of mortality[17]. For those species that are not targeted but caught as bycatch, success of the measure depends on the survival of discards. Survival of discards depends firstly on the condition at which they arrive at the vessel, and the numbers which are already dead, otherwise known as the AVM (AVM), the proportion of individuals that are dead upon gear retrieval. Following handling and release procedures, a further proportion of individuals die, resulting in post-release mortality (PRM). The instantaneous forms of at-vessel capture mortality (Fc) and post-release mortality (Fr) rates are additive (Musyl and Gilman, 2019) and together with the mortality arising from the retained component of artisanal fisheries (Fa) and the non-compliant component of the industrial fisheries (Fn), produce F, the instantaneous rate of total fishing mortality (Haddon, 2001); where ε is an error term to account for other (i.e. unmeasured) potential sources of mortality such as pre-catch and ghost fishing (Musyl and Gilman, 2019).

For a non-retention measure to be effective in achieving a substantial reduction in mortality, discard survival rates must be high, i.e., both low AVM and low PRM are required. Compliance levels must be relatively good and the fisheries that are exempt (in this case, the artisanal fisheries operating exclusively in the EEZ) should not comprise a large component of the fishery for that species. Therefore, following a retention ban, the total remaining fishing mortality would be made up of that exerted by the artisanal fisheries in addition to the non-compliant component of the industrial fleet, the AVM of captures and PRM of discards, plus any other unmeasured mortality (Equation 1).

Equation 1. $F = F_a + F_n + F_c + F_r + \varepsilon$

The rate of PRM of elasmobranchs has been considered to be species-specific and dependent on a number of factors, including specimen size, sex, gear type and location of capture. However, Musyl and Gilman (2019) conducted a meta-analysis concluding that PRM rates for a species were very robust across studies and remarkably similar across different fisheries, gear types and locations. The only significant variable to explain survival outcomes for a species was health condition at time of retrieval and tagging, following handling methods (Hutchinson and Bigelow, 2019). For silky sharks, those which were retrieved on longlines in an unhealthy condition, usually due to a longer hooked time, had PRM rates comparable to sharks that had been brailed during purse seine fishing operations. Similarly, sharks retrieved in good condition from longline gear, due to relatively short hooking times, had PRM rates comparable to sharks caught in purse sine operations that were released from the net prior to brailing (Musyl and Gilman, 2019). This indicates that health condition at the time of release is likely to be more important than gear type, sex, location or body size.

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[17] *"In light of the results of the next stock assessment of blue shark in 2021, the Scientific Committee shall provide advice, if possible, on options for candidate limit, threshold and target reference points for the conservation and management of this species in the IOTC Convention area".* IOTC Resolution 18/02, Para. 6.

A literature review was conducted to compile rates of AVM and PRM by species (Table 9). This centres on longline and purse seine fisheries where the majority of data are available and information is notably deficient for some important fisheries such as the Indian Ocean gillnet fleets, although information from these, and other gillnet fisheries, has been used where available. Where more than one article was found describing the same dataset only one was used to avoid replication of data. Similarly, if a study selected individuals of a certain condition, such as only tagging only healthy individuals or included the tagging of dead individuals, these were excluded to avoid bias in the mortality estimates. Raw data in the form of survival and mortalities were used so non-reporting tags were also not included in the estimates to avoid bias. This allowed studies with a greater sample size to be given a greater weighting, i.e., every tag across studies was given equal weighting. Overall weighted-average estimates of AVM and PRM were calculated and resampling techniques were used to construct 95% bootstrap confidence intervals (with the assumption of a binomial distribution with 10,000 replicates) for both AVM and PRM estimates. Overall AVM was estimated as 0.12 (0.11 - 0.13, 95% CIs) and PRM as 0.09 (0.02 - 0.17, 95% CIs) for oceanic whitetip sharks. For bigeye thresher sharks both mortality rates were higher; the estimate of AVM was 0.21 (0.20 - 0.22, 95% CIs) and PRM estimate was 0.24 (0.13 - 0.37, 95% CIs).

Neither Res. 13/06 nor Res. 12/09 specify how the sharks should be released unharmed. Based on recent studies, it has been suggested that more specific instructions as to how to handle and release unharmed, following best practices, should be indicated in the CMMs to minimise PRM. This might include specifying the length of trailing line left on the species when caught in longline gear, what tools should be used for cutting the line and whether the shark should be hauled close to the vessel before release (WCPFC, 2019). Condition of the shark was a significant factor affecting PRM and as the probability of injury is greater when sharks are hauled onboard, leaving them in water is likely to result in better condition at release and therefore lower PRM (WCPFC, 2019). While this is specified for oceanic whitetip sharks, it is not for threshers[18].

Based on these mortality estimates, the overall expected percentage reduction in annual fishing mortality for a species achieved by a retention ban was calculated by multiplying the proportion of captures taken by the industrial fleet by the at-haulback and post-release survival rates for a range of assumed compliance levels (70 - 100 %). Uncertainty in the AVM and PRM estimates was accounted for by introducing the bootstrap replicates across the range of estimates found in the literature. Figure 5 shows the resulting estimated reduction in mortality (%) achieved following the implementation of a retention ban under different assumed scenarios of compliance (70 – 100 %) for bigeye thresher and oceanic whitetip sharks. For oceanic whitetips, this ranged from 28 % - 33 % overall reduction in mortality with an assumed level of compliance of 100 %. While the AVM and PRM estimates were low, the estimated reduction in mortality was still fairly low due to the high proportion of captures taken by artisanal fisheries. For bigeye threshers the proportion of captures by the artisanal fleets was slightly lower, however, the higher AVM and PRM rates resulted in a lower estimated reduction in

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[18] Thresher sharks: *"CPCs shall require vessels flying their flag to promptly release unharmed, to the extent practicable, thresher sharks when brought along side for taking on board the vessel".* (Res. 12/09)

Oceanic whitetips: *"CPCs shall require fishing vessels…to promptly release unharmed, to the extent practicable, of oceanic whitetip sharks when brought alongside for taking onboard the vessel. However, CPCs should encourage their fishers to release this species if recognised on the line before bringing them onboard the vessels".* (Res.13/06) mortality, ranging from 22 % - 26 %. These are considered maximum estimates given that there is known to be some non-compliance Table 10.

These results highlight the importance of considering all the factors contributing to mortality of a population when evaluating a management measure. There are clear species-specific differences in survival rates which may make retention bans more appropriate for species such as oceanic whitetip, whereas for species with lower survival rates such as bigeye threshers, further work needs to be undertaken to improve post-release survival and a greater focus on mitigation measures may be warranted. Mitigation measures are notably absent from these resolutions. Nevertheless, the fleet exemptions are responsible for an even greater source of mortality and also need to be addressed, as does delayed or non-existent domestication of IOTC measures.

Other sharks

All shark species caught in IOTC fisheries are subject to a ban on finning (Res. 17/05). The effectiveness of this measure was recently reviewed, but concluded that the current reporting requirements associated with the measure were inadequate to fully evaluate whether and how a prohibition on shark finning is being maintained (Clarke, 2018). None of the shark measures require employment of longline or purse seine gear technology best practices for shark bycatch mitigation.

Mobulid rays

Retention rates

For mobulid rays it is still too early to be able to assess compliance with the non-retention measure introduced in 2019 (Res. 19/03[19]) given that data for 2020 are not yet available. The expected impact of the ban is also more uncertain as only subsistence fisheries that do not sell and part of the ray are exempt and the proportion of mobulid catches taken by these fisheries is unknown. Nevertheless, it is still useful to look at historic data to evaluate the frequency of retention prior to the Resolution as an indication of the likely prevalence following the ban.

An analysis of observer data collated from 16 tuna fleets operating in the Indian Ocean concluded that the majority of reported mobulid catches were discarded (93 %), while 4 % were retained (by the Pakistani gillnet fleet, Sri Lankan and French longline fleets and Seychelles purse seine fleet), and for the others the fate was not recorded (Martin, 2020a). There were apparent differences in discarding practices by fishery and species. No manta rays were reported as retained; those discarded were either devil rays or unknown species. This may be due to the greater awareness of the threats to mantas than devil rays and corresponding protective restrictions that have been put in place on manta rays ahead of devil rays in a number of countries as highlighted by Lawson et al., (2017), or it may be due to factors such as the greater size of mantas making them more difficult to handle, manoeuvre, preserve and transport if retained or the increased likelihood of damaging fishing gear, both of which have been

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[19] Resolution 19/03 On the conservation of mobulid rays caught in association with fisheries in the IOTC Area of Competence

reported in Sri Lanka (Fernando and Stevens, 2011). However, *M. mobular* reaches a similar size to *M. alfredi* so this would also apply to large individuals of that species.

While some retention was reported by all gear types investigated, this was particularly substantial for the gillnet fleet which retained 42 % of captures (31 % discarded and 27 % unknown), whereas for the purse seine and longline fleets almost all mobulids were discarded (Martin, 2020a). Given that the majority of previously retained captures were by the gillnet fleets, efficacy of the CMM is likely to depend on the proportion of the fleets, e.g. Sri Lanka, Pakistan and Indonesia (and presumably many others that have not reported catches), that are subsistence and the swiftness with which the national legislation is enacted.

Discard survival

Of the mobulids reported as discarded with known status in the IOTC observer data, 24 % were already dead while the remaining 76 % were released alive, however, there were difference by gear type (Martin, 2020a). For longline fisheries 90 % of discards were released alive, comparable with other literature which report AVM rates for pelagic longline fisheries as ranging from 0 to 5.2% in the Indian and Atlantic Oceans (Beerkircher, Cortés and Shivji, 2002; Coelho, Lino and Santos, 2011; Mas, Forselledo and Domingo, 2015). At-vessel mortality is potentially higher in purse seine fisheries based on estimates of 24 – 47 % from the European purse seine fishery operating in the Atlantic (Clavareau *et al.*, 2020), and rates of 36 % reported by observer data from the Indian Ocean. At-vessel mortality for gillnets is possibly higher still (50 %) (Martin, 2020a), potentially due to the extended soak times (12+ hours) (Moazzam and Khan, 2019), however, improved estimates are required for all fisheries (Ellis, McCully Phillips and Poisson, 2017).

While the information that exists suggests that the majority of mobulids caught are discarded alive, many may still ultimately die due to the weak condition they may be in following poor handling practices (Poisson et al., 2014; Mozzam pers. comm). There has only been one tagging study specifically evaluating the PRM of mobulid rays which took place in the New Zealand purse seine fishery, exclusively tagging the spinetail devil ray *M. mobular* (Francis and Jones, 2017). In this experiment only three out of seven rays survived and notably all tagged rays were reported to have swum away vigorously when released showing that improved data collection on the condition of releases by observers is not necessarily a good indicator of survival. All surviving specimens were brailed, while all entangled in the net did not survive release.

Nevertheless, as the AVM rates appear to be relatively low for mobulids compared with other elasmobranch species (Coelho, Lino and Santos, 2011; Clavareau *et al.*, 2020; Martin, 2020a), improved handling methods may prove successful in reducing mortality post-release, particularly if the long handling times can be reduced (Grande *et al.*, 2019). This highlights the importance of further tagging experiments, for the gillnet and longline fisheries as well as the purse seine fisheries, alongside routine data collection (Francis and Jones, 2017). While best practice handling and release guidelines have been developed for purse seine, longline and gillnet fisheries now (F. *et al.*, 2012; Francis, 2014; Hutchinson, Poisson and Swimmer, 2017; Jones and Francis, 2017; WCPFC, 2017a; Carlson, John; Horn, Calusa; Creager, 2019; Martin, 2020b; WWF-Pakistan, 2020), there needs to be further research into the efficacy of these methods through the collection of data on specific handling practices combined with satellite tagging studies across different gear types, species and sizes to review and determine which methods optimise survival (WPEB, 2018).

Whale sharks

The intentional setting on whale sharks by purse seine vessels in the Indian Ocean was prohibited by IOTC in 2013 (Resolution 13/05). Nevertheless, accidental setting continues to take place and results from the western Pacific Ocean suggest that of all whale shark entanglement events, 73 % were accidental as they were not sighted prior to the deployment of nets (SPC-OFP 2012). Multiple individuals may be caught during a set and the same individual might even be caught several times during a fishing season, identified by the presence of a rope attached around the tail used for the previous release (Murua et al., 2013). The use of handling and release methods that minimise the PRM of whale sharks is therefore critical for the management measures to be effective in reducing mortality on the species and a set of guidelines were agreed by the SC in 2013 (IOTC, 2013). The Spanish fleet follows a Code of Good Practices which aims to reduce the mortality of whale sharks to negligible levels when the recommended practices are followed (Grande *et al.*, 2019).

Artisanal fisheries operating exclusively in their respective EEZ are exempt from this measure, and due to the current lack of clarity surrounding the term artisanal, it is not clear if large scale vessels operating within coastal waters are also considered by the Resolution or not (WPICMM03, 2020). This resolution focusses solely on purse seine fisheries and does not address gillnet fisheries interactions, for which interactions are common (Nawaz and Moazzam, 2014). Whale sharks remain vulnerable to gillnets across the Indian Ocean, and sub-surface setting of nets does not appear to influence entanglement rates (Moazaam and Nawaz, 2017).

Discard survival

Data from the Spanish purse seine fleet operating in the Indian Ocean indicate that the AVM or capture mortality for whale sharks is low. A recent study monitoring observer data recorded a total of 163 individuals captured of which all but one escaped from the net or were discarded alive (Ruiz Gondra et al., 2017; Ruiz et al., 2018). In the Pacific Ocean, observers reported that 12 % of interactions with whale sharks resulted in mortality at the time of release (SPC-OFP, 2010), whereas a study using data derived from logbooks completed by captains of tuna purse seine fleets operating in the Atlantic and Indian Oceans reported much lower mortality rates of 0.9 % (n=107) and 2.56 % (n=38) respectively (Capietto *et al.*, 2014). These results suggests that overall, mortality is relatively low at capture for purse seine fleets. For gillnets, there is little available information on condition of capture. Anecdotal evidence from gillnet fleets in India indicates that most incidentally caught whale sharks are already dead or near dead at haul-back (Akhilesh et al., 2013), though observations from the Pakistani fleet suggest survival may be higher (20 %, n=5) (Nawaz and Moazzam, 2014).

In terms of PRM, the information that is available suggests that the prognosis for injured individuals may be relatively good. Information based on observational studies indicates that whale sharks are able to rapidly heal and recover from amputations and even the effects of deep wounding of internal organs (Riley, Harman and Rees, 2009) and studies indicate that the presence of major injuries has no significant impact on apparent survival, although there may be some behavioural changes such as reduced emigration associated with injuries and other stressors (Harvey-Carroll et al., 2021). High survival of whale sharks released alive is further demonstrated by tagging studies from purse seine vessels in the Atlantic Ocean where post-release survival has been estimated to be 100 %, although this was from a very small study with only 7 reporting tags (Clavareau et al., 2018).

This suggests that for purse seine vessels, the combination of the current regulations with best practice release approaches for accidental encirclements should be able to reduce mortality to sufficiently negligible levels. For gillnet fleets, these pose a much greater threat and currently remain relatively unregulated at the regional level, although there are some restrictions on the length of the net (large-scale drifting gillnets, over 2.5 km, are prohibited on the high seas, although still permitted in coastal waters until January 2022). Improved data collection and reporting are paramount to better understanding the impacts of the fisheries, however, this should not preclude management effort based on the precautionary principle and based on the evidence available suggests that mitigation measures should be explored and implemented. In areas, such as China, India, Mozambique, Taiwan and Tanzania, the close proximity of whale shark feeding areas or movement corridors with net fisheries leads to regular incidental bycatch (Pierce and Norman, 2016). In these locations in particular, restrictions on mesh size, net length, soak time and fishing location may help fishers avoid interactions while bycatch reduction technologies such as the incorporation of deliberate weak points in nets may help reduce the likelihood of mortality when interactions do occur (Pierce and Norman, 2016).

