IOTC-2012-WPEB08-INF20
Received: 11 September, 2011

COMMISSION DE L'OCEAN INDIEN

SmartFish Working Papers

No 00X

A Review of Bycatch and Discard Issues in Indian Ocean Tuna Fisheries

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Funded by European Union

This publication has been produced with the assistance of the European Union. The contents of this publication are the sole responsibility of the author and can in no way reflect the views of the European Union.

La bonne gouvernance et de la gestion des pêches et de l'aquaculture permettent d'améliorer la contribution du secteur à la sécurité alimentaire, au développement social, à la croissance économique et au commerce régional ; ceci en assurant par ailleurs une protection renforcée des ressources halieutiques et de leurs écosystèmes.

La Commission de l'Océan Indien (COI) ainsi que la COMESA (Common Market for Eastern and Southern Africa), l'EAC (East African Community) et l'IGAD (Inter-Governmental Authority on Development) ont développé des stratégies à cette fin et se sont engagés à promouvoir la pêche et l'aquaculture responsable.

SmartFish supporte la mise en œuvre de ces stratégies régionales en mettant l'accent sur le renforcement des capacités et des interventions connexes visant à :

- la mise en œuvre d'un développement et d'une gestion durables des pêcheries ;
- le lancement d'un cadre de gouvernance pour les pêcheries durables dans la région;
- le développment d'un suivi-contrôle-surveillance efficace pour les ressources halieutiques transfrontalières ;
- le développment de stratégies commerciales regionals et la mise en œuvre d'initiatives commerciales;
- l'amélioration de la sécurité alimentaire à travers la réduction des pertes post-capture et la diversification.

SmartFish est financé par l'Union Européenne dans le cadre du 10ème Fond Européen de Développement.

SmartFish est mis en œuvre par la COI en partenariat avec la COMESA, l'EAC et l'IGAD et en collaboration avec la SADC. Une collaboration étroite a également été développée avec les organisations régionales de pêche de la région. L'assistance technique est fournie par la FAO et le consortium Agrotec SpA.

By improving the governance and management of our fisheries and aquaculture development, we can also improve food security, social benefits, regional trade and increase economic growth, while also ensuring that we protect our fisheries resources and their ecosystems.

The Indian Ocean Commission (IOC), the Common Market for Eastern and Southern Africa (COMESA), the East African Community (EAC) and the Inter-Governmental Authority on Development (IGAD) have developed strategies to that effect and committed to regional approaches to the promotion of responsible fisheries and aquaculture.

SmartFish is supporting the implementation of these regional fisheries strategies, through capacity building and related interventions aimed specifically at:

- implementing sustainable regional fisheries management and development;
- initiating a governance framework for sustainable regional fisheries;
- developing effective monitoring, control and surveillance for trans boundary fisheries resources;
- developing regional trade strategies and implementing regional trade initiatives;
- contributing to food security through the reduction of post-harvest losses and diversification.

SmartFish is financed by the European Union under the 10th European Development Fund.

SmartFish is implemented by the IOC in partnership with the COMESA, EAC, and IGAD and in collaboration with SADC. An effective collaboration with all relevant regional fisheries organisations has also been established. Technical support is provided by Food and Agriculture Organization (FAO) and the Agrotec SpA consortium.

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A Review of Bycatch and Discard Issues in Indian Ocean Tuna Fisheries

Ardill, D., D. Itano and R. Gillett

Abstract

Public awareness and concern over the environmental impact of food production and security is rising rapidly. Whether real or perceived, scientifically justified or completely false, these perceptions can shape fisheries by influencing marketing, demand and product flow. In the fisheries sector, impacts can include overexploitation of both target and non-target stocks, damage caused to the environment by lost or discarded fishing gear, "ghost fishing" and pollution caused by discards, as well as the "carbon footprint" of fishing and baiting operations. The most recent estimates of non-target, associated and dependent species (NTAD) taken by global fisheries is of 7.3 million tonnes annually, 63% of which results from trawl fisheries with only 5% of the total from all tuna fisheries combined.

There is general agreement that this level of waste is unacceptable. Furthermore, although retained non-target catch may be recorded and reported to flag state authorities and Regional Fisheries Management Organizations (RFMOs), no track is usually kept of discards of dead organisms, whether or not of target-species, resulting in wastage and distortions of data sets used for stock-assessments. A clear distinction should therefore be made between bycatch and discards.

This study, based on official statistics and published material, concentrated on pole-and-line, purse seine and longline tuna fisheries of the Indian Ocean, which, although representing less than half the region's tuna landings, are the only sectors having sufficient statistical data and governance to permit analysis and the application of mitigation measures. It should be noted that, while often having significant non-target catch, artisanal fisheries rarely discard and fully utilize their retained catch.

Various Non-governmental organizations (NGOs) have embarked on media campaigns and direct action, pressuring markets to source surface tuna fishery products from pole-and-line and FAD[1]-free sources alone.

NTAD fishing mortality and discarding practices are reviewed here from pole-and-line, purse seine and longline fisheries in the Indian Ocean to establish the environmental impact of each fishery. Where possible, measures to mitigate unwanted NTAD mortalities are proposed.

The target species of the surface fisheries are skipjack, yellowfin and bigeye tunas. In the longline fishery, the latter two species are joined by albacore, swordfish, and now by blue sharks for some fleets. Management of tuna fisheries is under the responsibility of the Indian Ocean Tuna Commission which has determined that none of the target species of the surface fishery are at present overfished, although the level of exploitation of albacore by the longline fishery is unsustainable. Skipjack is however the most robust stock, the other two tropical oceanic species being longer lived and slower maturing, thus more vulnerable to overexploitation, with possible interactions between surface and high value longline fisheries.

The free-school purse seine fishery has by far the lowest bycatch (1.7%), but with only 20% skipjack, the most robust species and 80% yellowfin and bigeye tuna which are more sensitive to overfishing. Skipjack catches rise to 61% in the FO[2] purse seine fishery, but with 5.3% bycatch. In the two fishing modes combined, the bycatch level is 3.55%, 54% of which were neritic tunas and albacore. No bycatch species are threatened, and the tonnage of each is too small to impact stocks. Piracy has changed fleet operating patterns towards FO directed effort. A number of mitigating measures are

1 **F**ish **A**ggregating **D**evices are used to concentrate and hold fish in seasons when purse seining would not normally be possible in the absence of a well-defined thermocline.

2 Floating Object; includes virtually anything floating at or near the surface that can aggregate tuna

being studied in the context of the EU-MADE[3] and ISSF[4] projects.

In the pole-and-line fishery, skipjack with some yellowfin and bigeye tunas make up 87% and bycatch 4.3% and bait 8.3% of landings. As in the purse seine fishery, most of the bycatch, largely neritic tunas, is canned for local consumption or consumed fresh. In addition, the fuel used by pole-and-line fleets is estimated to be twice that of purse seine fisheries per tonne of catch.

By far the largest incidence of bycatch and of discards in the Indian Ocean tuna fisheries studied here comes from longline fisheries. Bait used in the fishery, which can be considered a "discard", amounts to half the total catch. Bycatch consists of 87 species or species groups, including sharks, seabirds and turtles, many of which are listed by the International Union for the Conservation of Nature (IUCN) as being threatened or endangered. Mitigation measures appear to have reduced seabird mortality in temperate waters, but in those fleets not targeting sharks, the actual shark catch was probably up to three times that reported.

The Portuguese fleet that utilizes wire leaders records high mortality levels of blue, mako, silky, whitetip and thresher sharks while 75% of blue sharks and most rays appears to survive.

The France-Réunion fleet which uses monofilament nylon leaders registered 80% reduction in the number of sharks caught. Mitigation measures could thus include mandating the use of nylon leaders in those fleets not targeting sharks.

Other mitigation measures suggested include full catch retention, which would improve food security and nutrition in coastal communities where bycatch is landed and mandatory monitoring of tuna vessels via observer programs or remote sensing devices.

The potential to replace floating object-associated purse seine catches by pole-and-line or FAD-free production is also examined. A total ban on FO sets in the purse seine fishery is not seen as a viable option as it might result in the purse seine fleet leaving the Indian Ocean, with disastrous consequences to the economies of coastal countries providing services to the industry and processing fish, as well as massive loss of employment. Substituting pole-and-line production for purse seine would actually result in a six fold increase in catch of non-target species and doubling the fuel used in the fishery. Finally, lack of baitfish stocks and human resources experienced with the pole- and- line method, as well as of investment capital are seen as major barriers to the expansion of the pole-and-line fishery. Realistically, landings by pole-and-line will never be able to supply the volume of raw materials that purse seine produces for the canning industry.

This study concludes that the Indian Ocean tuna fisheries discussed in this paper have a very low level of bycatch, particularly in comparison with other gear types fisheries. The level of discarding also appears to be negligible, other than that of sharks in some longline fleets.

3 Mitigating adverse impacts of open ocean fisheries
4 International Sustainable Seafood Foundation

Introduction

Public awareness and concern over the environmental impact of food production and security is rising rapidly. Whether real or perceived, scientifically justified or unfounded, these perceptions can shape fisheries by influencing marketing, demand and product flow. In the fisheries sector, impacts can include overexploitation of both target and non-target stocks, damage caused to the environment by lost or discarded fishing gear, “ghost fishing” and pollution caused by discards or, in aquaculture, unconsumed feed and waste products, as well as the “carbon footprint” of fishing and baiting operations and socio-economic elements, notably in developing coastal countries.

In the seminal paper on the subject of bycatch, Alverson *et al*. (1994) estimated that an average of 27 million tonnes (t) of fish were “discarded” annually, equivalent to 30% of the world fish landings, although the report stated that *some of this fish may have been landed and consumed*[5]. Levels of bycatch are now believed to be falling and have been estimated (using a different methodology) at 7.3 million tonnes annually between 1992 and 2001 (Kelleher, 2004)[6].

Whatever the levels are, there is general agreement that these levels of waste is unacceptable. Furthermore, although retained non-target catch may be recorded and reported to flag state authorities and RFMOs[7], no track is usually kept of discards of dead organisms, whether or not of target-species, resulting in distortions of data sets used for stock-assessments.

Driven by these concerns, NGOs[8] have embarked in publicity and direct action aimed at consumers and fish buyers in Europe advocating that coastal states develop domestic pole and line fisheries, which have the potential to be the most environmentally friendly method of fishing skipjack, condemning purse seining, in particular on Fish Aggregation Devices (FADs) (Stone *et al* 2009).

The elements cited by environmental NGOs include:

1. *Skipjack are fully exploited in the Indian Ocean;*
2. *Bycatch from FADs is unsustainable (including turtles, sharks and juveniles of yellowfin and bigeye tuna;*
3. *Distant water tuna fishing fleets provide little economic or social benefits to coastal states (a mere 6% of value of tuna caught in coastal waters);*
4. *Pole and line fisheries have the potential to be the most environmentally-friendly method of fishing skipjack if managed correctly. As the fish are caught one-by-one, the operation can be stopped at any stage if undersized fish get hooked.*
5. *The quality of pole and line caught skipjack is also much higher than that of fish caught using other methods, as every fish caught is brought on board alive.*
6. *The average cost of producing a ton of tuna caught with pole and line in the Eastern Pacific is about half the average cost of producing a ton of tuna caught by a purse seiner in the Eastern Pacific;*

5 The paper did point out, however, that pelagic purse seines had relatively low levels of bycatch.
6 63% from trawl fisheries and only 5% from tuna fisheries
7 Regional Fisheries Management Organizations
8 Non-governmental Organizations

7. *For coastal states, pole and line fisheries also offer greater employment opportunities;*

However, the same report states that:

8. *Pole and line is comprised of two interlinked fisheries; one for live bait and one for tuna. The target species of pole and line fisheries are skipjack, albacore or yellowfin tuna. In skipjack fisheries, between 70-100% of the final catch is the target species. Most of the remaining catch is other species of tuna, including juvenile yellowfin, which is mostly kept on board and used for local consumption.*
9. *Anecdotal discussions suggest that 70-80% of the skipjack in the Maldives is now caught around anchored FADs.*

The newly-created IPNLF[9] states: "*Pole-and-line is regarded as the most responsible way to fish tuna"*. and "*[Large-scale industrial fleets] provide little opportunity for employment and revenue flows to large enterprises – not to fishing communities.[10]"* and "*Our strategy is clear: engage the global markets to support procuring and sourcing from more equitable and sustainable tuna fisheries..."*

The current study, based on official statistics and published material, examines the potentially negative ecological impacts of the different export-oriented tuna fisheries in the Indian Ocean, both in absolute terms and in comparison with other fishing activities. It also examines potential measures to mitigate these impacts and compares the assertions of NGOs listed above with verifiable sources.

Definitions and concepts

The various uses of the term "bycatch" cause considerable confusion. In addition to "bycatch" having several meanings, there is the additional difficulty of applying the concept to small-scale fisheries. "Bycatch" and "target catch" can be relatively clear in large-scale fisheries of developed countries where there is an objective of capturing fish for particular market chains, but these concepts become increasingly irrelevant in the progression to small-scale fisheries in developing countries where almost everything in the catch has economic or subsistence value and can become a target (Gillett, R. 2011). Many of the small-scale fisheries that capture tuna, are truly multi-species – with the "target" being almost any type of fish. Alternatively, for some of the other fisheries covered in this report, there are specific targets, but they are not tuna (i.e. tuna could be considered a bycatch).

The word "bycatch" in the context of this study includes non-target marine organisms (non-target fin-fish, cetaceans, sea turtles, sharks, etc.), *whether retained and sold or discarded* (**bycatch or incidental catch**). Bycatch is a feature of virtually all fisheries and can sometimes be mitigated, but not totally avoided. In certain circumstances, notably most small-scale fisheries where all the catch is consumed, retained bycatch may have a high value.

Discards are a pernicious form of bycatch as they represent a waste of edible fish. Moreover, discarded organisms are virtually never reported in the absence of observers, which results in a distortion of data used in stock assessment.

9 International Pole-and-line Foundation

10 Data from the Indian Ocean Commission MCS project placed revenue to the western Indian Ocean islands at €500 million annually and employment in service industries at some 30,000 full- and part-time jobs.

These discards generally consist of:

- species which cannot be marketed or for which a viable market does not currently exist:
  - sharks, rays, triggerfish, seabirds, etc.
  - tuna-like species for which a market does not exist for the fishery (kawakawa, frigate, bullet tunas)
  - poor anticipated shelf life (eg dolphinfish which spoil easily) or from salt contamination in seiner wells
  - baitfish and accidental catches of associated species while baitfishing

- target species
  - sizes too small for the markets
  - heavy metal contaminants at large sizes (eg swordfish)
  - crushed by the gear
  - spoiled due to long immersion in the sea after death
  - depredation damage (predation by sharks, cetaceans or squid)
  - discarded due to lack of storage space at the end of a trip
  - discarded through the practice of "high-grading", particularly in quota-managed fisheries where only the highest value fish are retained[11].

The notion of discards is complicated further by the fact that some organisms such as large sharks, marine turtles and cetaceans are usually released alive and frequently survive. While observers routinely record these occurrences, most logbook formats do not permit this distinction and scales for condition factor are not standardized. There is also a shortage of studies that actually track or document post-release condition of discards through the use of satellite tags or observation in post-release confinement.