Cetaceans

While setting on cetaceans is prohibited for the purse seine fleet (Res.13/04), accidental setting may still occur. Encircled cetaceans generally escape by diving before the set is completed (Ruiz Gondra *et al.*, 2017; Ruiz *et al.*, 2018), swimming over the net, or ramming through the net wall (Romanov, 2002). Survival rates are generally very high, with recent studies reporting 100 % survival (Escalle et al., 2015; Ruiz et al., 2018), although a mortality on whale set events has been known to occur (Romanov, 2002). Post release survival rates have not been estimated, but are also likely to be high given the limited interaction.

Interactions with the gillnet fisheries are of greater concern, particularly given that they are still expanding and the illegal use of large-scale nets (>2.5 km) remains prevalent (Khan, 2020). Interaction rates with small cetaceans are high (see previous section) and AVM rates are very high for small cetaceans which quickly drown following entanglement, so the vast majority of individual are already dead at haulback (Shahid et al., 2016). Entanglements of large whales are thought to be rare events (Shahid et al., 2016) and where they do occur, whales are often able to force their way out of gillnets so mortality rates are not likely to be so high. Nevertheless, there may still be some trailing gear attached and there has been anecdotal evidence of the beaching of enmeshed whales, indicating that post-release survival of large whales is not 100 % (Nawaz and Moazzam, 2014).

Given the very low survival of small cetaceans in gillnets, the development of mitigation measures to prevent interactions is critical, however, few technical solutions currently exist. Research efforts focussed on acoustic deterrents or ‘pingers’ and net illumination have proved to be some of the most promising to-date (IWC, 2019). Acoustic deterrents have proved successful at reducing incidental bycatch of certain species interacting with certain gears, although not all species and there are concerns regarding underwater noise pollution and the associated impacts, as well as familiarly resulting in limited deterrence. Recent trials on net illumination in the Peruvian gillnet fishery have shown signs of success in reducing the probability of interactions with turtles and cetaceans by over 70 % (Bielli *et al.*, 2020), suggesting trials in the larger-scale driftnet fisheries of the Indian Ocean are warranted. Increased interactions with sharks and rays have also been observed associated with the illumination, however, so impacts on other taxa need to be fully investigated (IWC, 2019). Both pingers and lights are expensive devices and require maintenance, so are likely to be effective only in affluent countries that have the financial resources to support their long-term use (Dawson et al. 2013). Cheaper and readily available materials, such as recycled plastic and glass bottles to create passive acoustic reflectors and mechanical alarms are also being trialled as alternatives (IWC, 2019). Other potential gear modifications may include use of shorter nets, visually detectable nets, tauter nets, weaker nets, "buoyless" nets, incorporation of 'break away panels' which uses a lighter twine attaching net panels to head and foot ropes to allow large animals to 'break' through short sections of the net (Welch *et al.*, 2016; Hamilton and Baker, 2019).

While some have concluded that there is no simple technical solution to the problem of bycatch of small cetaceans in gillnets and that the long-term solution is the development of efficient, inexpensive, alternative fishing gear that can replace gillnets without jeopardizing the livelihoods of fishermen (Brownell et al., 2019), recent results from a preliminary study on sub-surface setting (2m depth) of drifting tuna gillnets that has taken place in Pakistan are promising, suggesting that cetacean bycatch may be reduced by 90 % while target catch remains unaffected (Kiszka, Moazzam, *et al.*, 2018). These results are still preliminary and further work to develop and trial low-cost and low-tech solutions for both mitigation and monitoring has been called for (IWC, 2019).

Nevertheless, in 2019, in response to these preliminary results, the Commission introduced the mandatory sub-surface (2 m) setting of gillnets, to be fully implemented by 2023 (Res.19/01). Two further actions were also introduced at this time: (i) the phasing out of gillnets or conversion to other gear types, and (ii) an increase in observer coverage, or field sampling, to 10 %, using alternative data collection methodologies (Res.19/01). Both of these were introduced as non-mandatory measures. Ongoing monitoring to evaluate the effectiveness of these measures will be needed.

While purse seine and gillnet fleets are now subject to some form management measures to reduce their impact on cetaceans, there are still no guidelines or cetacean bycatch mitigation requirements for longline fleets. The FAO has recently published voluntary technical guidelines on preventing and reducing marine mammal bycatch across all capture fisheries, providing current information on effective bycatch mitigation measures and tools to support countries in addressing marine mammal bycatch (FAO, 2021). This outlines current best practice approaches which IOTC could develop further.

Marine turtles

Retention

There is no evidence from data reported to IOTC that there is any retention of turtles in contravention of Resolution 12/04. Turtles are not reported in the nominal catches and the ROS data that has been published[20] reported the retention of 14 turtles, 13 of which were taken ashore for rehabilitation. Nevertheless, turtle meat consumption reportedly occurs in 75% of IOSEA[21] Signatory States, while trade in shell products seems to be predominant in East Asian countries (IOSEA, 2014). The direct exploitation of turtles is largely concentrated in the Coral Triangle region, which includes the waters of Indonesia, Malaysia and the Philippines, with much taking place in Indonesian waters, where in 2012, authorities warned that international

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[20] Source: IOTC-2020-WPEB16-DATA12

[21] Memorandum of Understanding on the Conservation and Management of Marine Turtles and their Habitats of the Indian Ocean and South-East Asia

trafficking of marine turtles was on the rise nationwide due to increasing demand from East Asia (IOSEA, 2014).

Directed illegal take of turtles has also been documented in the Western Indian Ocean, particularly in Kenya, Mozambique and Madagascar, where it has been reported to be particularly rife in southwest Madagascar, despite national prohibition. Poaching of turtles on a local scale is also encountered in many other countries (Jayathilaka, Perera and Haputhanthri, 2016). The main reasons for the continued targeting of marine turtles in the Indian Ocean were identified by IOSEA (2014) as socioeconomic (high price of turtle meat and demand for luxury items providing a high income or way out of poverty, nutritional value in the absence of affordable alternatives, poverty relief); cultural (traditional beliefs, specific taste preferences) and political (inadequate legislation and/or enforcement of existing regulations). Specific compliance issues identified in Sri Lanka which may also be typical of other countries in the region were: inadequate knowledge and skilled personnel for effective enforcement of the law, insufficient public awareness on the conservation status of marine turtles, inadequate legal, institutional and field level infrastructure (Jayathilaka, Perera and Haputhanthri, 2016).

In addition to the mortality of marine turtles from direct take, bycatch from unintended interactions with fishing gear is a substantial threat, which Resolution 12/04 seeks to address. For longline fisheries, while the current measure requires the possession and use of handling and release equipment, no measures to reduce or minimise interactions have been stipulated and legally binding requirements for longline fisheries to use best practices to mitigate against marine turtle bycatch are still needed (Gilman, 2011; WCPFC, 2017b). For purse seine fisheries there are more specific regulations to reduce interactions in the form of avoidance of setting on a turtle, to the extent practicable, and safe handling and release methods outlined, although the procedures by which the vessels should avoid encircling turtles have not been specified (Gilman, 2011). While gillnets have historically had very limited regulation at the regional level, a recent requirement (Res. 19/01) to set nets 2 m sub-surface has been introduced based on preliminary analyses indicating that turtle bycatch may be reduced by ~90 % (Moazaam and Nawaz, 2017). Visual deterrents, using net illumination through LEDs and chemical light sticks have also proved effective in some fisheries, with 40 - 60 % reductions in marine turtle bycatch (Wang, Fisler and Swimmer, 2010).

Discard survival

The mortality rate of turtles at the point of capture is generally very low. Estimates of AVM range from <1 % for both FAD and free school purse seine fisheries (Ruiz Gondra *et al.*, 2017) to 5 % (Bourjea *et al.*, 2014) in the Atlantic Ocean, with estimated rates slightly higher in the Indian Ocean, ranging from 4 % (Ruiz *et al.*, 2018) to 13 % (Bourjea *et al.*, 2014). For longliners, estimates of AVM mortality are similarly low, ranging from 0 % (Swimmer *et al.*, 2006) to 1.2 % (Chaloupka, Parker and Balazs, 2004) in the Pacific and 3.8 % in the Atlantic Ocean and Mediterranean (De Quevedo, Félix and Cardona, 2013), although sample sizes are lower and published estimates for the Indian Ocean were not found.

Little information is available on AVM of turtles in gillnet fisheries. A study on the capture of loggerhead turtles in Mediterranean Sea gillnets estimated AVM to be very high, at 69.5 %, however, soak times in this fishery were often extremely long, ranging from 1 - 5 days (Echwikhi et al., 2010), whereas in the Indian Ocean nets are generally soaked only overnight (Moazzam and Khan, 2019). A survey carried out for the Pakistani gillnet fleet estimated the

AVM rate at 10 % for marine turtles (Shahid *et al.*, 2015). As this study was carried out prior to the change in fleet behaviour to sub-surface setting, it might be useful to subsequently repeat the study to see whether the AVM rate has changed. While sub-surface setting appears to dramatically reduce entanglements, it is possible that there is a higher mortality associated with those turtles that do become entangled, as they are held lower in the water column and are less likely to be able to reach the surface to breathe, a phenomenon observed by Eckert and Lien (1999) in gillnet fisheries in Trinidad.

Post-release mortality is not well defined for any species of sea turtle and is variable depending on the type and extent of the injures due to the high variability among turtle handling methods after capture in fishing gear (e.g., if hooks are removed or not) (Swimmer and Gilman, 2014). For longline fisheries mortality rates have been estimated to be relatively high (28 %) in the Mediterranean/north Atlantic, although these fisheries typically have smaller hook sizes (De Quevedo, Félix and Cardona, 2013), 10 % to 19 % in the Atlantic (Sasso and Epperly, 2007; Swimmer and Gilman, 2014), 0 % for Olive Ridleys in the east Pacific Ocean (Swimmer et al., 2006), 28 % for loggerheads in the north Pacific ocean (Swimmer et al., 2014) and variable results for loggerheads in the Pacific, depending on whether lightly hooked (8 %) or more deeply hooked (34 %) (Chaloupka, Parker and Balazs, 2004). Nevertheless, other studies have found no data to support the hypothesis that deeper ingestion of the hook is more likely to result in mortality (Swimmer and Gilman, 2014). Hook removal has been observed to generally result in a lower PRM (Chaloupka, Parker and Balazs, 2004; Swimmer et al., 2006; Sasso and Epperly, 2007) whereas leaving hooks in place resulted in a higher mortality (Chaloupka, Parker and Balazs, 2004), but the presence of a line remaining in released turtles is most likely the single most crucial factor that determines a turtle’s fate after capture due to the internal injuries caused (De Quevedo, Félix and Cardona, 2013). Safe-handling best practices are extremely important, including the use of dip nets to bring turtles on board, hook removal or line cutters to cut line as close to the hook as possible (Swimmer and Gilman, 2014).

Gillnet fisheries in the Atlantic were observed to have a PRM of 28.6 %, however, these studies are all based on very small sample sizes (n < 27). In general studies suggested that, following capture, overall mortality appears to be higher in gillnet fisheries followed by longline fisheries, with rates lowest in purse seine fisheries (Casale, 2011; Wallace et al., 2013; Bourjea et al., 2014; Williams et al., 2018). Therefore, management efforts would benefit from prioritising the implementation and enforcement of mitigation measures, particularly for gillnet and longline fisheries (Williams et al., 2018).

Effectiveness of non-retention measures

Despite the lack of objectives for bycatch management in the IOTC Agreement, the IOTC has adopted a number of CMMs specifically developed for the management of non-target species, mainly centred on non-retention with some avoidance and mitigation measures. Retention bans may be effective in that they are very clear, relatively easy to enforce, can generate awareness of the vulnerable status of the species in question and they should prevent the development of target fisheries for the species. But results suggest that the current non-retention and other measures may have only a limited impact on overall mortality levels and a number of factors need to be considered to improve effectiveness. These are discussed below.

Consider the ecological and biological traits of species to design more effective CMMs

Differences in biological and ecological traits among species may lead to varied consequences when exposed to fishery stressors (Gallagher et al 2014). It is apparent that the reduction in mortality achieved is likely to vary by species, given that some species are more physiologically sensitive to capture-related stress (Hutchinson and Bigelow, 2019), and so the potential effects of retention bans should be explored on a species-specific basis. Results from this study suggest that for oceanic whitetips, the estimated reduction in mortality is likely to be greater than for bigeye threshers. Consideration of species-specific traits, particularly for species with particular biological and ecological characteristics that contribute to high AVM and PRM rates, may be useful in determining which management strategies offer the most effective conservation benefits in the future (Gallagher et al 2014).

Develop approaches to reduce AVM and PRM rates

Improving the survival of discards is a clear priority for increasing the impact of non-retention measures. Reducing AVM is not straightforward and may be very difficult to achieve. For longline and gillnet fisheries shorter soak times do not necessarily equate to shorter fight times, which are crucial for survival. For purse seine fisheries, measures such as releasing individuals prior to brailing result in less stress on the animals and associated with better condition for survival, however, this is not always possible (Grande et al 2019).

Opportunities for reducing PRM are greater, and efforts have focussed in recent years on determining which handling practices optimise survival across different species and gear types and increasing awareness of these. As an example, practices such as minimising the length of trailing gear left on release sharks has been found to be a significant factor in reducing the PRM of certain shark species, outweighing the negative effects of increased handling time (Anon, 2019; WCPFC, 2019). Issues such as this need to be explored quantitatively in order to improve best practice guidance.

Estimates of PRM are generally obtained through resource-intensive programmes involving pop-up archival satellite tags and so studies are necessarily limited. Nevertheless, AVM rates may provide information about species-specific sensitivities to fishing related stressors and so, in the absence of PRM estimates for a given species, it may be useful to consider at-vessel condition and survival as an indicator of post-release fate (Campana *et al.*, 2016; WCPFC, 2019). Recent meta-analyses of PRM data (Musyl and Gilman, 2019) also suggest that results are fairly consistent for a given species and condition across a number of factors such as regions and gear types, so pooling existing datasets globally may yield more effective and timely results.

Mitigation measures including gear technology best practices are needed to support the effectiveness of retention bans

Retention bans will not be effective without other, complementary, forms of management (Tolotti, Filmalter, *et al.*, 2015). While they may be more complex to investigate and implement, techniques that reduce fisheries interactions in the first place are likely to be the best strategy for protecting highly vulnerable species (Gallagher et al 2014). The development and implementation of alternative mitigation measures must be considered alongside retention bans to improve survival rates. There are a vast range of mitigation methods that are being investigated for different species and gear types (e.g. Tolotti, Bach, *et al.*, 2015; Hamilton and Baker, 2019; Gilman *et al.*, 2020), as well as trade-offs among some species that must be evaluated. Adequate attention and resourcing must be given to analysing the efficacy of these measures and methods of implementation. Most management measures fall short of current gear technology best practices (Gilman, 2011).

Consider exemptions from CMMs more closely

Results also indicate that the effect of fisheries which are exempt from the ban should be considered closely. For both oceanic whitetip and bigeye thresher sharks, over 50% of the catches were estimated to come from artisanal fisheries. This obviously had a substantial impact on the overall estimates of mortality reduction and indicates that closer review of the types of fisheries that are dependent on the various species and more specific exemptions for those most vulnerable (such as the subsistence fisheries described in Res. 19/03) could have a significant impact on the overall reduction in mortality achieved. This highlights the importance of developing finer scale classifications of the different types of fleets fishing within the 'artisanal' category. In addition to ensuring vessels >24 m fishing within the EEZ are not considered artisanal (WPICMM03, 2020), this may also include refining fleet classifications beyond vessels <24 m (WPDCS, 2019). Where exemptions comprise a particularly large proportion of the fleet, sustainability objectives may not be met and so may also undermine long-term social and economic objectives.

Bycatch CMMs have tended to focus on the impacts of purse seine fleets and there is currently a concerted effort underway to improve transparency and reduce the impacts of fishing in the PS fleets. While maintaining this progress for the purse seine fisheries, a renewed focus on the other fleets is also needed.

Performance standards would facilitate more effective review

Gilman et al., (2014) observed that RFMOs such as the IOTC which did not reference non-target catch management in their Agreement text had poorer bycatch performance. Nonetheless, IOTC is in the process of updating its Agreement text and drafts include impacts on associated species, including discards, so it is critical that this is included in the final adopted Agreement (IOTC-2019-TCPR02-03). Despite this, the IOTC has adopted a range of measures in relation to the minimisation and mitigation of the effects of fishing on bycatch species with vague conceptual objectives (Juan-Jordá et al., 2016). Most CMMs set a date for review, but clear operational objectives have not been defined (e.g. for target species MSY objectives exist, while for stocks certified by the MCS there are a number of closely defined objectives for P2 species such as not to hinder recovery of the population etc) and hence evaluation of the effectiveness of these measures is not straightforward.

CMMs are generally lacking performance standards which they can be evaluated against, which hinders any analysis of the efficacy of the measures. None of the management measures adopted for bycatch species have been linked to pre-established operational objectives and associated indicators which can be activated when thresholds are exceeded, as has been undertaken for dolphin species in the IATTC. Examples might be catch rates or catch levels that could be compared before and after implementation of a management measure. In a cross-tRFMO review of ecosystem based management by (Juan-Jordá et al., 2016), the IOTC was criticised for the lack of any progress on reference points which would ideally be included in CMMs for all bycatch taxa.

A precautionary approach is advisable

Findings regarding uptake of non-retention management measures at a national level suggests that consideration should be given to factors such as incomplete uptake due to delayed enactment and low enforcement by some CPCs. Given that many of these issues cannot be easily or rapidly addressed and are likely to continue regardless of the specific type of management approach, it is even more critical that a precautionary approach is taken to accommodate these factors. The principles of Resolution 12/01[22] should be applied in the development of bycatch CMMs, specifically regarding the uncertainty related to the effects of fishing activities on non-target and associated or dependent species where factors such as the AVM, PRM, incomplete and delayed uptake of regulations should be taken into consideration.

Summary of mortality reduction recommendations

- *The differing ecological and biological traits of species need to be considered to design more effective CMMs*
- *Approaches to reduce PRM need to be developed for all gear types*
- *Mitigation measures including gear technology best practices are needed to support the effectiveness of retention bans*
- *Exemptions from CMMs should be considered more closely*
- *Performance standards would facilitate more effective review of CMMs*
- *A precautionary approach is advisable*

CMM data and research/assessment-related objectives

This section reviews the progress made in achieving the objectives of the Commission with respect to improvements in data quality and research-related objectives as indicated in bycatch CMMs.

Data and monitoring requirements

Each of the CMMs regarding a particular bycatch species of concern seek to improve data collection and reporting and so include some form of data monitoring requirements, generally focussing on the reporting of numbers interactions (Table 11). Though as these CMMs were typically developed in isolation and at different points in time, there is a lack of coherence and numerous inconsistences in data requirements among CMMs. In some cases this has resulted in gaps in data requirements.

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[22] Paragraph 3 of Resolution 12/01, *On the implementation of the precautionary approach*: *"In the determination of appropriate reference points and harvest control rules, consideration must be given to major uncertainties, including the uncertainty about the status of the stocks relative to the reference points, uncertainty about biological, environmental and socio-economic events and the effects of fishing activities on non-target and associated or dependent species".*

For turtles, the reporting of total estimated annual interactions of fleets is explicitly required[23], however, for other species such as cetaceans or seabirds there are no requirements for reported interactions to be total enumerations or pre-extrapolated totals[24]. This results in what little discard data are reported to the IOTC for these species groups being of limited use, given that they are not accompanied by effort (IOTC, 2015). This is particularly important because much of the data on discards reported to IOTC (through Form_1DI) does not contain detailed information on associated coverage or effort so requires data to be total enumerations or pre-estimated totals. While not covered here, the same is also true for seabirds.

In most other cases where there have been gaps in reporting requirements (e.g. where data reporting has been described as non-mandatory[25,26]) these have generally been addressed through the subsequent adoption of data-related CMMs, primarily 15/01 and 15/02. Nevertheless, the inconsistencies remain, often resulting in some confusion regarding the exact requirements (e.g. WWF, 2020).

Species-level reporting is not required for turtles (12/04), mobulids (19/03), cetaceans (13/04)[27], threshers, makos and hammerheads for total annual interaction estimates. Nevertheless, all species are to be identified as far as possible in observer data so the lack of species-level data reporting requirements is not an issue for fleets with good coverage and reporting programmes, but for the fleets with limited observer coverage there may be poor species-level information based on the current resolutions. Table 11 summarises the main IOTC data collection and reporting requirements for bycatch species.

Data and monitoring issues

Overall, the data monitoring and reporting requirements for bycatch species are relatively comprehensive, however, the reality in terms of the data actually reported to IOTC has been extremely poor, and although it is improving in some areas, it remains very limited for bycatch species.

For sharks, the biggest problem is unreported catches. Historical catches are thought to be grossly under-reported by most fleets due to a lack of collection of fishery statistics in earlier years. Reporting requirements have increased year on year, resulting in more data, but making evaluation of trends over time difficult. There are also a number of fleets which are still not reporting on their interactions with bycatch species, despite fleets using similar gears reporting high catch rates of bycatch. even though nominal catches comprise the most comprehensive dataset held by the IOTC, they are still considered incomplete, to the extent that the time series have been regarded as inadequate to even attempt stock assessments for both oceanic whitetip and threshers in recent years. Non-retention measures render the nominal

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[23] *"The data shall include the level of logbook or observer coverage and an estimation of total mortality of marine turtles incidentally caught in their fisheries". IOTC Res. 12/04*

[24] As required by reporting Form_1DI

[25] Data reporting for whale sharks and cetaceans are described as non-mandatory for fisheries with national legislation protecting them, however, subsequent CMMs on data collection (15/01) and reporting (15/02) for all species include both whale sharks and cetaceans in their mandatory reporting requirements (Table 3).

[26] For oceanic whitetip and thresher sharks, reporting of interactions is merely "encouraged" in these Resolutions, however, all shark species included in this review (including whale sharks and mobulids) are subject to Res. 15/02 which requires estimates of total annual interactions (catches and discards).

[27] species identifications are to be reported to the flag state, not to IOTC (Res. 13/04)

catch database even less complete which has serious consequences for evaluating the status of the stocks.

Compliance with data monitoring and reporting is low, generally due to limited resources in many of the developing coastal nations which have fleets made up of numerous small-scale vessels, presenting further challenges to monitoring. Hence, for blue sharks a CMM was developed to try and encourage reporting according to the requirements already in place, as well as further encouraging research efforts (18/02). For species other than the most commonly caught sharks, data reporting is extremely poor, sparse and unstandardised; not conducive to supporting regional level analyses. Non-retention measures render the nominal catch database even less complete which has serious consequences for evaluating the status of the stocks and makes observer data even more crucial. A summary of the main reporting issues by data type as presented to the WPEB in 2020 are provided in Table 11.

Priorities areas for data improvements

Sharks

Data mining to reconstruct historical catch data

An accurate catch trend is critically important to stock assessments and is known to be poor for most shark species, generally dominated by reporting from just one or two countries (IOTC, 2020c). A data mining exercise is important to improve historical time series for the most important shark species, as recommended by the SC in 2019 (IOTC, 2019c).

Improve species identification

The proportion of unidentified shark catch has reduced in recent years, however, in 2019 30 % of sharks catches were still reported as unidentified sharks, and the accuracy is generally unknown, so species identification is regarded as a high priority by the SC (WPEB, 2020). Methods to improve identification include regional training workshops and the development of alternative tools to assist identification such as genetic analyses, machine learning approaches and artificial intelligence have been recommended by the SC in 2019 (IOTC, 2019c). An approach which has proved successful at IATTC involves the use of identification keys to identify characteristics, stopping short of identifying the species. This type of approach may prevent ‘observer bias’ which can occur when an incorrect species identification has inadvertently been learned. Given that a number of initiatives have taken place and there are a number of options, it has been proposed that speaking to data providers directly to ascertain the type of assistance required is likely to yield the most effective support (Clarke, 2018).

Improve consistency among data requirements in bycatch CMMs

Improved clarity and consistency when developing future CMMs for bycatch species would likely result in improvements to data reporting. A simple solution may be for species-specific CMMs to remove data requirements and simply refer to the general data collection and reporting resolutions (15/01 and 15/02, and any subsequent iterations of these) and for these to include the requirement for total estimates of discards. Reference to the observer scheme (Res.11/04) is also important.

Review and update the list of bycatch species in Res. 15/01

Several species groups are not required to be identified to species level, despite encompassing species with different life history characteristics and threat statuses (Table 3), e.g. the thresher sharks. Management efforts to conserve these taxa need information at the species level for the development of indicators and stock assessments. Therefore, the addition of species to Res. 15/01, specifically separation of the makos, thresher and hammerhead sharks as well as for mobulids (while leaving the aggregate grouping codes available) should improve data for assessments. This was discussed at the SC in 2018 following the report by Clarke (2018). Silky sharks are notably absent from the list of species in Res.15/01 to be reported by gillnet fisheries (Table 3), however, studies suggest that gillnets are the primary fishery catching silky sharks (Garcia and Herrera, 2018) and comprise a quarter of shark captures for some fleets (Shahid *et al.*, 2015). This may be an important species addition to the list for gillnet fisheries in Res.15/01.

Improve awareness and clarity regarding discard reporting requirements

The patchy use of IOTC discard reporting forms and highly incomplete catches arising suggest a lack of clarity that total annual estimates of discards are required by fleets for bycatch, as for nominal catches. Any raising that takes place is ideally undertaken nationally by those with a comprehensive knowledge of the fisheries and specific factors affecting fleet bycatch, rather than regionally where inappropriate proxies and extrapolations may be made. Previous suggestions of updating the discard reporting form introducing further information on season and spatial information as with catch-and-effort data (discussed at WPEB13 in 2017) are likely to worsen reporting (catch-and-effort reporting is poor for artisanal fleets) when simplification may be preferable to obtain increased accuracy over precision. Given that observer data requires a high level of detail, a simpler, coarser, but more complete dataset from discards reporting forms from logbook data should provide a complementary dataset. Discard reporting is critically important for obtaining an estimate of overall interactions. Discard data are due to be included in the next assessment of blue shark to improve estimates of total catch (Rice, 2017b).

Support the collection of biological information

Biological information including size frequencies and conversion factors between different length and weight measurements are important for standardising and collating datasets. This should be supported and encouraged as part of routine operations (Clarke, 2018).

Cetaceans

Data reporting on cetacean interactions has been extremely limited, and even basic information on cetacean distributions and fisheries overlap are lacking. Some observer data has recently been made available, all from longline fleets and centred on depredation (IOTC, 2020c) and some information has been published on the Spanish purse seine fisheries (Ruiz et al., 2018) and Pakistani gillnet fisheries (Kiszka *et al.*, 2009), but most officially reported data are severe underestimates (Anderson *et al.*, 2020) and more systematic and comprehensive data collection efforts are required (Kiszka *et al.*, 2017). Cetaceans have previously been considered to be a lower priority than sharks, seabirds and turtles for the Scientific Committee, however, this seems to be primarily due to a lack of information resulting in limited attention. Data have been improving for the purse seine fleets due to the increasing level of observer coverage and priority area for data improvements recommended by the SC have focussed on the longline and gillnet fisheries (Table 12).

Turtles

Data reporting for turtles has historically been very limited, but some observer data are now available, primarily from the small-scale WIO longline and purse seine fleets (IOTC, 2020c). Improved reporting of marine turtle interactions is needed across all fisheries to identify factors that contribute to higher interaction and mortality rates. This information is essential to underpin the development and implementation of effective mitigation strategies for turtles (Williams et al., 2018). Priority fleets for the provision of total catch estimates identified by the SC in 2010 are listed in Table 13. The addition of turtle species to the species lists in Res. 15/01 may also improve species-specific reporting, while leaving the aggregate taxon grouping code available for where it has not been possible to identify to species level.

Observer data

Non-retention measures may have negative consequences for data collection undertaken by enumerators at landing sites, therefore observer data is even more vital since the adoption of these measures.

Support the development of observer programmes

There are huge gaps in observer data, and while the overall coverage is currently 2.15 %, this is primarily due to the recent high coverage by EU purse seine vessels and remains non-existent for gillnets fleets and the artisanal sector (IOTC, 2020d). A key priority remains to support the fleets identified as most important in terms of gaps in bycatch information (i.e. the major gillnet fleets) in developing an observer scheme as a priority (e.g. Iran, Indonesia, India, Sri Lanka). While initiating an observer programme can be a challenging task, the IOTC Pilot Project has the ability to support the establishment of a programme, however, in some CPCs the project has failed to start, due the administrative, legislative, human resources, technical and financial burdens associated with establishing an observer programme. In these cases, communication must continue to explore how progress can be achieved.

Expand observer coverage in existing programmes

There are some CPCs that have been making good progress in establishing observer programmes but for which activities are still very small scale relative to the size of the fleet such as Sri Lanka (0.39% coverage of longline fleet in 2018) and Indonesia (0.55% coverage of the longline fleet in 2018). Support for these CPCs to expand the current programmes to a greater number of vessels and to other gear types, notably gillnets, is important. Resources should deliver results quickly given that the institutional infrastructure is already well developed and many of the issues with getting a programme up and running and off the ground have already been overcome. For bycatch species, programmes should aim for observer coverage ≥ 20% as agreed by the SC (IOTC, 2010).

Develop finer-scale classifications of artisanal fisheries

While the working IOTC definition of artisanal (or ‘coastal’) fisheries is being tightened (WPICMM03, 2020), further work is needed to develop appropriate working classifications of fleets within these fisheries. This would enable finer-scale reporting and a better understanding of the bycatch issues specific to each fleet segment. This might be done based on vessel length, such as re-classifying vessels into categories so that those 20 – 24 m, which are often semi-industrial, are subject to greater onboard monitoring requirements (WPDCS, 2019), or other traditionally used vessel characteristics such as the level of mechanisation, or fishery characteristics, such as area fished. Nevertheless, there are many issues with such classifications based on a limited set of quantitative metrics which tend to allow large-scale vessels to be included in the small-scale fleet or exclude fishers that should be considered small-scale. An alternative approach may be to use a matrix-based method including a range of quantitative and qualitative descriptors with scores that can be summed and classifications made based on overall cut-offs (FAO, 2020). This may result in substantial data gains and increased understanding of the impacts of small-scale fleets.

Support alternative means of data collection

Due to the difficulties with placing independent scientific human observers onboard vessels of fleets with vast numbers of small vessels, there has been substantial discussion by the SC around alternative means of collecting observer quality data. This has centred around (i) Electronic Monitoring Schemes, (ii) crew-based/self-sampling data collection and (iii) port sampling. These development of these ideas complementary forms of data collection have been encouraged by the SC for some time (IOTC, 2010). (IOTC, 2019b). Similar to the standards adopted for human onboard observer schemes (IOTC, 2019a), standards need to be adopted for EMS and work is ongoing. There is also a need to continue comparative studies between EMS and onboard human observer data to identify and address issues such as systematic bias in bycatch estimates (Briand *et al.*, 2017). While new port sampling schemes could also help to fill in the gaps where other forms of onboard data collection are not possible, this has been discussed in various IOTC working parties for a number of years and a scoping study, ideally developed by a CPC/s, is needed to define a clear project is needed, particularly given that this proposal has apparently a high level of support from CPCs (IOTC, 2019b).