Issues to consider in relation to bycatch include:

(a) Is the species truly threatened or endangered (or the subject of particular concern such as cetaceans, marine turtles, sharks and seabirds)?
(b) Will reduction of the species have knock-on ecological effects (negative or positive)?
(c) What use is made of the landed bycatch?
(d) What measures could be taken to reduce bycatch (including exploiting the target species with other fishing methods)?

Issues related to target catch

The term **target catch** is used here only as a descriptor of the different fisheries, as targeting of particular species is evolving as new markets are developed and "retained bycatch" is now virtually all consumed, often distributed free[12] after sorting when landed. Two issues remain, however, related to the size of fish in the catches.

11 Longliners routinely discard tunas which are too small for the sashimi market These vessels used to discard billfish as well, but rarely do so now as the value of these species has risen.

12 In certain cases, free distribution of bycatch has undercut the traditional markets of small-scale fishers with undesirable social effects, even though food security may have been enhanced.

Yellowfin and bigeye tunas in surface fisheries

The principal target of surface tuna fisheries (pole-and-line and purse seine) is the skipjack tuna that is the primary raw product for canning, also used by the Maldivians and Japanese for specialty dried products. The stocks are generally considered to be “robust” in that the species is fast-growing, reproducing in the first year with rapid turnover, are widely distributed and accessible in high volume in tropical and sub-tropical waters of all the oceans.

Some authors consider bigeye and to a lesser extent yellowfin tunas as a “bycatch” of the surface fisheries (e.g. the recent assessment for MSC of the Maldives skipjack pole-and-line fishery). These species are longer lived, reproduce later and are thus more susceptible to over-exploitation. These two species are also targeted by longline fisheries when they have a far higher value in the sashimi markets. There is thus an issue of interaction between the longline and purse seine fisheries. Finally, the capture of small fish can contribute to “growth overfishing” and to a reduction of the reproductive potential of the stocks.

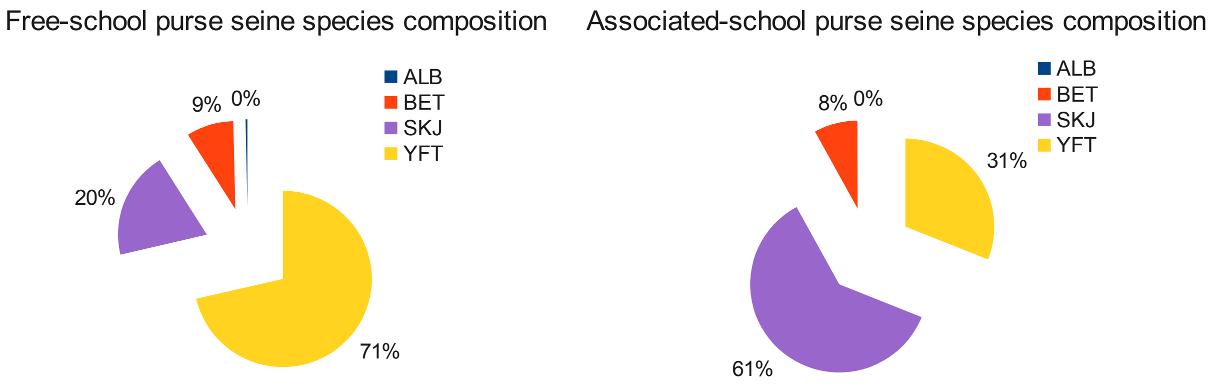

Figure 1: Free- and associated-school species composition, 2010 (IOTC)

However, free-school purse seine sets catch less than 20% skipjack in the Indian Ocean[13] (Figure 1) and there is thus little justification for considering these two species as not forming part of target catch, although there may be a case to consider specific mitigation measures to limit their exploitation in surface fisheries because of growth overfishing and the fishery interactions identified above.

Furthermore, in purse seine FO[14] sets and in pole-and-line catches, the contribution in weight of the predominantly juvenile fish is modest, while the removals in numbers at sizes where natural mortality is falling might have a disproportionate effect on stock status[15] (Figure 2).

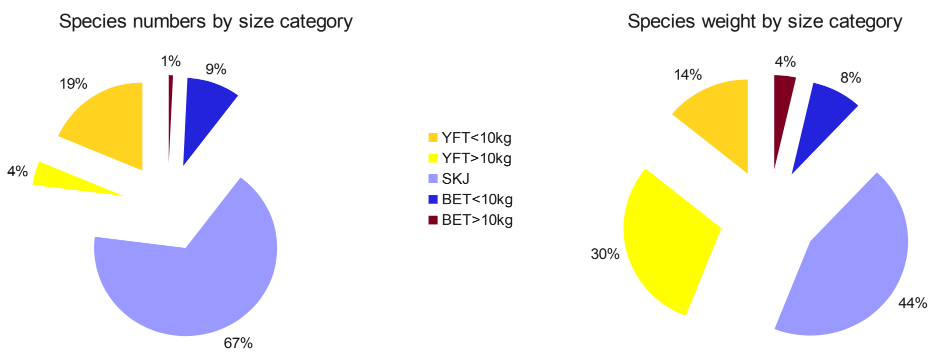

Figure 2: Species and size composition in Indian Ocean purse seine FAD catches 2000-2006 (Fonteneau, 2007)

Observers reported that least 15% of the target species are under the commercial size of 40cm FL (Amandé *et al.* 2008) which do not enter the cannery trade in the Indian Ocean, but seiner skippers now try to avoid setting on such small fish, not least because of the possibility of meshing in the nets and the loss of fishing time from catching and releasing unwanted fish.

Fish sizes by gear

Figure 3 below shows the evolution of the sizes caught by various gears:

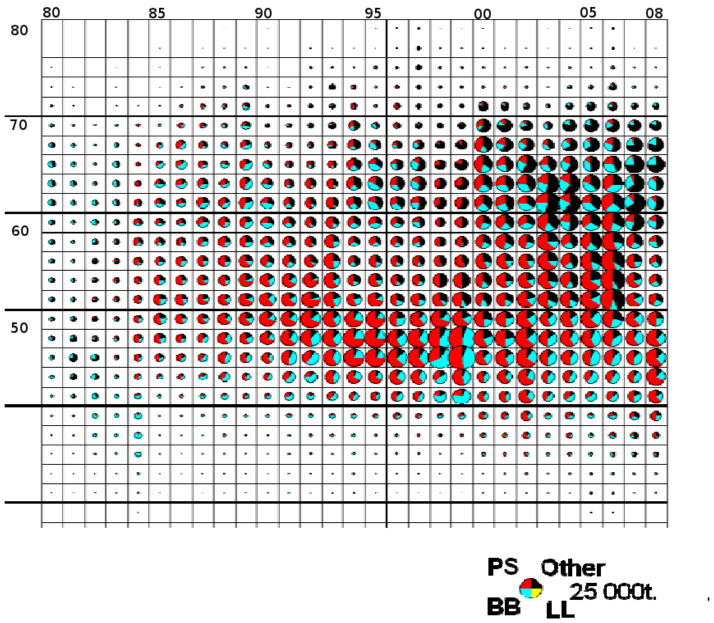

Figure 3: Fish sizes by gear and year

Purse seine fisheries catch the whole range of sizes between 40 and 70cm FL, whereas pole-and-line catches show two modes, below 50cm and above 60 cm FL[16]. As pole-and-line production is about one third that of purse seine production, it appears that the proportion of small fish is greater from this fishery.