Improve ROS data reporting to IOTC

Of the ROS data reported to the IOTC, 32 % have not been included in the database due to the unstandardised nature of the information (IOTC, 2020d). It is critical that data are not only reported to the IOTC in a timely manner, but also provided in an approved electronic format[28], to ensure it can be included in the Regional Observer Database. This is also true for data collected by alternative means, some of which is still not incorporated in the IOTC Regional Database (IOTC, 2019b).

Begin preliminary analyses of the existing published information

While the regional-level observer information published to-date remains in a preliminary state as the scheme progresses, CPC scientists can nevertheless begin to use this in a preliminary way (Martin, 2020a; IOTC, 2021). This will progress the process of identification of errors and anomalies as well as further highlighting missing information which will catalyse discussion, review of priority areas of focus and encourage further improvements by CPC data providers and the IOTC Secretariat.

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[28] As specified in the Regional Observer Scheme draft programme standards (IOTC–2019–S23–10_Rev1[E])

Summary of data recommendations

- *Data mining to reconstruct historical catch data*
- *Improve species identification*
- *Increase consistency in CMMs*
- *Review and update the list of bycatch species in Res. 15/01*
- *Improve awareness and clarity regarding discard reporting requirement*
- *Support the collection of biological information*
- *Support the development of observer programmes*
- *Expand observer coverage in existing programmes*
- *Develop finer-scale classifications of artisanal fisheries*
- *Support alternative means of data collection*
- *Improve ROS data reporting to IOTC*
- *Begin preliminary analyses of the existing published information*

Priority areas for research

Sharks

Stock structure determination

Determining the stock structure of selected shark species is considered to be one of the top priorities for the SC. Stock assessments carried out for shark species have assumed that there is a single stock for the entire Indian Ocean, distinct from Atlantic and Pacific stocks, however, this is currently an assumption and preliminary genetic research for blue sharks suggests some connectivity may exist, although sample sizes need to be increased in more locations to further evaluate genetic clusters (Davies *et al.*, 2020).

Evaluation of PRM rates through tagging

With retention bans as the main approach for species of conservation concern, determining the AVM rates of these species through observer programmes and PRM rates through tagging experiments is an important part of evaluating the effectiveness of the measures. Priority species-gear for tagging identified in the SC programme of work are: blue sharks[29] in longline fisheries, mobulids[30] in gillnet and purse seine fisheries and whale sharks, to evaluate connectivity and movement rates as well as mortality estimates.

Given the high cost of these studies and time taken to implement when rare bycatch events, it is important to harmonise methods with studies globally so that joint analyses can be undertaken to develop best practices for safe release. Recommendations from an expert workshop help in the Pacific highlighted the importance of collecting data on a) handling practices and release methods, b) condition at haulback and condition at release (and standardisation of condition codes among studies); c) shark length; d) length of trailing gear; e) gangion material; and f) hooking location and hook type (WCPFC, 2019).

Improved biological and ecological information

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[29] Resolution 18/02

[30] Resolution 19/03

Improving biological parameters for stock assessment is also a top priority research item for the SC. Blue, shortfin mako, oceanic whitetip and silky sharks have been identified as the highest priority species for research into age, growth and reproduction by the SC while the identification of potential nursery areas for oceanic whitetip and thresher sharks has been called for by the Commission.[31] Acknowledging the vital nature of good biological data for stock assessments, the IOTC initiated a research programme called “The Shark Year Programme” in 2013 which developed some momentum in research efforts for shark species. It was recently recommended that the Shark Year Plan is revisited, updated and revised based on the current status of information and data needs with the aim to develop new projects, source funding and continue to build on the framework in place (Clarke, 2018). This type of initiative seems particularly pertinent ahead of an ambitious stock assessment schedule for the next few years (IOTC, 2020b, Appendix 36).

Mitigation measures

Few measures to mitigate against interactions with bycatch species have been applied in the Indian Ocean and this is a substantial area for research. (Gilman, 2011) provided a set of criteria required that an ideal bycatch mitigation method would meet: effective in reducing unwanted catches to nominal levels, practical, safe, economically viable, require minimal alteration to traditional gear, tolerant of crew behaviour, easy to monitor and enforce, incorporate measurable performance standards and will not cause increased bycatch of another species. This sets a high bar for performance for mitigation measures and hence there has been extensive research into the topic.

The priority shark species for bycatch mitigation measures is currently the blue shark[32], following its assessment. Research needs identified for longline fleets include assessment of the effects of hook type, bait type and trace materials on shark catch rates, hooking mortality, bite-offs and fishing yields (socio-economics). Research needs for gillnets includes assessment of the effect of mesh size, hanging ratio and net twine on shark and ray catch composition (i.e. species and size), and fishing yields (socio-economics) (IOTC, 2019b). Gear technology mitigation methods have also not been explored extensively for mobulids and more research is needed in this area (Stewart et al., 2018; Martin, 2020a).

Improved CPUE

The development of standardised CPUE series is crucial for use as indicators and input to stock assessments. Priority species identified by the WPEB include blue shark, shortfin mako, oceanic whitetip and silky sharks.

Given the conflicting CPUE series resulted in one of the major sources of uncertainty in the blue shark and shortfin mako stock assessments, the development of a joint CPUE for longline fleets based on detailed operational level data is a research priority. A collaborative workshop to develop a new combined series for blue sharks would be beneficial ahead of the next assessment.

Reference points

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[31] Resolutions 12/09 and 13/06

[32] Resolution 18/02

In the absence of any formal reference points, shark stocks have been assessed against B_{MSY} and F_{MSY} target reference points, however, no limit reference points have been defined by the IOTC for any shark species. This is important as more data become available and stock assessments are increasingly carried out. In recognition of this the Commission has requested the SC to provide advice on candidate limit, threshold and target ref points for blue sharks[33].

Reconstructed catch series

Uncertainty in the nominal catch series were identified as key sources of uncertainty in both the shortfin mako and blue shark stock assessments. Ahead of the blue shark assessment, reported catches in the IOTC database were not considered to be reliable and so a range of alternate catch series were developed using a variety of different estimation methods (trade data, ratio estimator and gam estimator) (Rice, 2017b). It is important that catch reconstructions are carried out for other species ahead of assessments and that these estimates are revised ahead of the next blue shark assessment.

Cetaceans

It has been suggested that cetaceans have received disproportionately little attention by the IOTC in previous years, compared with other bycatch taxa given the scale of the threats (Kiszka *et al.*, 2017; IWC, 2019; Elliott, 2020). Indeed, a stock status summary for the taxa containing management advice and a programme of work has only been included in the Scientific Committee annual reports since 2017. Recent support from the IWC and US Marine Mammal Commission in improving scientific capacity related to cetaceans has assisted in promoting cetaceans on the management agenda (IOTC-WPEB, 2017). The IOTC has recently become a high priority for the IWC and while the IWC does not have regulatory influence over small cetaceans, it can provide technical advice and could support the IOTC and its member states with data collection and monitoring. Greater awareness of cetacean bycatch and the urgent need to address it is needed within RFMOs and national governments in the region (IWC, 2019).

Ecological Risk Assessment

Past research efforts have been fairly focused on depredation rates and less regarding interactions, hooking or entanglement of marine mammals with longline or other gear, primarily due to a lack of information. This lack of information meant that cetacean research has historically featured less at the IOTC, however, recent studies on purse seine and gillnet fisheries, however, have looked at interaction rates, mortalities and estimations of total catches for these fleets. The main priority for this species group now is to carry out an ocean wide Ecological Risk Assessment, covering all of the major fleets. A major collaborative effort will be necessary to do the data mining necessary to inform the assessment and the involvement of international bodies such as the IWC will be important to this (WPEB, 2020).

Best practice handling and release guidelines

While substantial research has been undertaken to develop best practice handling and release guidelines which have recently been endorsed by the IWC, these have yet to be recommended to the SC and adopted formally by the IOTC (WPEB, 2020), despite this being a direct requested from the Commission[34]. Nevertheless, the IOTC and IWC are forming a sub-working

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[33] Resolution 18/02

[34] Resolution 13/04

group dedicated to discussing cetaceans to better understand the levels of bycatch in the Indian Ocean, potential mitigation measures and methods for overcoming data deficiencies (IOTC, 2020b).

Turtles

Ecological Risk Assessment

Research efforts on turtles have focussed on risk assessments which assess the relative risk of longline, purse seine and gillnet fisheries (Nel et al., 2013; Williams et al., 2018). An improvement to these would be the application of a risk assessment model that quantifies the cumulative impacts of multiple fisheries and reports the vulnerability status against recognised biological reference points (e.g. BMSY, FMSY) (e.g. EASI-Fish, Griffiths et al. 2018) (WPEB, 2018).

Mitigation measures

Although Resolution 12/04 requires annual evaluation by the SC, very little progress has been made regarding this request in terms of updating best practice advice and recommendations for improvements. Measures that have proved to be successful in the Pacific for mitigating interactions and mortalities in longline fisheries include the use of large circle hooks[35], finfish bait and the removal of the first and/or second hooks next to the floats (WCPFC, 2017b). While the WPEB agreed to consider these in the Indian Ocean, they could also be implemented as a precautionary measure and evaluated to explore any regional/fleet differences in effects on target or other bycatch species (WPEB14, 2018). A workshop to evaluate the results of the mitigation measure as part of a regional analysis for the Indian Ocean would be beneficial and has been recommended by the SC, but requires resourcing (SC20).

PRM

AVM rates are generally low across all gear types which is promising for the success of the conservation measure. A number of PRM studies have been conducted for longline fleets in the Pacific and Atlantic (Table 9) but there have been few evaluations of PRM for purse seine and gillnet fisheries, so this remains a priority area of work for the WPEB (WPEB, 2020).

Summary

Different bycatch taxa have received varied levels of attention by the IOTC, often due to the amount of data available at the time, and limited time available to provide advice, given the broad remit of the WPEB. In general, shark species have received more attention than other taxa, with the clear focus being species for which there is a sufficient level of information to undertake an integrated stock assessment. Risk assessments to compare relative threats across different gear types have been conducted for the remaining shark species and turtles, while mobulids and cetaceans have had considerably less attention until very recently. A summary of key research recommendations is provided below.

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[35] to reduce mortality of turtles that are hooked, not necessarily reduce the capture of turtles

Summary of research recommendations

- *Stock structure determination for key shark species*
- *Evaluation of post-release mortality rates through tagging*
- *Improve biological and ecological information*
- *Develop and trial mitigation measures*
- *Improve CPUE and work towards joint analysis*
- *Developed appropriate reference points*
- *Reconstruct historical catch series ahead of assessments*
- *Conduct an ERA for cetaceans*
- *Consider best practice handling and release guidelines for cetaceans*
- *Conduct a quantitative ERA for turtles*

Ecosystem considerations

Cross taxa solutions

Different bycatch taxa have received varied levels of attention by the IOTC, often due to the amount of data available at the time, and limited time available to provide advice, given the broad remit of the WPEB. In general, shark species have received more attention than other taxa, with the clear focus being species for which there is a sufficient level of information to undertake an integrated stock assessment. Risk assessments to compare relative threats across different gear types have been conducted for the remaining shark species and turtles, while mobulids and cetaceans have had considerably less attention until very recently. While bycatch CMMs and associated research have often taken a single species approach to management, bycatch reduction efforts clearly need to apply multi-taxa approaches, focussing on cumulative impacts to avoid simply transferring the problem to another species group and address both the species- and ecosystem-level effects of bycatch (Lewison *et al.,* 2014).

In reviews comparing the performance of IOTC with other tRFMOs in terms of ecosystem management and bycatch governance, beyond the main target species of the Commission, it has not fared particularly well (Gilman, Passfield and Nakamura, 2014; Juan-Jordá et al., 2016; Elliott, 2020). In a review by (Elliott, 2020), the IOTC ranked poorly in terms of the management of cetaceans bycatch risks compared with other tRFMOs primarily due to its prevalent use of gillnets compared with any other RFMO, the gear type believed to be most high-risk gear for cetaceans (Brownell et al., 2019), and the limited data and management of these fisheries.

In terms of the mortality inflicted through entanglement with FADs, there are now restrictions on the total numbers of FADs that may be used (Resolution 19/02) and the requirement for all FADs to be non-entangling and biodegradable by 2022[36]. While the non-entangling and biodegradable requirements demonstrate clear progress in reducing ecosystem impacts, how meaningful the total limits are is unclear. Estimations of the number of FADs in use suggest it is unlikely that many vessels deploy a number above the upper limit (Maufroy *et al.*, 2014). In addition, it has been suggested that skippers in some fleets (e.g. Spain) share FADs which may

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[36] IOTC Resolution 19/02 Procedures on a Fish Aggregating Devices (FAD) management plant

allow them access to a greater number of FADs that the limit (Moreno et al., 2007) (MRAG, 2017). Nevertheless, the limit has been lowered year on year since the introduction of the measure (originally set at a maximum number of operational buoys followed by any purse seine vessel at any one time as 550 FADs, currently at 300), presumably in recognition of the fact that the initial level was unlikely to cause any change, but it paves the way for future conservative action and may halt the increasing trend (Maufroy *et al.*, 2014).

The gillnet fisheries in the Indian Ocean emerge from this review as a cross-cutting issue across all bycatch taxa (Aranda, 2017). The prevalence of gillnet fisheries and associated high risks for sensitive species (Gillett, 2011), the expanding fleet size, extensive length of nets, long soak times (Moazzam and Khan, 2019) extremely poor information, limited observer coverage, limited management measures in place and contravention of measures that there are (Khan, 2020) combine to form a very serious threat to bycatch.

The IOTC has recently started to attempt to address these issues. In 2017 the IOTC implemented a ban on the use of large scale (>2.5km) driftnets on the high seas[37], and in 2022 this is due to be extended to the entire Area of Competence, including EEZs (Res.17/07). Since then, the Commission introduced the mandatory sub-surface (2 m) setting of gillnets, to be fully implemented by 2023 (Res.19/01). Two further actions were also introduced at this time: (i) the phasing out of gillnets or conversion to other gear types, and (ii) an increase in observer coverage, or field sampling, to 10 %, using alternative data collection methodologies (Res.19/01). Both of these were introduced as non-mandatory measures.

Preliminary results suggest that the modification to sub-surface gillnetting appears to be effective in dramatically reducing bycatch rates across a range of taxa including cetaceans, turtles and sharks, however the results are still preliminary and undergoing fuller evaluation to explore issues such as potential effects on other species including mobulids and whale sharks, and changes in species composition of shark catches, noting that interactions with makos have been reported to be higher with sub-surface setting (Moazzam, 2019). The lengthy (4 years) timescale for implementation of sub-surface gillnetting agreed by the Commission suggests there may also potentially be some resistance to the practice which needs exploring further. As with the retention bans, incorporation of gear restrictions into national legislation is needed by most CPCs for there to be legal provision for the measures. This again is not always the case; as an example no gear restrictions have been enacted for tuna gillnet fisheries in Pakistan so as a result there are no limits to total length of nets despite AIS data confirming that these fisheries extend to the high seas (WWF, 2020). It has been suggested that the phasing out of gillnets over the longer term and replacement with alternative fishing gear methods may be the only real long-term solution (Brownell et al., 2019), however, for the IOTC a combination of approaches may prove more successful in achieving both socio-economic and ecological objectives.

Socio-economic considerations

If the IOTC is to fully transition to a more ecosystem-based fisheries management approach, consideration needs to be taken not only of the biological and ecological consequences of fishing, but also the social and economic implications of management interventions. The importance of these considerations is well understood as Article V of the IOTC Agreement

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[37] IOTC Resolution 12/12 To prohibit the use of large-scale driftnets on the high seas in the IOTC Area

clearly mandates to the Commission to keep the economic and social aspects of the fisheries under review, being particularly mindful of the interests of developing coastal states (IOTC, 1993). Baseline economic and social data are needed to provide a better understanding of the current level and nature of dependency on fishing among CPCs, and among fleets within CPCs. With better information on these factors, research into potential bycatch mitigation measures can incorporate the differential social and economic impacts of management and allow these aspects to be incorporated into management decisions.

While the importance of social and economic considerations is explicitly acknowledged for target stock and discussions surrounding quota allocations and have led to increased focus in recent years[38], these issues also likely to be pertinent for bycatch species. Industrial vessels are often associated with issues such as high grading and discarding of unwanted catch, whereas small-scale fleets are well known for their high utilisation of catches, to the point that there is often considered to be very little actual ‘bycatch’, but rather it constitutes a multispecies fishery. This is, nevertheless, still a cause for concern when fishing is at a level which is considered to be unsustainable for particular populations, of which marine megafauna are particularly susceptible. Yet it means that the economic and social burden of a bycatch CMM may fall disproportionately on developing coastal nations with small-scale fisheries[39] and therefore needs due deliberation and discussion as part of the management process so that optimal solutions across a range of criteria (not only ecological) may be sought (e.g. payments for ecosystem services as compensation; subsidies for alternative gear).

The current status of economic and social data collection by CPCs is patchy and inconsistent and the IOTC is currently working towards establishing a basic set of priority data. These data are increasingly being recognised as necessary for successful ecosystem-based fisheries management and other RFMOs are increasingly collecting economic and social data which is proving useful in the decision-making process. Yet the process is proving slow as obtaining this information presents an additional administrative and financial burden on CPCs, and regional level analysis and interpretation of the data requires resourcing before it can being to be used in forming policy (Macfadyen and Defaux, 2019).

The social and economic considerations are complex and have primarily been dealt with through exemptions to-date. While the initial rationale for these exemptions seems obvious, in practice their broad-brush nature of implementation means the management measures are probably not able to achieve the level of reduction in mortality required for recovery of impacted populations and to achieve sustainability of the stocks[40]. To this end, social and economic factors must be considered in the long-term as well as the short-term.

The inconsistency in the nature of exemptions applied among the various CMMs is further indicative of the limited analysis that has gone into these aspects. Finer-scale identification of the most vulnerable groups who need to be made exempt from legislation[41] while ensuring that the more capable majority adhere to them may enable the measures to have a meaningful impact on stock recoveries, and ultimately, sustainable livelihoods.

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[38] Resolution 18/09

[39] SDG10 commits Member states to “Reduce inequality within and among countries”

[40] SDG12 commits Member states to “Ensure sustainable consumption and production patterns”

[41] SDG1 commits Member states to “Goal 1 End poverty in all its forms everywhere”

In light of UN Sustainable Development Goal[42] regarding food security, retention bans may be considered as the antithesis of this as it promotes the discarding of dead, as well as live, individuals. This perceived notion of wastefulness has been identified by some coastal CPC fishers and can result in a reluctance to adhere to bans (Rice, 2017a), however, from a compliance perspective, allowing landings of any species with a retention ban could prove very difficult to enforce in practice. Nevertheless, the concept has been introduced for mobulids in Res. 19/03[43], so it will be interesting to see how this eventuates and, if successful, whether the same approach can be applied to other species.

It has been postulated that prohibitions on the retention of species with generally low survival rates may not substantially reduce bycatch mortality, but might have the effect of reducing social or economic benefits (Beerkircher, Cortés and Shivji, 2002). In light of this, an alternative way to improve the utilisation of fish that are already dead upon haulback may be to evaluate the potential effects of including shark species not subject to a retention ban to the discard ban in Res.19/05. However, this would be need to be investigated further as silky sharks are the primary shark species caught in purse seine fleets and are considered vulnerable (Rigby *et al.*, 2017; Murua *et al.*, 2018). Nevertheless, results from AVM and PRM studies indicate that survival is likely already low and mitigation measures used prior to brailing are likely to be more effective in reducing mortality. Increased focus on effective mitigation measures might allow greater consideration of measures such as discard bans to enable biological and socio-economic objectives to be met.

Summary of ecosystem recommendations

- *Solutions need to be effective across all taxa*
- *Review of the economic and social impacts of bycatch regulations in small-scale fisheries is needed to determine the scale of impacts*
- *Solutions to mitigate disproportionate impacts on small-scale fisheries need to be explored in more detail alongside exemptions*
- *Long-term social and economic solutions are needed that meet ecological sustainability objectives*

Approaches to management

Squires et al., (2021) categorised the approaches to bycatch management as involving (1) private voluntary solutions such as moral suasion and intrinsic motivation; (2) direct or “command-and-control” (3) incentive- or market-based to alter producer and consumer behaviour and decision-making; and (4) a hybrid of approaches.

Regional level management is typically centred around top-down direct regulation starting with the fisheries management authority down to the vessel. Direct management can be achieved

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[42] SDG2 commits Member states to “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”

[43] “Mobulid rays surrendered in this manner may not be sold or bartered but may be donated for purposes of domestic human consumption”.

through technology, process, and performance standards. Technology developments such as mitigation measures are input controls that can be effective, but they tend to remove incentives for fishery operators to find other ways to reduce bycatch and are often not updated regularly enough as technology developments advance and best practices change. Process standards are also input controls that limit fishing effort such as through time-area closures, vessel trip or size limits. Performance standards require vessels to meet a standard, eg a bycatch quota or rate (differentiated by vessels as appropriate), while allowing vessels to choose any appropriate method to meet that standard. These tend to create stronger and more direct incentives and so might improve the effectiveness of bycatch management, but they may also be more difficult and costly to implement (Squires et al., 2021). The IOTC has applied process standards in the past, e.g., through the implementation of a time-area closure, but has tended to focus more on technology developments though has not regularly updated these to meet current best practice. Investigating potential management methods through the use of performance standards may create stronger incentives and improve the effectiveness of bycatch management.

Market based measures have also been used by some fleets in the IOTC who have adopted or are pursuing MSC certification. Market-based methods can create similarly strong and effective incentives for bycatch reduction, however, they are primarily suited to fleets which have a market to a country where a price premium will be gained, often involving an export market. For many of the artisanal fisheries in the IOTC which have predominantly domestic markets this is approach is less feasible and bycatch policy may do better to focus on intrinsic motivation. Intrinsic motivation includes social and personal norms of conservation and altruism for their own sake rather than the desire for an external reward and may traditionally be in place in many fisheries. This may be particularly important for small-scale and artisanal fisheries where the practical reality of enforcing regulations is extremely difficult and social norms may have a greater effect on compliance with bycatch regulation (Gillett, 2011). With better communication and awareness raising, vessels may be more motivated to comply with regulations, and even go beyond literal compliance, not only because of the threat of legal sanctions but also because of social pressures and norms. An example of a voluntary initiative from the Indian Ocean is the Pakistani gillnet fishery where training crew to collect detailed observer data, training in best practice handling and release approaches and collaboratively developing and trialling mitigation methods such as sub-surface gear setting has led to a change in behaviour of many fishers on a voluntary basis (Moazzam Khan, pers. comm.). One report from the project indicated that “participating captains felt valued and are proud to collect data using their phones and with cameras provided by the project. They often share reports on social media championing the process” (IWC, 2019). Another example of a voluntary initiative is from the Spanish tuna purse seiner association voluntary agreement for the application of a code of good practices (Grande et al., 2019). While this may have been implemented with awareness of growing regulatory controls and longer-term market-based incentives, it still provides an example of a voluntary initiative that works to change social norms and practices, not only in small-scale fisheries but also in industrial fleets. These types of initiatives pave the way for longer term behavioural changes leading to new social norms.

The idea of intrinsic motivation being important for bycatch management ties in with the emerging consensus that there is a need for greater collaboration with fishers in bycatch management (IWC, 2019). Awareness raising and education regarding the status of some bycatch species and the implications of taking them as bycatch may result in a tendency to refrain from practices that have negative effects (Gillett, 2011). Direct involvement of fishers is crucial to the development of approaches to bycatch reduction, utilising their extensive experience and in-depth knowledge of the fisheries in which they operate to develop methods that are appropriate, effective and which will be accepted in the long-term (Brownell et al., 2019). Management approaches where fishers have taken an active role in developing and trialling mitigation measures to reduce bycatch have already proven effective in many areas (Lewison et al., 2014). By going beyond simply focussing on top-down direct regulation and utilising a combination of management approaches, the IOTC is more likely to be successful in reducing pressure on bycatch species.

Summary of recommendations relating to management approaches

- *Direct management approaches should consider incentives and work towards performance standards for bycatch species*
- *Fishers should be more actively involved in the management of bycatch species, especially in the development of appropriate mitigation measures*
- *A combination of approaches beyond direct top-down management should be explored, including an increased focus on voluntary initiatives*

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Tables

Table 1. Summary of vulnerability status of Indian Ocean shark species

Species	ERA ranking[44]			IUCN status	CITES Appendix II	IOTC management advice[45]
	LL	PS	GN	Global		
Blue shark *(Prionace glauca)*	6	19	17	Near threatened	-	Reduce catches by 10 % (recent catches (2019) have been well below the estimated MSY (IOTC, 2020b)).
Common thresher (*Alopias vulpinus*)	10-11	6&8	14-15	Vulnerable	Y	Uncertain
Smooth hammerhead (*Sphyrna zygaena*)	14	18	2	Vulnerable	Y	Uncertain
Bigeye thresher shark (*Alopias superciliosus*)	4-5	14-15	9-10	Vulnerable	Y	Uncertain
Silky shark *(Carcharhinus falciformis)*	2	5	5	Vulnerable	Y	Assessment inconclusive but anecdotal evidence suggests a five-fold decrease in catch rates (1980 - 2005)[46].
Shortfin mako (*Isurus oxyrinchus*)	1	9	12	Endangered	Y	Assessment inconclusive and indicators show conflicting trends
Longfin mako (*Isurus paucus*)	7	4	7	Endangered	Y	Uncertain
Pelagic thresher shark (*Alopias pelagicus*)	12-13	2-3	3-4	Endangered	Y	Uncertain
Scalloped hammerhead shark (*Sphyrna lewini*)	17	12	6	Critically endangered	Y	Uncertain
Great hammerhead (*Sphyrna mokarran*)	8	7	13	Critically endangered	Y	Uncertain
Oceanic whitetip shark *(Carcharhinus longimanus)*	9	11	8	Critically endangered	Y	Uncertain and no stock assessment, however, indicators show signs of a substantial decline (Tolotti et al., 2016) (Rigby, Barreto, Carlson, *et al.*, 2019a).

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[44] Murua et al., 2018

[45] IOTC–2020–SC23–R

[46] Silky shark stock status summary supporting information: https://www.iotc.org/node/3379

Table 2. IUCN threat status for marine turtles reported to interact with IOTC fisheries (IOTC, 2020a)

Common name	Latin name	IUCN threat status
Flatback turtle	*Natator depressus*	Data deficient
Green turtle	*Chelonia mydas*	Endangered
Hawksbill turtle	*Eretmochelys imbricata*	Critically endangered
Leatherback turtle	*Dermochelys coriacea* *(NE Indian Ocean)* *(SW Indian Ocean)*	 Data deficient Critically endangered
Loggerhead turtle	*Caretta caretta* *(NW Indian Ocean)* *(SE Indian Ocean)*	 Critically endangered Near threatened
Olive Ridley turtle	*Lepidochelys olivacea*	Vulnerable

Table 3. Species included in study and data reporting requirements contained in Resolutions 15/01 and 15/02

	Species	**Retention ban in IOTC (CMM)**	**Included in Resolutions 15/01 & 15/02**			
			LL	**PS**	**GN**	**PL**
1	Blue shark		Y		Y	
2	Shortfin mako		Mako sharks (*Isurus* spp.)		Mako sharks (*Isurus* spp.)	
3	Longfin mako					
4	Scalloped hammerhead		Hammerhead sharks (*Sphyrna* spp.)		Hammerhead sharks (*Sphyrna* spp.)	
5	Smooth hammerhead					
6	Great hammerhead					
7	Bigeye thresher	12/09	Thresher sharks (*Alopias* spp.)	Thresher sharks (*Alopias* spp.)	Thresher sharks (*Alopias* spp.)	
8	Common thresher	12/09				
9	Pelagic thresher	12/09				
10	Silky shark		Y	Y		
11	Oceanic whitetip	13/06	Y	Y	Y	
12	Whale shark	13/05		Y	Y	
13	Mobulids	19/03	Y (optional)	Y (optional)	Y (optional)	Rays
14	Marine mammals	13/04	Y	Y	Y	
15	Marine turtles	12/04	Y	Y	Y	Y
	Unidentified sharks		Y	Y (optional)	Y	Y

Table 4. Key IOTC Conservation and Management Measures related to bycatch

Species	CMM	Review date	Exemptions	Data requirements	Research requirements	Mitigation measures (prior to capture)	Mortality reduction requirements	Issues
Oceanic whitetip	13/06	Evaluation by SC in 2016	Not applicable to artisanal fisheries operating exclusively in EEZ Not binding on India (objection)	Reporting of catches and discards encouraged. Standard Res. 15/02 applicable. Observers may collect data from sharks that are dead at haulback. Catch(discard) data must be raised total raised for entire fishery (Res. 15/02, para.2)	Identify potential nursery areas	None	Non-retention: release unharmed. Preferably before bringing onboard. Applicable to all gear types	Concern that vessels >24m operating inside EEZ may be included in this exemption (WPICMM03, 2020). Most CMMs set a date for review, however, often the information has been too limited and performance measures undefined for many conclusions to be drawn, as was the case for OCS in 2016. Does not specify how the sharks should be released unharmed. Mitigation measures absent.
Thresher sharks	12/09	None proposed	Applicable to all on RAV[47] (i.e. not vessels<24m operating exclusively in EEZ)	Reporting of catches and discards encouraged. Standard Res. 15/02 applicable (does not require reporting of THR to species level). Observers may collect data from sharks that are dead at haulback. Catch (discard) data must be raised total raised for	Identify potential nursery areas	None	Non retention: release unharmed when brought alongside vessel. Applicable to all gear types Must carry equipment for live release (recreation and sports fisheries with a high risk of catching threshers)	Does not specify how the sharks should be released unharmed. More specific instructions as to how to handle and release unharmed following best practices, should be indicated to reduce PRM. This might include specifying the length of trailing line left on the species when caught in longline gear, what tools should be used for cutting

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[47] Res. 19/04 Concerning the IOTC Record of Vessels Authorised to operate in the IOTC Area of Competence

				entire fishery (Res. 15/02, para.2)				the line and whether the shark should be hauled close to the vessel and left in the water before release (WCPFC, 2019). Mitigation measures absent.
Whale sharks	13/05	Review of guidelines in 2014 by Commission	Not applicable to artisanal fisheries operating exclusively in EEZ CPCs having national and state legislation protecting these species shall be exempt from reporting to IOTC	Report PS interactions (inc. condition of release) Report all interactions by other gear (inc. condition) Catch(discard) data must be raised total raised for entire fishery (Res. 15/02, para.2)	Develop best practice guidelines for handling and release	Prohibit intentionally setting purse seine around a whale shark, if sighted prior to commencement of the set. Adopt non-entangling FADs	If unintentionally encircled in a purse seine net, take all reasonable steps to ensure safe release. Only applicable for purse seine fleets	No mitigation measures have been implemented for the gillnet fleets; sub-surface setting of nets does not appear to influence entanglement rates (Moazaam and Nawaz, 2017). Concern that vessels >24m operating inside EEZ may be included in this exemption (WPICMM03, 2020).
Cetaceans	13/04	Review of guidelines in 2014 by Commission	Not applicable to artisanal fisheries operating exclusively in EEZ CPCs having national and state legislation protecting these species shall be exempt from reporting to IOTC (required by 15/01 and 15/02 nevertheless)	Report PS interactions (inc. species and condition of release) to flag state Report all interactions by other gear (inc. species and condition) to flag state **No requirement for total interactions (data raised for entire fishery).**	Develop best practice guidelines for handling and release	Prohibit intentionally setting purse seine around a cetacean, if sighted prior to commencement of the set Adopt non-entangling FADs	If unintentionally encircled in a purse seine net, take all reasonable steps to ensure safe release. Only applicable for purse seine fleets	Given that the AVM of cetaceans is particularly high, mitigation measures that reduce interactions with the gillnet fleet are critical (e.g. 19/01). No requirement for total interactions to be reported (data raised for entire fishery) so discard data are limited.