Indian Ocean tuna fisheries included in this study

Indian Ocean tuna fisheries support a wide range of economic activities. Artisanal fishing is a significant contributor to employment and nutrition, while large-scale fishing is associated with revenue derived from foreign fishing access, onshore processing and payments for supplies and port fees. The total value of the tuna catch in the Indian Ocean is not well understood. Several estimates of the landed value of the catch are in the range of €1.5 to 3 billion, with the relatively high prices paid for artisanal catches a major factor in the large over-all value.

More than half Indian Ocean tuna catches are made by small-scale gears. The largest tuna catch by gear is now from driftnet fisheries, which now report catches of more than 650,000 t (IOTC[17] Nominal Catch data). Driftnets of more than 2.5,km in length are banned by decision of the UNGA, but there are virtually no controls on the 3,000 vessels using this gear

16 Sharp (*pers.comm.*) suggested that skipjack associated to coastal areas have a slower growth than those involved in trans-oceanic migrations.

17 Indian Ocean Tuna Commission

(Fonteneau, 2011). Another difficulty in trying to gauge the severity of the impact of gillnets on species of special concern in the Indian Ocean, as well as in other regions, is expressed by Northridge (1991): "*For most of the gillnet fisheries of the world, information on catch rates is too poor to make any reasonable estimate of total catches of non-target species*". In the absence of observer or other reliable data, driftnet fisheries will not be considered in this study, despite the fact that this gear is known to have particularly high bycatch, including species such as turtles, cetaceans and sharks which are listed as endangered by IUCN[18]. It should be noted, however, that artisanal fishers rarely discard "non-target" catches, which are all consumed.

Handline, troll-line and ringnet fisheries are other artisanal gears catching tunas and are also not considered further for the reasons enumerated above.

The following fisheries for which there is sufficient data for study are all oriented towards the international export markets:

1. The Maldives pole-and-line fishery, including the associated bait fishery;
2. Longline:
   - 2.1. Asian tropical and temperate tuna longline;
   - 2.2. Spanish and Portuguese swordfish longline;
   - 2.3. French swordfish longline;
   - 2.4. South African longline;
   - 2.5. Indonesian longline.
3. European purse seine

IOTC Resolutions – the regulatory framework

Management of Indian Ocean tunas is under the responsibility of the Indian Ocean Tuna Commission (IOTC)[19]. Under the provisions of UNCLOS and of its Fish Stocks Agreement[20], all Parties fishing for tunas in this ocean are obliged to adhere to this commission and to implement its decisions. Its mandate includes the collection of official statistics and the organisation of scientific sessions dealing *inter alia* with stock assessment and issues related to the management of the tuna stocks.

IOTC has taken a number of resolutions related to reporting of data on bycatch in Indian Ocean tuna fisheries.

At the 2007 meeting of the Commission the name of the WPBY[21] was changed to the Working Party on Ecosystems and Bycatch (WPEB) and its terms of reference were expanded. The terms of reference emphasize

1. monitoring bycatch, improving the statistical database for all fleets, and improving information on interactions with species not under the mandate of IOTC;

18 The International Union for the Conservation of Nature

19 The Southern bluefin tuna are managed by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT)

20 The 1995 United Nations conference on straddling fish stocks and highly migratory fish stocks: agreement for the implementation of the provisions of the United Nations Convention of the Law of the Sea of 10 December 1982, relating to the conservation and management of straddling fish stocks and highly migratory fish stocks.

21 Working Party on Bycatch

2. research to evaluate the impact of both abiotic and biotic factors affecting abundance, distribution and migration of IOTC species;
3. development and monitoring of reference points and indicators that incorporate ecosystem considerations; and
4. development of mechanisms which can be used to better integrate ecosystem considerations into the scientific advice provided by the Scientific Committee to the Commission.

Resolution 05/05 calls on CPCs[22] to annually report catches of sharks, requests the Scientific Committee to provide preliminary advice on the status of key shark species and propose a research plan for comprehensive assessment of these stocks of sharks, calls on CPCs to undertake research to identify ways to make fishing gear more selective, calls for full utilization of captured sharks, and provides a number of guidelines regarding shark finning. It also requires that the total weight of shark fins on board not exceed 5 percent of the weight of sharks on board, and encourages the live release of all sharks taken incidentally to other targeted species.

Resolution 09/06 calls on all CPCs to require their fishermen to make every effort to avoid the incidental capture of turtles and, when captured, to release them alive. Purse-seine operators are requested to avoid encirclement of sea turtles to the extent practicable, to develop and implement appropriate gear specifications to minimize bycatch of sea turtles, to monitor FADs and release entangled sea turtles as quickly as possible and to remove the FADs when not in use. Longline operators are asked to develop and implement appropriate combinations of hook design, bait type, gear specifications and fishing practices in order to minimize bycatch of turtles, and are requested to retain on board and use de-hookers, line cutters, and scoop nets for releasing turtles.

IOTC has also approved three resolutions dealing with the conservation of seabirds. One resolution, approved in 2005, calls on CPCs to implement national plans of action for reducing incidental catches of seabirds in longline fisheries which are complementary to the IPOA-Seabirds. The resolution also encourages CPCs to collect information on interactions with seabirds, including estimates of mortality caused by vessels fishing under their flag. The second resolution, approved in 2006, notes that the ultimate aim of the IOTC and the CPCs is to achieve a zero bycatch of seabirds in longline fisheries, especially threatened albatross and petrel species. In an additional resolution approved in 2006, the Commission set a number of guidelines for design and deployment of tori lines. The most recent resolution approved in 2008 for seabirds specifically requires longline vessels fishing south of 30°S to use any two of the following measures to reduce seabird bycatch: night setting, bird-scaring devices such as tori lines, weighted branch lines, blue-dyed bait, line-shooting devices, and offal control. Longline vessels fishing north of that line are required to use only one of the methods.

Finally, Resolution 10/01 establishing time-and-area closures for longline and purse seine fisheries in the Somali Basin is aimed at reducing the catch and the mortality of juvenile yellowfin and bigeye tunas.

22 IOTC Contracting Parties (or Cooperating Non-Contracting Parties)

Stock status of target and bycatch species

The "target species"

The "target" species for the longline, pole-and-line and purse seine fisheries include Albacore, Bigeye, Yellowfin and Skipjack tunas, as well as Swordfish. The most recent stock-assessments conducted by IOTC concluded that:

- **Albacore** (exploited by the longline fishery): It is considered likely that recent catches have been above MSY, recent fishing mortality exceeds FMSY (F2010/FMSY > 1). There is a moderate risk that total biomass is below BMSY (B2010/BMSY ≈ 1);
- **Bigeye** (exploited by all fisheries but only by longlines as target species): Both assessments suggest that the stock is above a biomass level that would produce MSY in the long term and that current fishing mortality is below the MSY-based reference level (i.e. SBcurrent/SBMSY > 1 and Fcurrent/FMSY < 1);
- **Yellowfin** (exploited by all fisheries): The stock assessment model used in 2011 suggests that the stock is currently not overfished (B2009>BMSY) and overfishing is not occurring (F2009<FMSY);
- **Skipjack** (exploited by pole-and-line and purse seine): The weighted results suggest that the stock is not overfished (B>BMSY) and that overfishing is not occurring (C<MSY, used as a proxy for F<FMSY);
- **Swordfish** (exploited by the longline fishery): All models suggest that the stock is above, but close to a biomass level that would produce MSY and current catches are below the MSY level.

Previous assessments had indicated that yellowfin stocks were heavily exploited, but, possibly as an indirect result of the piracy in the western Indian Ocean which have affected both purse seine and longline targeting, the stock has recovered.

The albacore stocks is currently the only subject of concern, in particular as the longline fleets that traditionally targeted tropical tunas have moved to temperate waters, targeting albacore. While yellowfin and bigeye tuna catches have dropped in recent years, albacore catches have continued to rise. Piracy (see Figure 4) has thus changed the targeting of the longline fleets, putting additional pressure on the most heavily exploited stock.

Neritic tunas and billfish

The estimated bycatch of neritic tunas by oceanic purse seines is of 5,200 t (Table 5). This is a small proportion of the 129,000 t of kawakawa caught in 2010 from mainly coastal fisheries (IOTC-NC), 60% of which was from ringnet gear in the eastern Indian Ocean, with most of the balance from the northern Indian Ocean. The same is true of frigate and bullet tunas, which had landings of 38,000 t in 2009 (FAO-FishStatJ). Over the last five years, the Maldives catch of kawakawa has averaged nearly 4,000 t, while that of frigate tuna averaged 2,500 t.

Total Indian Ocean billfish catches in 2010 were reported at 44,000 t, 50% of which were sailfish. Here again, the purse seine bycatch of 149 t is negligible in comparison.

It is unlikely, therefore, that the surface fishery bycatch could influence the stock status of neritic tunas or billfish.

Other finfish

Of the 50 or more species of other finfish in the purse seine bycatch, the only significant quantities are of rainbow runner (1,200 t), oceanic triggerfish (776 t) and dolphinfish (356 t). All these species are pan-oceanic, short-lived and have high reproductive capacity, such that the relatively small amounts caught by seiners cannot impact on the stocks.

Shark catches

Prior to the adoption by IOTC of resolution 05/05, there was no requirement for sharks to be recorded at the species level in logbooks. As a consequence, it is only since 2008 that some very patchy statistics are becoming available on shark catch, mostly representing retained catch and not accounting for discards.

Blue sharks

The blue shark (*P. glauca*) which is now a target species for some longline fleets, notably Spain and Japan which have the most complete data. Available records for longline catches total about 5,500t for 2010. If Spanish CPUE is applied for the European fleets and Japanese CPUE for Asian fleets, the actual catches are could be as high as 13,775 t, or 725,000 fish, suggesting a discard of 8,400 t.

The practice of shark finning is considered to be regularly occurring and on the increase for this species (Clarke 2008; Clarke *et al*. 2006) and the bycatch/release injury rate is unknown but probably high. Preliminary estimations of mortality at haulback showed that 24.7% of the blue shark specimens captured in longline fisheries targeting swordfish are dead at time of haulback. Specimen size seems to be a significant factor, with larger specimens having a higher survival at haulback (Coelho *et al*. 2011a).

There is no quantitative stock assessment and limited basic fishery indicators currently available for blue shark in the Indian Ocean, therefore the stock status is highly uncertain. Blue sharks are commonly taken by a range of fisheries in the Indian Ocean and in some areas they are fished in their nursery grounds. Because of their life history characteristics – they are relatively long lived (16–20 years), mature relatively late (at 4–6 years), and have relativity few offspring (25–50 pups every year), the blue shark is vulnerable to overfishing. Blue shark assessments in the Atlantic and Pacific oceans seem to indicate that blue shark stocks can sustain relatively high fishing pressure.

Shortfin Mako sharks

Again, a reconstruction of possible catches based on CPUE of the different fleets would give catches of over 1,585 t for the shortfin mako sharks (*Isurus oxyrinchus*), but a similar exercise was not possible for the other species. Data are not available at the IOTC Secretariat for stock assessment, but historical research data shows overall decline in CPUE and mean weight of mako sharks (Romanov *et al.* 2008). CPUE in the South African fisheries is fluctuating without any trend (Holmes *et al.* 2009).

Oceanic Whitetip shark

There is no quantitative stock assessment and limited basic fishery indicators currently available for oceanic whitetip sharks (*Carcharinus longimanus*) in the Indian Ocean therefore the stock status is highly uncertain. Oceanic whitetip sharks are commonly taken by a range of fisheries in the Indian Ocean. Because of their life history characteristics – they are relatively long lived, mature at 4–5 years, and have relativity few offspring (<20 pups every two years), the oceanic whitetip shark is vulnerable to overfishing. Despite the lack of data, it is apparent from the information that is available that oceanic whitetip shark abundance has declined significantly over recent decades.

The practice of shark finning is considered to be regularly occurring for this species (Clarke 2008; Clarke *et al.* 2006) and the bycatch/release injury rate is unknown but probably high. At-haulback mortality of oceanic whitetip sharks in the Atlantic ocean longline fishery targeting swordfish was estimated to be at 30.6% (Coelho *et al*., 2011). Reported catches in 2010 were of 450 t, but it is likely that catches were considerably higher.

Silky sharks

There is no quantitative stock assessment or basic fishery indicators currently available for silky sharks (*Carcharinus falciformis*) in the Indian Ocean, therefore the stock status is highly uncertain. Silky sharks are commonly taken by a range of fisheries in the Indian Ocean. Because of their life history characteristics – they are relatively long lived (over 20 years), mature at 6–12 years, and have relativity few offspring (<20 pups every two years), the silky shark is vulnerable to overfishing. Despite the lack of data, it is clear from the information that is available that silky shark abundance has declined significantly over recent decades. The practice of shark finning is considered to be regularly occurring and on the increase for this species (Clarke 2008; Clarke *et al*. 2006) and the bycatch/release injury rate is unknown but probably high.

Reported landings in 2010 were of 1,153 t, compared to the 5-year average (2006-2010) of 670 t.

Other sharks and rays

Finally, the thresher sharks (*A. vulpinus* and *A. superciliosus*) are all discarded, as are all the sharks and rays caught in small numbers (Appendix 1).

IUCN classification

The classification established by the IUCN Shark Specialist Group (Camhi *et al.* 2009) on the status of sharks caught by various Indian Ocean fisheries is given in Appendix I.

Virtually all the sharks and rays listed are classified as being “Near endangered” to “Vulnerable”. The blue, mako and porbeagle sharks are caught mainly by longline fisheries, but silky and oceanic whitetip sharks are caught, mainly at small sizes, in FO purse seine fisheries.

Bycatch and discards in tuna fisheries

Pole-and-line, including their associated bait fishery

Pole-and-line fishing with livebait has been practiced in Maldives for over 1000 years (Gibb, 1929). This is still the main pole-and-line fishery in the Indian Ocean, together with small fisheries in the Lakshadweep islands to the north and in South Africa, targeting albacore. Pole-and-line landings reached a high of 167,000 t for the Indian Ocean in 2006 but have since fallen to 72,657 t (2010), of which 56,496 t were the primary target skipjack, 11,036 t of yellowfin and bigeye and 5,126 t of non-target tuna species (frigate and bullet tunas) which were retained and thus presumably consumed. The catch of other non-target species (mostly dolphinfish and rainbow runners) is negligible and is not reported (M. Shiham Adam, *pers. Comm.*). These fish are landed and consumed.

The Maldives fishery depended originally for bait on various small coral-dwelling baitfish (cardinalfish, damselfish...), whereas now the major bait species are silver sprat, blue sprat and Indian anchovy[23] which are all fast growing, fast reproducing fishes with high rates of natural mortality (Lewis, 1990; Dalzell, 1993). Anderson (2009) used the relationship between the potential yield from small pelagic fisheries in tropical coastal waters and primary productivity to estimate MSY for baitfish to be 13,000 t (±2,000 t). Using the tuna to bait ratio of 8.6 to 1, the 2010 catch of 72,657 t would require 8,448 t of baitfish. It has also been estimated that up to 30% of the baitfish caught can be unspecified lagoon fish (Anderson *et al.* 1995), which could be a subject of concern, although it is now reported that 95% of the bait used is from the light fishery (Adam *pers.com.*) where capture of juvenile lagoon species would be minimal (Anderson 2009).