									Concern that vessels >24m operating inside EEZ may be included in this exemption (WPICMM03, 2020).
Turtles	12/04	Commission to review in 2013 with a view to adopting further measures to mitigate interactions. SC to review annually.	All on RAV[47] Para. 6 "…require *fishermen on vessels targeting species covered by the IOTC Agreement…"* suggests the artisanal fisheries are not exempt from the safe release requirement.	Total number of turtle interactions (i.e. raised estimates for all fisheries). Species-specific reporting not specified and Res. 15/02 does not require reporting of TTX to species level.	Research mitigation measures and other impacts e.g. nesting sites, swallowing of marine debris. Trial circle hooks, whole finfish bait, alternative FAD designs, alternative handling techniques, gillnet design, fishing practices and other mitigation methods which may improve mitigation of adverse effects. Develop regional standards covering data collection, data exchange and training; Develop improved FAD designs to reduce the incidence of entanglement of marine turtles, including the use of biodegradable materials.	Implement FAO guidelines (voluntary). Must report progress annually. Fishers are required use "proper mitigation" techniques, however, these are not defined other than the (encouraged) use of whole finfish bait for longline fisheries and avoiding encirclement by purse seine fleets.	Bring aboard comatose or inactive turtles and foster recovery, including aiding resuscitation before safely retuning to the water. Keep onboard and use equipment for safe release (line cutters and de-hookers for longliners and dip nets for purse seiners). Release marine turtles observer entangled in FADs or other gear.	Mitigation measures needed for gillnet (e.g. 19/01) and longline fisheries and best practice handling and safe release practices to be updated. List of species added to Res. 15/01 may improve data.
Mobulids	19/03	Commission to review advice from the SC on the status of *Mobula spp*. in 2023	Not applicable to subsistence fisheries that do not sell any part of the ray. Accidental catches may be donated for purposes of domestic human consumption.	Species-specific reporting not specified and Res. 15/02 does not require reporting of mobulids (MAN) to species level. CPCs must develop sampling plans for monitoring catches by artisanal fisheries. Catch(discard) data must be raised total raised for	Investigate at-vessel and PRM in mobulids. Identify possible hot-spots for conservation and management Further improvements to handling guidelines.	Prohibit intentionally setting any gear on mobulids, if sighted prior to commencement of the set.	Retention ban: must promptly release unharmed following provided handling requirements. Must keep onboard equipment needed for safe handling and release	Expected impact of the ban is more uncertain as both the proportion of the fisheries that are subsistence (and therefore exempt) and PRM rates are relatively unknown.

				entire fishery (Res. 15/02, para.2) Scientific observers may collect biological samples from rays that are dead at haul-back.				
Blue shark	18/02	In 2021 the Commission will review and consider CMMs which may include a catch limit or bycatch mitigation	Improve data collection and scientific information available to managers	Record catches according to 15/01 and report according to 15/02 (catch and discard) data must be raised total raised for entire fishery (Res. 15/02, para.2) Implement data collection programmes to improve reporting of catch-and-effort, discard and size data.	CPCs are encouraged to undertake scientific research on blue shark that would provide information on key biological/ecological/behavioural characteristics, life-history, migrations, post-release survival and guidelines for safe release and identification of nursery grounds, as well as improving fishing practices. SC to provide advice on candidate limit, threshold and target ref points and potential management options for ensuring long-term sustainability of the stock such as mitigation measures, improved gear selectivity, spatial/temporal closures or minimum sizes, ban on wire trace/shark lines or catch limit.			No management measures yet agreed.
Mako sharks	No specific CMM, however, the provisions of 17/05, 19/02, 12/02, 19/01 and 11/04 all apply							
Hammer head sharks	As above							
Silky shark	As above							

Table 5a. Reported retained captures of oceanic whitetip sharks since 2014 (Res. 13/06 came into force). Nominal catch dataset. Source: [IOTC-2020-WPEB16-DATA03 – NC].

Reporting CPC	**Type of operation**	**2014**	**2015**	**2016**	**2017**	**2018**	**Retained catches (t)**
Comoros	Artisanal	5.21	2.53	457.48		11.92	477.13
I.R. Iran	Artisanal Industrial	52.68 44.27	54.17 63.33	28.19 11.04	0.02 43.90	0.83 22.29	135.89 184.83
Sri Lanka	Artisanal Industrial	36.00 43.00	89.00				125.00 43.00
Indonesia	Industrial	3.03	17.02	0.50		0.01	20.56
India	Industrial	1.24	6.32	3.80			11.36
Maldives	Industrial	7.76					7.76
Seychelles	Industrial	0.09	0.11	0.24	0.65	0.06	1.16
Tanzania	Industrial	0.31					0.31
EU, Spain	Industrial				0.18		0.18
EU, France, Reunion	Artisanal (t) (individuals)	 10	 1		0.04 6	 2	0.04 19*
Total		**194**	**232**	**501**	**45**	**35**	**1007**

Table 5b. Reported retained captures of oceanic whitetip sharks since 2014 (Res. 13/06 came into force). Catch-and-effort dataset. Source: [IOTC-2020-WPEB16-DATA12_CE]

Reporting CPC	**Type of operation**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Retained catches**
EU, France, Reunion	Artisanal	10	1		6	2	3	22 (individuals)
Seychelles	Industrial			13	98	30		141(kg)

Table 5c. Reported retained captures of oceanic whitetip sharks since 2014 (Res. 13/06 came into force). Observer data. Sources: [IOTC-2020-WPEB16-DATA12_Interactions]; WWF-Pakistan observer dataset

Reporting CPC	**Type of operation**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Retained catches (individuals)**
EU, France, Reunion	Artisanal	10	1		6	2	3	22
Japan	Industrial		1	1				2 (retained or discarded unknown)
Seychelles	Industrial			1		1		2
Pakistan	Industrial	8	5		3			16

Table 6. Fleet responses regarding compliance with IOTC Resolution 13/06

Fleet	**Compliance report 2020**[48]	**Year**	**Ref**
Comoros	While previously considered non-compliant, there are currently no vessels on the RAV so the CMM is not applicable. Nevertheless, in 2020 it was noted that a draft decree on the prohibition on oceanic whitetip sharks is in the process of being signed.	2020?	IOTC-2020-CoC17-CR04 IOTC-2021-CoC18-CR04
I.R. Iran	Banned since 2010. National regulation of Tuna Fishing Article No. 2-4 and 2-6.	2010	IOTC-2020-CoC17-CR10
Sri Lanka	Prohibited. Shark Fisheries Management (High Seas) Regulations 2015.	2015	IOTC-2020-CoC17-CR26
Indonesia	Banned since 2014. Ministerial Regulation 12/2012 & 5/2018	2014	IOTC-2020-CoC17-CR09
India	Not applicable (Objection S17). Banned since 2004: F.No.21005/1/2001-FY(Ind) dated 6/9/2004.	2004	IOTC-2020-CoC17-CR08
Maldives	Prohibited. All sharks species are protected in the Maldives under Maldives Fisheries Regulation/ License Regulation.	2010	IOTC-2020-CoC17-CR16
Seychelles	Banned: Shark Finning Regulation 2006 and Fisheries Act 2014.	2014	IOTC-2020-CoC17-CR22
Tanzania	Incorporated in Act 5 of 2020, Part IV and Regulations 2020, Part II, Fisheries Conservation, Management and Development	2020	IOTC-2020-CoC17-CR28
EU, Spain	Banned since 2013: Art 28 Regulation (EU) No 605/2013	2013	IOTC-2020-CoC17-CR06
EU, France (Reunion)	Banned since 2013: Art 28 Regulation (EU) No 605/2013	2013	IOTC-2020-CoC17-CR06
Pakistan	The Fisheries Departments, Government of Sindh & Government of Balochistan have issued a Notification dated 18-05-2016 under Sindh Fisheries Ordinance 1980 & a Notification dated 08-09-2016 under Balochistan Sea Fisheries Ordinance, 1971, wherein catching oceanic whitetip sharks & thresher sharks are prohibited.	2016	IOTC-2020-CoC17-CR20

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[48] Downloaded from [www.iotc.org/compliance/monitoring] on 11.12.2020

Table 7a. Reported retained captures of thresher sharks since 2010 (Res. 10/12, superseded by 12/09). Nominal catch data. Source: [IOTC-2020-WPEB16-DATA03 – NC].

Fleet	Type of operation	2011	2012	2013	2014	2015	2016	2017	2018	Retained catches (t)
Indonesia	Artisanal	4392.21	4406.62	4956.39	4511.44	4455.04	4261.93	4200.84	3330.21	34514.69
Pakistan	Artisanal	212.00	232.00	247.00	275.00	301.00	375.00	401.00	387.00	2430.00
Madagascar	Artisanal	224.60	224.60	224.60	224.60	224.60	224.60	224.60	224.60	1796.80
Sri Lanka	Artisanal	178.65	793.25							971.90
India	Artisanal Industrial	2.74						5.66	4.24 47.70	60.33
Maldives	Industrial			8.52	8.52					17.04
EU, Portugal	Industrial								1.10	1.10
EU, France Reunion	Artisanal					0.49				0.49
Seychelles	Industrial				0.10		0.29			0.39
EU, Spain	Industrial	0.10								0.10
South Africa	Industrial	0.08			0.02					0.10
Tanzania	Industrial		0.00	0.01	0.01					0.01
Total		5010	5656	5437	5020	4981	4862	4832	3995	39 793

Table 7b. Reported retained captures of thresher sharks since 2010 (Res. 10/12, superseded by 12/09). Catch-and-effort dataset. Source: [IOTC-2020-WPEB16-DATA12_CE]

Reporting CPC	**Type of operation**	**2011**	**2018**	**2019**	**Retained catches (individuals)**
EU, France, Reunion	Artisanal	18	1		19
Sri Lanka	Artisanal			1	1

Table 7c. Reported retained captures of thresher sharks since 2010 (Res. 10/12, superseded by 12/09). Observer data. Source: [IOTC-2020-WPEB16-DATA12_Interactions]; WWF-Pakistan observer dataset

Reporting CPC	**Type of operation**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**Retained catches (individuals)**
EU, France, Reunion	Artisanal	18							1		19
Japan (fate undeclared)	Industrial		9	33	49	56	53				200
Sri Lanka	Artisanal									1	1
Pakistan	Industrial			56	100	234	43	25			485

T*able 8. Fleet responses regarding compliance with IOTC Resolution 12/09*

Fleet	Legal mechanism[49]	Year	Reference
Indonesia	Banned since 2012: Ministerial Regulation No. 12/2012.	2012	IOTC-2020-CoC17-CR09
Pakistan	The Fisheries Departments, Government of Sindh & Government of Balochistan have issued a Notification dated 18-05-2016 under Sindh Fisheries Ordinance 1980 & a Notification dated 08-09-2016 under Balochistan Sea Fisheries Ordinance, 1971, wherein catching oceanic whitetip sharks & thresher sharks are prohibited.	2016	IOTC-2020-CoC17-CR20
Madagascar	Decree No. 12665/2014 of 28.03.2014 regulating the conservation of thresher sharks (Alopiidae family) caught by fisheries.	2014	IOTC-2020-CoC17-CR14
Sri Lanka	Prohibited: Prohibition of Catching Thresher Shark Regulations 2012; Shark Fisheries Management (High Seas) Regulations 2015.	2012	IOTC-2020-CoC17-CR26
India	Banned since 2004 by Terms & Conditions of authorisation to fish	2004	IOTC-2020-CoC17-CR08
Maldives	Prohibited: all sharks species are protected in the Maldives under Maldives Fisheries Regulation/ License Regulation.	2010	IOTC-2020-CoC17-CR16
EU, Portugal	Banned since 2010: Art 28 Regulation (EU) No 605/2013	2010	IOTC-2020-CoC17-CR06
EU, France Reunion	Banned since 2010: Art 28 Regulation (EU) No 605/2013	2010	IOTC-2020-CoC17-CR06
Seychelles	Banned by Shark Finning Regulation 2006 and Fisheries Act 2014.	2014	IOTC-2020-CoC17-CR22
EU, Spain	Banned since 2010: Art 28 Regulation (EU) No 605/2013	2010	IOTC-2020-CoC17-CR06
South Africa	Banned under permit conditions: Large Pelagic Fishery	unknown	IOTC-2020-CoC17-CR25
Tanzania	Prohibited by the DSFA Act, Regulations & Directives 008/2020,004/2020 and 005/2020.	2020	IOTC-2020-CoC17-CR28

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[49] Downloaded from [www.iotc.org/compliance/monitoring] on 11.12.2020

Table 9. A summary of at-vessel mortality (AVM) and post-release mortality (PRM) rates collated from the literature

Gear	Fishery	Ocean	AVM (%)	n	PRM (%)	n	Condition	Reference
Blue shark (Prionace glauca)			***17.3***	***938 367***	***10.2***	***104***		
LL	Pelagic longline (35-60 m)	Atlantic	12.2	434				(Beerkircher, Cortés and Shivji, 2002)
LL	Cruise sampling (shallow sets of <100m depth)	Pacific	5	172				(Moyes *et al.*, 2006)
LL	swordfish/albacore	Mediterranean	4.5	513				(Megalofonou *et al.*, 2005)
LL	tuna	Pacific	0	21				(Boggs, 1992)
LL	tuna	Pacific	13.5	7838				(Francis, Griggs and Baird, 2001)
LL	swordfish	Indian	51.1	92				(Poisson *et al.*, 2010)
LL	swordfish	Indian	24.7	2358				(Coelho, Lino and Santos, 2011)
LL	swordfish	Atlantic	14.3	30168				(Coelho *et al.*, 2012)
LL	swordfish and tunas	Atlantic	15	15592				(Campana *et al.*, 2016)
LL	swordfish and tunas	Atlantic	15.1	17780				(Gallagher *et al.*, 2014)
LL	Swordfish, tunas, dolphinfish, sharks	Atlantic	17	863153				(Dapp *et al.*, 2016)
LL	research LL vessel	Pacific	5.9	203	6.25	16		(Musyl *et al.*, 2011)
LL	tuna	Pacific	7	43	22.2	9	unknown	(Hutchinson and Bigelow, 2019)
LL	tuna	Pacific			8	25	healthy	(Hutchinson and Bigelow, 2019)
LL	tuna	Pacific			33.3	6	injured	(Hutchinson and Bigelow, 2019)
LL	Cruise sampling (shallow	Pacific			0	11	healthy	(Moyes *et al.*, 2006)
LL	swordfish and tunas	Atlantic			(0)	(10)	healthy	(Campana *et al.*, 2016)
LL	swordfish and tunas	Atlantic			(33)	(27)	injured	(Campana *et al.*, 2016)
LL	swordfish and tunas	Atlantic			9.8	37	all[50]	(Campana *et al.*, 2016)
Blue shark summary			**17.3**	**938 367**	**10.2**	**104**		
Shortfin mako (Isurus oxyrinchus)								
LL	swordfish/albacore	Mediterranean	16.1	31				(Megalofonou *et al.*, 2005)
LL	tuna	Pacific	28.4	299				(Francis, Griggs and Baird, 2001)