The baitfish are the only significant bycatch (species caught in the process of the fishery) of the pole-and-line fishery, amounting to some 11.6% of the catch of target tunas.

Longline

Asian tropical and temperate tuna longline

Longline fishing was initiated by the Japanese fleet in 1952 and rapidly spread over the whole of the Indian Ocean (Figure 4). Korean, Taiwanese[24] and Chinese freezer fleets followed, joined later by over 1,000 small Indonesian fresh fish longliners which fish with fewer hooks but otherwise in a similar manner to the deep-feezer longliners.

23 MRC (2011) indicates that the livebait fishery is a multi-species one. Over 40 different species have been recorded, but less than a dozen dominate the catch. The single most important bait species in the Maldives is the silver sprat (*Spratelloides gracilis*).

24 A Taiwanese drift gillnet fishery exploited albacore stocks for several years until this gear was banned by decision of the UNGA.

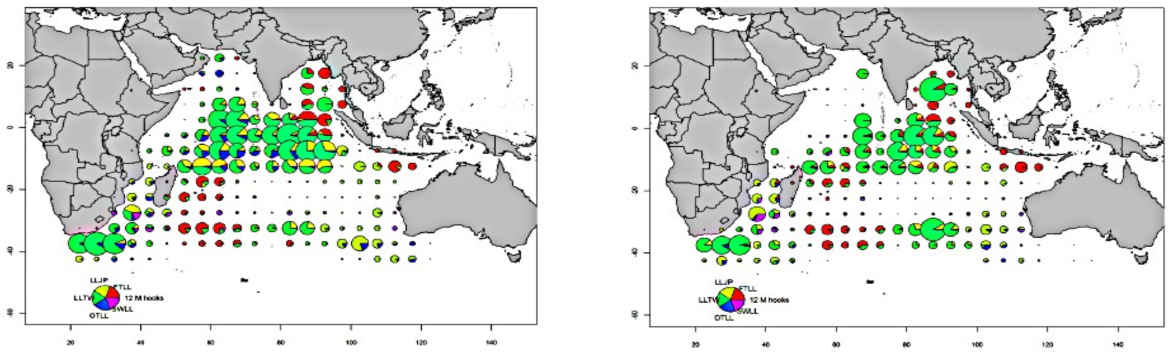

Figure 4: Number of hooks set (millions) from longline vessels by five degree square grid and main fleets, for the years 2009 (left) and 2010 (right) (Data as of August 2011) (Source IOTC 2011)

Figure 4 shows the progressive movement of the fleets away from the East African coast which was previously one of the most heavily exploited areas due to piracy. Much of the effort was redistributed towards the eastern basin of the Indian Ocean and notably to temperate waters.

This fishery can be divided into four sectors:

1. The fishery for tropical tunas which targets mainly yellowfin and bigeye tuna for the sashimi market;
2. The southern bluefin fishery for sashimi, managed by the CCSBT and exploiting southern latitudes and which is not studied here;
3. The albacore fishery, virtually all Taiwanese: most of the fish is transhipped in Mauritius and is destined to the US canned fish market; and
4. The swordfish fishery.

The large freezer vessels involved are all of the same type and can easily transfer from one fishery to the other, as gear and bait modifications can be effected “on the fly”. Sashimi-grade fish is frozen and stored at ultra-low temperatures, whereas cannery fish is generally placed in holds at above -35°C.

Bycatch data reported by longline fleet

Reporting of bycatch is extremely inconsistent depending on the fleets concerned, with only retained catch reported in most cases. An attempt is made here to estimate the missing data using the CPUE[25] provided by observers or from those fleets which were thought to have reported accurately. This was only done for the two most common sharks in the longline catches.

Because of differences in targeting of the various fleets, the estimates were made considering the fleets targeting tunas and those fishing for swordfish, as the latter is normally a night fishery using shallow longlines which have shark catch rates twice as high as the deep day sets used for tropical tunas. It should be noted, however, that the figures arrived at can only be considered as a first approximation, as the fleets do not necessarily operate at the same latitudes. Blue, mako and porbeagle sharks are much more abundant in temperate waters

25 **C**atch **p**er **U**nit of **E**ffort

where southern bluefin and albacore tuna fisheries operate, while silky and oceanic white-tip sharks are more common t in tropical waters.

Japan

In 2010, 84 Japanese longliners were fishing in the Indian Ocean, with a total effort of 37.6 million hooks for a total catch of 17,579 t, including 1,008 t of retained sharks. In August 2008, the Japanese government required Japanese distant water longliners to land all the parts of sharks (although heading, gutting and skinning are allowed). The quantities given in Table 1 represents the whole weight including the weight of fins (Anon, 2011b) for the three most common shark species in the longline fishery. The reported shark landings in 2010 from this table were actually slightly higher than those reported to IOTC and presumably do not include releases alive. Prior to 2008, it would seem that only mako sharks were systematically retained and reported in logbooks.

year	Blue shark		Porbeagle		Mako shark	
	tonnes	number	tonnes	number	tonnes	number
2006	228	13,633	16	896	162	4,083
2007	452	25,993	8	607	122	3,190
2008	1,280	67,992	35	2,515	156	4,399
2009	1,518	73,053	17	1,087	116	3,096
2010	905	49,734	9	866	137	3,220

Table 1: Shark catches by year in the Japanese distant water longliners (Source Anon 2011b)

SHARKS	number		RAYS	number
Unidentified sharks	3		Sting ray	549
Velvet dogfish	126		Unidentified Sting ray	1
Unidentified thresher shark	12		SEABIRDS	
Unidentified mackerel shark	4		Unidentified albatrosses	1
Shortfin mako shark	32		Wandering albatross	1
Longfin mako shark	4		Black-browed albatross	2
Porbeagle	54		White-capped albatross	1
Silky shark	3		Yellow nosed albatross	2
Oceanic whitetip shark	10		Unidentified petrels	1
Tiger shark	2		Flesh-footed shearwater	2
Blue shark	961		Unidentified gannets & boobys	1
Scalloped hammerhead shark	1		SEA TURTLES	
Smooth hammerhead shark	1		Loggerhead turtles	1
Bigeye thresher shark	162		Olive ridley turtle	12
			Leatherback turtle	1

Table 2: Summary of bycatch information collected by 6 observers (vessels) after the IOTC ROP started (July, 2010-January, 2011) (Source Anon 2011b)

Table 2 lists the incidence of bycatch species in the Japanese longline catches collected by observers. Numbers released alive were not recorded.

Korea

The number of Korean longliners in the Indian Ocean has dropped in recent years and was reported as 13 in 2009. The total catch was reported as 2,724 t in 2010, including 11 t of sharks and 628 t unspecified fishes (NTAD), similar to 2009 levels, albeit with an increase in the effort from 3.8 to 5.1 million hooks. It would seem that only the sharks retained on board were reported as, assuming the same catch rates as for the Japanese fleet, shark catches of the order of 144 t would have been expected, bringing the discard level to some 770 t.

Taiwan

Taiwan has the largest longline fleet in the Indian Ocean, with 196 vessels which set 163.5 million hooks in 2010. The total reported catch was 61,996 t, including 2,965 t of sharks and 2,404 t NTAD. Again, using Japanese CPUE, the catch of the two main species of sharks should have been of the order of 4,530 t, indicating a high level of discards. This could well be an underestimate, as, outside the southern bluefin season, the Japanese fleet fishes in more equatorial waters than the Taiwanese fleet, which tends to target albacore and swordfish in more temperate waters where catches of blue, mako and whaler sharks are generally higher.