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[50] An overall post-release mortality estimate was obtained by calculating a condition class weighted average using the proportion in each condition class and the condition-specific PRM

Gear	Fishery	Ocean	AVM (%)	n	PRM (%)	n	Condition	Reference
LL	swordfish	Atlantic	35	80				(Beerkircher, Cortés and Shivji, 2002)
LL	swordfish	Indian	56	430				(Coelho, Lino and Santos, 2011)
LL	swordfish	Atlantic	35.6	1414				(Coelho *et al.*, 2012)
LL	swordfish and tunas	Atlantic	56	520				(Campana *et al.*, 2016)
LL	Swordfish, tunas,	Atlantic	7	66750				(Dapp *et al.*, 2016)
LL	swordfish or tuna (mixed)	Atlantic	28.6	2126				(Gallagher *et al.*, 2014)
LL	research LL vessel	Pacific	0	8	0	2		(Musyl *et al.*, 2011)
					12	57		(Anon, 2019)
LL					22.9	35		(Anon, 2019)
LL	swordfish and tunas	Atlantic			30	23	healthy	(Campana *et al.*, 2016)
LL	swordfish and tunas	Atlantic			33	3	injured	(Campana *et al.*, 2016)
LL	swordfish and tunas	Atlantic			31.3	26	all[51]	(Campana *et al.*, 2016)
Shortfin mako summary			**8.3**	**71 658**	**21.2**	**146**		
Longfin mako (Isurus paucus)								
LL	Swordfish, tunas, dolphinfish. sharks	Atlantic	13	7367				(Dapp *et al.*, 2016)
LL	swordfish	Atlantic	30.7	168				(Coelho *et al.*, 2012)
LL	swordfish or tuna (mixed)	Atlantic	51.1	139				(Gallagher *et al.*, 2014)
Longfin mako summary			**14.1**	**7674**				
Scalloped hammerhead (Sphyrna lewini)								
LL	Swordfish, tunas,	Atlantic	25	13062				(Dapp *et al.*, 2016)
LL	swordfish	Atlantic	61	199				(Beerkircher, Cortés and Shivji, 2002)
LL	shark	Atlantic	91.4	455				(Morgan and Burgess, 2007)
LL	swordfish or tuna (mixed)	Atlantic	54.1	727				(Gallagher *et al.*, 2014)

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[51] An overall post-release mortality estimate was obtained by calculating a condition class weighted average using the proportion in each condition class and the condition-specific PRM

Gear	Fishery	Ocean	AVM (%)	n	PRM (%)	n	Condition	Reference
LL	swordfish	Atlantic	57.1	21				(Coelho *et al.*, 2012)
Scalloped hammerhead summary			**29.6**	**14459**				
Smooth hammerhead (Sphyrna zygaena)								
LL	Swordfish, tunas,	Atlantic	19	9922				(Dapp *et al.*, 2016)
LL	swordfish	Indian	84	25				(Coelho, Lino and Santos, 2011)
LL	swordfish	Atlantic	71	372				(Coelho *et al.*, 2012)
Smooth hammerhead summary			**20.6**	**10319**				
Great hammerhead shark (Sphyrna mokarran)								
LL	shark	Atlantic	93.8	178				(Morgan and Burgess, 2007)
Hammerheads NEI (Sphyrna spp.)								
LL	Swordfish, tunas, dolphinfish. sharks	Atlantic	22	23238				(Dapp *et al.*, 2016)
Bigeye thresher (Alopias superciliosus)								
LL	swordfish/albacore	Mediterranean	0	1				(Megalofonou *et al.*, 2005)
LL	swordfish	Atlantic	53.1	81				(Beerkircher, Cortés and Shivji, 2002)
LL	swordfish	Indian	68.4	19				(Coelho, Lino and Santos, 2011)
LL	swordfish	Atlantic	50.6	1061				(Coelho *et al.*, 2012)
LL	swordfish or tuna (mixed)	Atlantic	51.7	367				(Gallagher *et al.*, 2014)
LL	Swordfish, tunas,	Atlantic	17	13227				(Dapp *et al.*, 2016)
LL	tuna	Pacific	28.9	28	12.5	24	healthy	(Hutchinson and Bigelow, 2019)
LL	research LL vessel	Pacific	25	12	0	3		(Musyl *et al.*, 2011)
LL		Pacific			50	2		(Hutchinson *et al.*, 2015)
LL	swordfish and tuna(mixed)	Indian			41	17		(Romanov *et al.*, 2020)
Bigeye thresher summary			**20.9**	**14796**	**23.9**	**46**		
Common thresher (Alopias vulpinus)								
LL	swordfish/albacore	Mediterranean	6.25	16				(Megalofonou *et al.*, 2005)
Troll	recreational	Pacific			26	19		(Heberer *et al.*, 2010)
Troll		Eastern Pacific			78	9	tail hooked	(Sepulveda *et al.*, 2015)

Gear	Fishery	Ocean	AVM (%)	n	PRM (%)	n	Condition	Reference
Troll		Eastern Pacific			0	7	mouth	(Sepulveda *et al.*, 2015)
Common thresher summary			**6.25**	**16**	**34.3**	**35**		
Pelagic thresher (Alopias pelagicus)								
LL	research LL vessel	Pacific	35.7	28				(Musyl *et al.*, 2011)
Threshers NEI (Alopias. Spp.)								
LL	Swordfish, tunas,	Atlantic	14	5248				(Dapp *et al.*, 2016)
LL	tuna	Pacific	40	6				(Boggs, 1992)
Silky shark (Carcharhinus falciformis)								
LL	swordfish or tuna (mixed)	Atlantic	42.2	1090				(Gallagher *et al.*, 2014)
LL	swordfish	Atlantic	66.3	1446				(Beerkircher, Cortés and Shivji, 2002)
LL	swordfish	Indian	74.2	31				(Coelho, Lino and Santos, 2011)
LL	swordfish	Atlantic	55.8	310				(Coelho *et al.*, 2012)
LL	Swordfish, tunas, dolphinfish. sharks	Atlantic	23	42647				(Dapp *et al.*, 2016)
LL	tuna	Pacific	35.8	30	0	29	healthy	(Hutchinson and Bigelow, 2019)
LL	research vessel	Pacific	11.4	35	0	10		(Musyl *et al.*, 2011)
UN					11	53		(Anon, 2019)
PS	tuna	Indian	72	191	48	23	Brailed	(François Poisson *et al.*, 2014)
PS	tuna	Indian	18	11	0	4	Entangled in net[52]	(François Poisson *et al.*, 2014)[53]
PS	tuna	Pacific	60	275	36	14[54]		(Hutchinson *et al.*, 2015)
Summary silky shark[55]			11.4 – 74.2		0 – 84.17			
Oceanic whitetip (Carcharhinus longimanus)								
LL	swordfish	Indian	58.9	17				(Poisson *et al.*, 2010)
LL	swordfish	Indian	50	28				(Coelho, 2016)

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[52] Only 5% of captures were entangled so overall AVM and PRM of 81% based on typical proportions caught at each stage in the fishing operation

[53] Based on an entanglement rate of 5 %, the total overall post capture survival rate was 19%

[54] Total AVM and PRM of 84.17% based on typical proportions caught at each stage in the fishing operation

[55] Ranges provided as estimated totals for typical operations provided in some studies

Gear	Fishery	Ocean	AVM (%)	n	PRM (%)	n	Condition	Reference
LL	swordfish	Atlantic	27.5	131				(Beerkircher, Cortés and Shivji, 2002)
LL	swordfish	Atlantic	34.2	281				(Coelho *et al.*, 2012)
LL	swordfish or tuna (mixed)	Atlantic	25.7	213				(Gallagher *et al.*, 2014)
LL	Swordfish, tunas, dolphinfish. sharks	Atlantic	11	10847				(Dapp *et al.*, 2016)
LL	tuna	Pacific	15	26				(Boggs, 1992)
LL	research LL vessel	Pacific	5.3	19	0	13		(Musyl *et al.*, 2011)
LL	tuna	Pacific	33.6	33	8.3	24	healthy	(Hutchinson and Bigelow, 2019)
LL	tuna	Pacific			33.3	6	unknown	(Hutchinson and Bigelow, 2019)
LL	Tuna and swordfish	Indian Ocean			0	3	good	(Bach *et al.*, 2019)
PS	tuna	Indian Ocean			8.3	12	mixed	(Bach *et al.*, 2019)
Summary Oceanic whitetip			**12.1**	**11 595**	**8.6**	**58**		
Whale shark (Rhincodon typus)								
PS	encircled	Pacific	12	186				(SPC-OFP, 2010)
PS	encircled	Atlantic			0	7		(Escalle *et al.*, 2017)
PS	encircled	Atlantic	0.9	107				(Capietto *et al.*, 2014)
PS	encircled	Indian	2.56	38				(Capietto *et al.*, 2014)
GN	entangled	Indian	20	5				(Nawaz and Moazzam, 2014)
Summary whale shark			**7.7**	**336**	**0**	**7**		
Marine turtles (Testudines)								
PS	Encircled (turtles)	Atlantic	5	397				(Bourjea *et al.*, 2014)
PS	Encircled (turtles)	Indian	13	180				(Bourjea *et al.*, 2014)
PS	encircled FAD (turtles)	Atlantic	<1	925				(Ruiz Gondra *et al.*, 2017)
PS	encircled FS (turtles)	Atlantic	<1	301				(Ruiz Gondra *et al.*, 2017)
PS	Encircled (turtles)	Indian	4	140				(Ruiz *et al.*, 2018)
LL	Hooked (Loggerhead)	Pacific	1.2	168				(Chaloupka, Parker and Balazs, 2004)
LL	Hooked (Loggerhead)	Atlantic/Med	3.8	26	28	25		(De Quevedo, Félix and Cardona, 2013)
LL	Hooked (Olive Ridley)	Eastern Pacific	0	10	0	10		(Swimmer *et al.*, 2006)
LL	Hooked (Loggerhead)	Pacific			34	27	Deep	(Chaloupka, Parker and Balazs, 2004)
LL	Hooked (Loggerhead)	Pacific			8	13	Lightly	(Chaloupka, Parker and Balazs, 2004)

Gear	Fishery	Ocean	AVM (%)	n	PRM (%)	n	Condition	Reference
LL	Hooked (Loggerhead)	Pacific			28	25		(Swimmer *et al.*, 2014)
LL	(Loggerhead)	Atlantic			19	10	Lightly	(Sasso and Epperly, 2007)
LL	Hooked (Loggerhead)	Atlantic			10	21		(Swimmer and Gilman, 2014)
GN	Bottom set gillnets (loggerhead)	Mediterranean	69.5[56]	36				(Echwikhi *et al.*, 2010)
GN	Drifting gillnets (turtles)	Indian Ocean	2.5					(Nawaz and Moazzam, 2014)
GN	Drifting gillnets (turtles)	Indian Ocean	10	600				(Shahid *et al.*, 2015)
GN	Entanglements (turtles)	Atlantic			28.6	14		(Snoddy and Williard, 2010)
Summary marine turtles			**3.4**	**2783**	**22.8**	**145**		
Mobulids (Mobula spp.)								
LL	swordfish	Indian	0	14				(Coelho, Lino and Santos, 2011)
LL	Tuna and swordfish	Indian	10	198				(IOTC ROS data; unpub.)
LL	swordfish	Atlantic	1.4	145				(Coelho *et al.*, 2012)
LL		Atlantic	5.4	201				(Mas, Forselledo and Domingo, 2015)
LL		Atlantic	0	113				(Beerkircher, Cortés and Shivji, 2002) [57]
GN		Indian	50	14				(Shahid pers comm., unpub. data)
PS		Indian	36	173				(IOTC-2019-WPEB15-DATA)
PS	FAD and FS (Spinetail)	Atlantic	46.94	343				(Clavareau *et al.*, 2020)
PS	FAD and FS (Spinetail)	Indian	30.68	88				(Clavareau *et al.*, 2020)
PS	FAD and FS (Giant manta)	Atlantic	43.03	79				(Clavareau *et al.*, 2020)
PS	FAD and FS (Giant manta)	Indian	24.32	111				(Clavareau *et al.*, 2020)
PS	Brailed (Spinetail)	west Pacific			57	7	Healthy	(Francis and Jones, 2017)
Summary mobulids			**23.7**	**1479**	**57**	**7**		
Cetaceans								
PS	tuna	Western central Pacific	4	25			*Baleen whales*	(SPC-OFP, 2010)

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[56] Included very long soak times (1-5 days)

[57] Unidentified batoids: mostly pelagic stingrays (*Dasyatis violacea*) and some manta rays (Mobulidae)

Gear	Fishery	Ocean	AVM (%)	n	PRM (%)	n	Condition	Reference
PS	tuna	Western central	66	770			*Toothed*	(SPC-OFP, 2010)
Summary cetaceans			**64.7**	**795**				

Table 10. Mortality rates used to estimate overall reduction in mortality with a retention ban

	OCS		THR	
Artisanal component of fishery	0.586[58]	0.646[59]	0.569[58]	0.636[59]
Non-compliant component of industrial fleet	0 (assumed full compliance)		0 (assumed full compliance)	
At-vessel mortality	0.12 (0.11 - 0.13)		0.21 (0.20 - 0.21)	
Post-release mortality	0.09 (0.02 - 0.16)		0.24 (0.13 - 0.37)	
Estimated total reduction in mortality with a retention ban	**0.33 (0.36-0.27)**	**0.28 (0.23-0.31)**	**0.26 (0.18-0.33)**	**0.22 (0.15-0.28)**

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[58] Murua et al., 2013

[59] Garcia and Herrera, 2018

Table 11. Mandatory data reporting requirements for bycatch species

Data set	Description	IOTC form	Species group	CMM	Status of reporting/key issues[60]
Nominal catches	Total annual retained catches by IOTC area, species group[61] and type of fishery	Form 1RC	Sharks (live weight)	15/02 17/05 18/02	Historical catches have gone unreported in many cases and many fleets suspected to still be not reporting/under-reporting. Species-specific reporting remains an issue (30% unidentified) and misidentification is common.
Discards	Estimates of total annual discard levels by IOTC area, species group and type of fishery	Form 1DI	Sharks (live weight)	15/02 12/09	Longline fleets of the EU (Spain, UK), Japan and Taiwan,China, and purse seine fleets of I.R. Iran, Japan, Seychelles and Thailand have not provided estimates of total discards of sharks, by species.
			Marine turtles (numbers)	12/04 15/02	No incidental catches reported by the gillnet fleets of Pakistan and Indonesia, longline fisheries of Malaysia, Oman, India, Philippines and Seychelles and the purse seine fisheries of Japan, I.R.Iran and Thailand.
			Cetaceans (numbers)	13/04	Data reporting is extremely poor
			Whale sharks (numbers)	13/05	Data reporting is extremely poor
Catch-and-effort	Catch by species group and fishing effort by type of fishery :1° grid area (surface fisheries) 5° grid area (longline fisheries) geographic area (coastal fisheries)	Form 3CE	Sharks (live weight)	12/09 15/01 15/02 17/05 18/02	Data not reported / not reported to IOTC standards by: Gillnet fisheries of Pakistan, I.R.Iran, Oman and Taiwan,China (historic); longline fisheries of Japan, Taiwan,China, Indonesia and Rep. of Korea,Malayisia, Indonesia, EU,Spain and India; coastal fisheries of India, Madagascar, Yemen, Oman and Indonesia.

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[60] Summarised from (WPEB, 2020)

NB: While a number of CPCs have been mentioned specifically here, as they have important fisheries or have not provided any information, there are still many CPCs that are providing data that are not consistent with the IOTC minimum reporting standards.

[61] Species groups as per Table 3

	month strata (this should be extrapolated to annual catch)				
FADs	Interactions with floating objects (FADs and natural objects) by purse seiners and supply vessels, including number of sets and corresponding catches by 1° grid area and month strata	Form 3FA	All	15/02 19/02	NA
Size frequency data	Length/weight data by species, type of fishery and 5° grid area and month strata	Form 4SF	Sharks	17/05	The gillnet fisheries of I.R.Iran and Pakistan, longline fisheries of India, Malaysia and Oman and coastal fisheries of India and Yemen have not reported size frequency data.
Observer data	Fine scale catch and effort, including details of setting and hauling operations and all species level interactions.		All	11/04	Coverage remains low at 2.15% and that there is no coverage of the artisanal fleet which comprise a large proportion of catches taken in the Indian Ocean (IOTC, 2020b).

Table 12. Data improvements for cetaceans recommended by the Thirteenth Session of the Scientific Committee (IOTC, 2010)

Data/information/work required	Fishery	Major fleets involved
Provision of historical data on incidental catches of marine mammals, by species and fishing area.	Industrial longline fisheries	Longline: Taiwan,China, Japan, Indonesia, Malaysia, Philippines, Spain, Portugal, Seychelles and South Korea
Provision of data collected through observer programmes, as specified by the Commission	Gillnet fisheries on the high seas	Iran, Pakistan, Sri Lanka

Table 13. Data improvements for marine turtles recommended by the Thirteenth Session of the Scientific Committee (IOTC, 2010)

Data required	Fishery	Major fleets involved
Provision of data collected through observer programmes and estimates of total levels of bycatch of marine turtles, as specified by the Commission	Countries having industrial longline fisheries	China, Taiwan,China and Japan
	Gillnet/ gillnet-longline Industrial purse seine fleets	Gillnet fisheries operating on the high seas (Pakistan and Iran) Gillnet fisheries operating in coastal waters (India, Indonesia, Oman and Yemen) Gillnet longline fisheries of Sri Lanka EU (<2003), Seychelles, Iran, Japan and Thailand

Figures

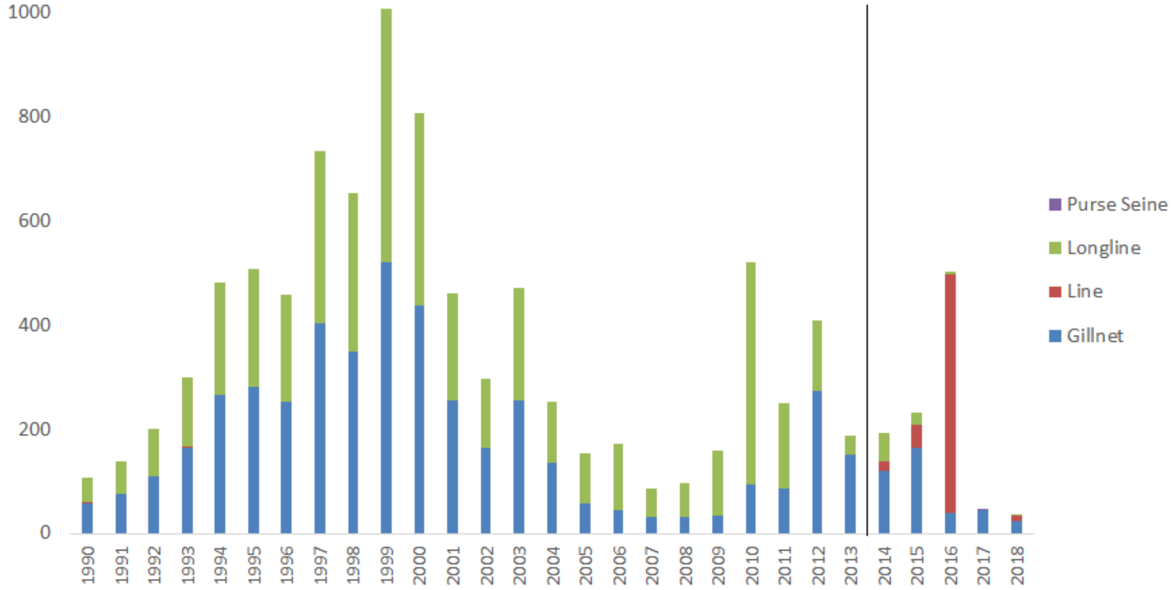

Figure 1. Reported nominal catches (tonnes) of oceanic whitetip shark by gear. The black line indicates the year the ban first came into effect (2013).

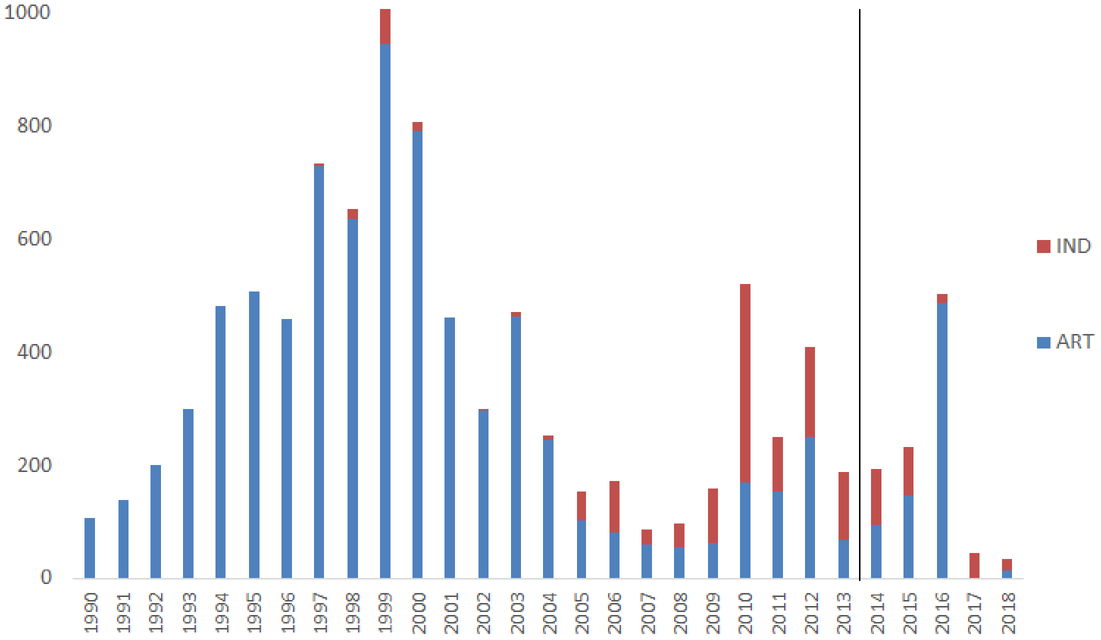

Figure 2. Reported nominal catches (tonnes) of oceanic whitetip shark by the industrial and artisanal fleets. The black line indicates the year the ban first came into effect (2013).

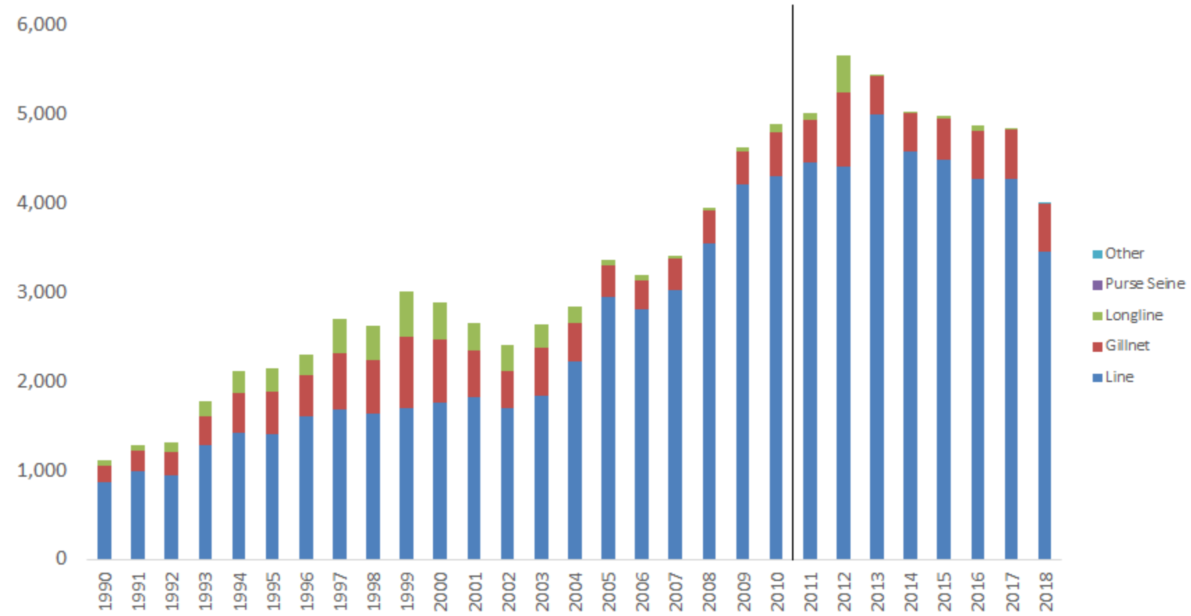

Figure 3. Reported nominal catches (tonnes) of thresher sharks by gear. The black line indicates the year the ban first came into effect (2010).

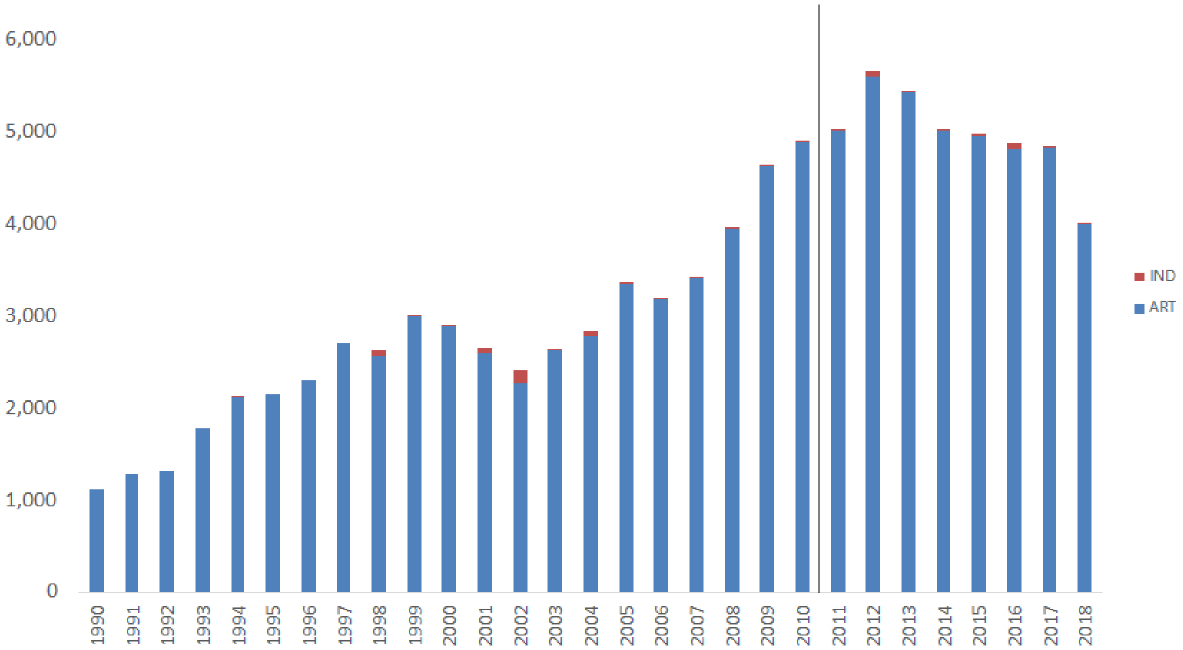

Figure 4. Reported nominal catches (tonnes) of thresher sharks by the industrial and artisanal fleets. The black line indicates the year the ban first came into effect (2010).

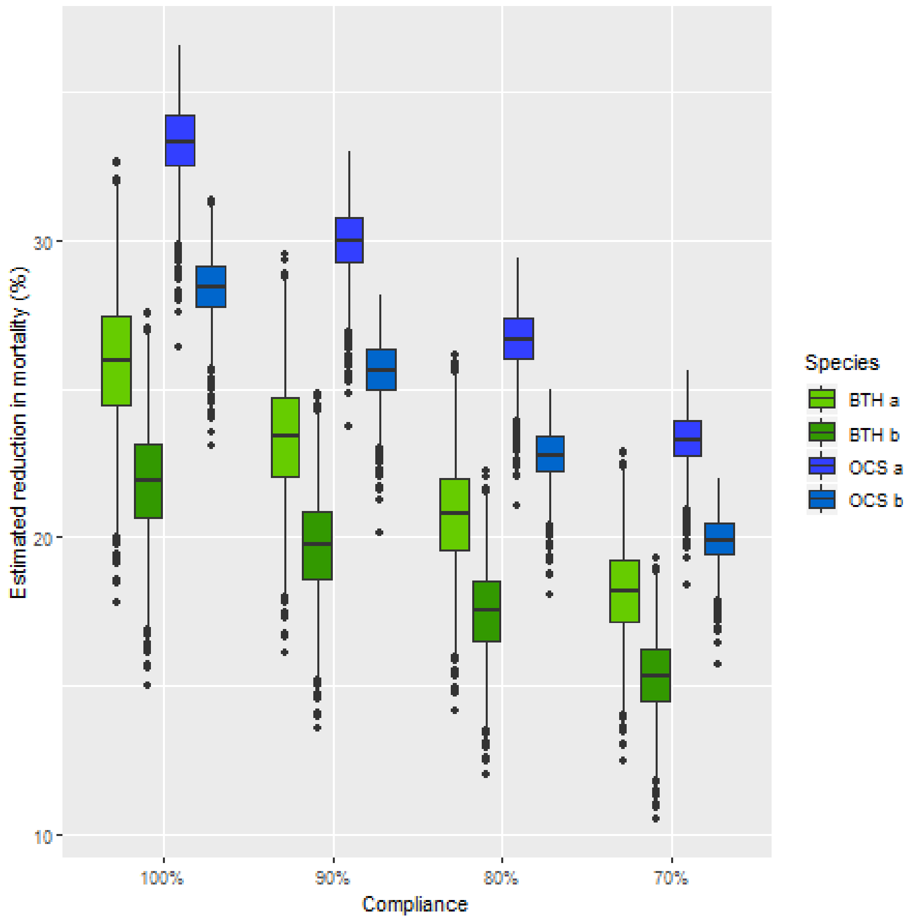

Figure 5. Estimated reduction in species mortality (%) achieved with a retention ban under different scenarios of compliance (70, 80 90 and 100 %) for bigeye thresher shark (BTH) and oceanic whitetip sharks (OCS) using two estimates of artisanal fisheries contribution (a) Murua et al., 2013 and (b) Garcia and Herrera, 2018.