China

The Chinese fleet set 15 million hooks in the Indian Ocean in 2010, for a total reported catch of 4,760 t, including 405 t of sharks and 215 t of NTAD. These figures are indicative of a high level of discards as, using the Japanese CPUE as comparator, 417 t of blue and shortfin mako sharks would have been expected.

Indonesia

The Indonesian longline fleet in the Indian Ocean was reported as 1,188 vessels. While many of these boats are still small fresh-fish FRP longliners, the recent tendency has been for this class of boats to set nearly as many hooks as the larger deep-freezing vessels. The tuna catches reported to the IOTC Scientific Committee in 2011 was 45,167 t. The IOTC Nominal Catch database gives 3,074 t of billfish in addition, together with 1,447 t of sharks and 1,184 t of NTAD. Applying the Japanese CPUE to the total catches again gives possible combined blue and mako shark catches of 3,900 t.

Spanish and Portuguese swordfish longline

Data from a Spanish experimental longline cruise (Lezama *et al.* 2011) provided valuable information on discards and bycatch to the WPBY. During that campaign 531,916 hooks representing 539 longline sets were made, and a total of 28,106 individual animals weighing 1,162 t were caught. Of this total, 86 t were returned to the sea as discards, 15 t were discarded due to predation, 40 t were discarded for other reasons and 30 t were discarded bycatch, including 25 turtles, 3 birds and 3 marine mammals, as well as a variety of sharks, rays, and other finfish, most of the latter lancetfish and molas. The mammals and turtles were released back to the sea alive.

2010	Spain	Portugal
Hooks	3,174,705	780,000
Total catch	7,364	2,091
Istiophoridae nei		20
Tunas nei		126
Others nei		88.5

2010	Spain	Portugal
Carcharinus falciformis	60.4	33.6
Carcharinus longimanus	79.0	2.2
Carcharhinus brachyurus	143.1	
Carcharhinus galapagensis	0.2	
Carcharhinus limbatus	6.2	
Carcharhinus obscurus	3.8	
Carcharhinus plumbeus	9.4	
CARCHARHINIDAE (nei)		10.2
Exanthus griseus		0.1
Isurus paucus	0.3	
Isurus oxyrinchus	350.0	120.7
Prionace glauca	2,422.1	661

Table 3: Spanish and Portuguese longline bycatch in 2010 (Anon. 2011c)

Both these fleets use wire leaders, but their practices differ in that the Portuguese longliners discard all sharks, whereas the Spanish fleet now considers blue shark as a target species, such that the reported catches are assumed to be a true reflection of catches.

Comparison of Spanish CPUE with Portuguese catches suggests that the latter are accurate and consistent with slightly larger average size of the sharks in the catches.

French swordfish longline

The French swordfish longline fleet is composed of small vessels operating from La Réunion[26]. These vessels differ from all the other longline fleets in that monofilament nylon leaders are used instead of wire. Their bycatch is therefore influenced by the difference in catchability of this gear, as well as the possibility for certain species to bite through the leader. This offers a comparison of what could be the catches of the other swordfish fleets if the use of nylon leaders were to be generalised. In addition, many of the species which have no commercial outlets in the distant water fleets are readily sold on the Réunion market and are retained. The small size of the vessels may however make the retention of sharks difficult because of damage from contact and contamination of the finfish catch.

From April to December 2007 and from July 2008, observers from IRD took part in pelagic longliner cruises, covering 63,525 hooks. The data collected was entered in the SEALOR database (Bach *et al.* 2008). A detailed list of all the species caught, retained catch and discards was kept. The observers counted 28 bycatch species which were discarded, and 8 which were retained. Sharks represented 46% of discards, mostly alive, with the blue shark amounting to 6.7% of total catches. This is a highly relevant observation, as the corresponding figure in the Spanish and Portuguese catches is 33 and 34.5% respectively. In other words, nearly 80% of the blue sharks were able to release themselves by biting through the nylon leaders. It would appear that both “J” and circle hooks are used in this fleet, and therefore the hook effect cannot be ascertained.

26 Typically less than 25m LOA

South African longline

A study on the South African domestic longline fishery which also had some information on foreign longliners fishing from South African ports was reviewed by the WPBY. The report dealt with only turtles, birds and sharks. A total of 4.1 million hooks were set during 2000-2003 by domestic longliners, and 9% of these were examined for catches of birds, turtles and sharks. In addition to the domestic fishery, about 350,000 hooks set by foreign-flag vessels fishing in the study zone were included in the data base. It was estimated that 0.82 birds per thousand hooks were killed by the foreign fleet and 0.2 birds per thousand hooks by the South African fleet For turtles the catch rate for the domestic fleet was 0.05 animals per thousand hooks, and 85% of all turtles captured were released alive. The catch of sharks for the domestic fleet was 7 per thousand hooks. An update of the South African report was presented to the WPBY at its most recent meeting. The information presented corroborated the earlier data.

South Africa licensed 35 domestic longliners in 2005 (for 10 years) targeting either swordfish or tunas. These boats set 775,825 hooks in 2009, for a reported catch of 1,967 t (Clarke *et al.* 2009) and 518 t of sharks (IOTC – Nominal Catch database). The reported species breakdown was 34.7 t of mako and 76 t of blue sharks, suggesting that these were retained and not total catches.

Blue and mako sharks account for the most common shark species caught in the longline fishery. In total, the weight of blue sharks and mako sharks accounted for 16% of that of the tuna caught by longline vessels targeting tuna. Similarly, these sharks accounted for 32% by the combined weight of tuna and swordfish caught in the longline fishery targeting swordfish, a rate coherent with the Spanish CPUE.

A considerable amount of sharks are released due to the current shark bycatch limit which restricts tuna vessels to a bycatch of 10% of tuna landed. In the swordfish longline fishery, this bycatch limit is 10% of the combined weight of tuna and swordfish. South Africa was exploring the implementation of an “Upper Precautionary Catch Limit” for pelagic sharks for 2008 (Clarke *et al.* 2009).

Average seabird mortality has been estimated at 2,460 birds per annum, from 1998-2005. The three most common species caught in the longline fishery is the white-chinned petrel, the white-capped albatross and the black-browed albatross. The average catch rate for tuna and swordfish-directed longliners combined was estimated at 0.44 birds per1000 hooks. Although catch rates in the tuna-directed fleet is significantly higher than in the swordfish-directed fleet, both fleets are catching birds at a rate much higher the FAO International Plan of Action of 0.05 birds per 1000 hooks. In 2008, South Africa imposed a bird limit (of 25 birds) per vessel per year in its large pelagic fishery as a means of reducing seabird mortality (456 birds were caught for the entire fleet as at 24th November 2009).

Turtle catch rates in the Indian Ocean has averaged 0.05 turtles per 1000 hooks for the years 2000-2003. The most commonly caught in 2008 was the loggerhead (36%) followed by the leatherback (31%). Green and Olive Ridley turtles were also recorded but in small numbers. A small number of turtles (13%) were unidentified by the observer.

Other catches such as billfish have remained low as longline skippers are required through permit conditions to release live billfish. Oilfish and Escolar probably constituted over 70% of the "other" bycatch, with Dorado accounting for 10%. There are a large number of ray and shark species (including crocodile sharks) that are also caught but not reported as they are discarded at sea.

Estimated total Blue shark and Shortfin Mako catches

The catches estimated above from CPUE of the Japanese and Spanish longline fleets give totals for blue and shortfin mako which are roughly three times the reported landings, at respectively 13,775 and 1,583 t, compared to 728 and 525 t. Some of the unreported catches of sharks may have been released alive.

Depredation in longline fisheries

Depredation of fish caught on longlines may be a major problem in that these losses are virtually never reported. Japan is operating a research programme on the subject and reported from 832 longline operations that 32% of depredation was caused by false killer and killer whales and 62% by sharks. Depredation seems higher in longline sets made in proximity to islands as Seychelles and Mauritius reported rates of 19-20%, whereas La Réunion, where the fishery operates offshore, reported 6% of sets were affected (IOTC, 2001). No effective mitigation measures have yet been successful (Hamer *et al.* 2011).

Bait use

As in the pole-and-line fishery, the bait used by longliners should be considered a "discard", although the bait – saury pike for tropical fisheries targeting tuna and squid for those targeting swordfish – is caught in completely different fisheries. No records were found on bait use in Indian Ocean longline fisheries, but on the assumption of an average bait weight of 100 g per hook, some 45,000 t of bait would be needed annually, i.e. half as much as the total recorded catch of longliners in this ocean.

The European purse seine fishery

The tuna purse seine fishery developed in the Indian Ocean during the 1980s and produces 300,000 t of tuna annually, mostly for canning. The main fleet is European owned and operated, although some seiners are flagged in Seychelles. Small fleets were flagged in Japan, which have ceased to operate in the Indian Ocean, and in Iran, fishing mainly in the Arabian Sea.

Purse seine fishing takes place either on free-swimming (FS) schools or on FADs and floating objects (FO) such as trees washed into the sea, and occasionally on schools associated with sea-mounts. The FO fishery has been categorised as having relatively high levels of bycatch compared to other purse seine methods.

The European purse seine fleet is composed of a majority of Spanish vessels (including Spanish-owned seiners under Seychelles flag) and some French seiners. The Spanish seiners, which have support from "supply" vessels, fish almost exclusively on drifting FADs and other FOs, whereas the French fleet set on free schools (FS) during the short season when a well-established thermocline keeps the fish in surface waters.

Logbook data from this fishery consists in estimated catches for each set The estimation error is thought to average about 10%[27]. In addition, catches are reported by commercial species groups, rather than as individual species. Because of this, caches are sampled at

27 Usually under-reporting as skippers are reluctant to appear to exaggerate catches.

landing using a stratified scheme permitting a reconstruction of the species and size composition of sets with each stratum and set-type. This scheme, however, only samples tunas, and any bycatch retained on board is not sampled (Fonteneau *et al*. 2009). It has therefore proved necessary to re-create estimates of purse seine bycatch from observer data.

A French observer programme provided bycatch and discard data for a sample of purse-seine vessels operating during 2005 and 2006. A total of 194 purse-seine sets were made, 116 of which were successful. About 85 percent of the sets were on free schools (FS) and the rest on floating objects (FO). There were virtually no discards of tunas reported, and bycatch was reported to amount to about 1% by weight of the total catch. About 5% of the bycatch was billfish, 12% sharks, and the remainder a variety of other fish, mainly triggerfish, rainbow runners and wahoo. No turtles or seabirds were reported captured.

Data were collected during a series of 11 cruises aboard Spanish purse-seine vessels during 2003 and 2004. Scientific observers collected data from 224 sets over a period of 336 days. For sets on unassociated schools, the bycatch was comprised of about 85% sharks, 10% finfish, and 5% billfish; for sets on floating objects[28] the percentages were 35%, 55%, and 10%, respectively. Similar to the situation in other oceans, the amount of bycatch on floating objects was far greater than that on unassociated schools.

Both fleets discard large sharks alive where possible (Poisson *et al.* 2011). Large sharks are sorted out on the upper deck, where 33% mortality was observed, whereas small specimens sent down the hopper to the lower deck where 73% mortality was registered. Higher mortalities were registered in large sets than in small sets. In total, 20 silky sharks (125.3 ± 33.8 cm total length) were tagged with MiniPATs (Wildlife Computers, Redmond, WA, USA) to study their survival after release. Six silky sharks and the mako shark died immediately after release. The tagging experiment shows that 50% of the released sharks survived. This leads to the conclusion that approximately 19% of all sharks caught by purse seine could survive the fishing operation.

The French vessels discard some bycatch because the vessels are smaller and have less carrying capacity, while the Spanish retain most of the bycatch. At landing or transhipment (mostly in Seychelles), stevedores routinely sort out most of the bycatch which is consumed locally. Some of the bycatch tunas transhipped onto reefers are landed in Mauritius and are sorted out prior to canning, but are not discarded.

The data available for purse seine fisheries are limited to observer coverage from 2003 to 2007 from the French and Spanish programme, related to 4% of sets during the period (Amandé *et al.* 2008). These data have been raised to totals for the whole fishery[29]. Bycatch data were also collected from Soviet purse seiners between 1986 and 1992 (Romanov *et al.*), as well as in the context of the BIOT (Chagos Archipelago) observer programme (Mees *et al.* 2008), but the latter are not considered further here as the BIOT data were not published. Nevertheless, the Soviet data for log sets is virtually identical to the programme referred to above, both in respect to species composition and to the relative proportions of bycatch species to tuna catches in log/FAD sets.

According to these estimations, total annual average bycatch for the period was estimated at 9,585 t, corresponding to 35.5 t bycatch per 1,000 t of tuna landed. Tuna represents 54% of the total bycatch amount, followed by other fin fish (34%), sharks (10%), billfishes (1.5%)

28 Driftwood, dead cetaceans, etc.
29 Stratified by quarter, fishing area and fishing mode (log/FAD or free school sets).

and rays (0.7%). The amounts estimated by fishing mode and species group are reported in Table 4 below.

Over half the bycatch are tunas. These can be species which are not canned for export markets although they are often canned for local markets (*Euthynnus affinis* – kawakawa, frigate and bullet tunas) undersized fish or fish which have been crushed or otherwise damaged in the fishing operations, handling and storage.

Finfish bycatch averaged 3,232 t/year. The main species was rainbow runner (*Elegatis bipinnulatus*, 37% of the total), followed by pelagic triggerfish (*Canthidermis maculatus*, Balistidae, 24%), dolphinfish (*Coryphaena* spp., 11%) and carangids (*Caranx sexfasciatus*,

	Average annual Bycatch					Total		
Fishing mode	Tuna	Fishes	Sharks	Billfish	Rays	Average annual bycatch	Average annual catch (t)	Percentage bycatch
FAD & sea mounts	4,246	3,161	961	109	40	8,517	160,454	5.31%
Free schools	1,026	167	32	41	22	1,288	109,781	1.17%
Total	**5,178**	**3,232**	**965**	**149**	**65**	**9,588**	**270,235**	**3.55%**
Percentage of bycatch	**54.00%**	**33.71%**	**10.06%**	**1.55%**	**0.68%**			

Table 4: Estimated annual average 2003-2007 bycatch of the purse seine fishery (in tonnes)

Seriola rivoliana, Naucrates sp.*, Carangoides* spp., 7%), with the balance (21%) being made up of some 50 other species. Finfish species composition between FO and log schools was rather similar, although there were more dolphinfish on FOs, and the greatest species diversity was from FO schools.

The next most important bycatch group was "sharks", with a total estimated average annual catch close to 1,300 t (range 1,000-1,650 t). Shark bycatch was dominated by carcharhinids, the most important being the silky shark (*Carcharhinus falciformis*, 79%) followed by the oceanic whitetip shark (*C. longimanus*, 11%). 97% of sharks were caught in FO sets. Shark species composition was quite similar between FO and free schools sets.

"Billfish" bycatch was relatively low, with an average annual catch of 150 t (range 140-210 t). The most important species were marlins (70%, mainly *M. indica* and *T. audax*) and sailfish (27%). Most billfish (72%) were caught on FO sets. Billfish species composition was quite similar between FO and log sets.

"Rays" were caught in smaller quantities, with an average annual catch of 65 t (range 40-70 t). 65% of rays were caught on FOs. The most important species group was the Mobulidae (42%), followed by the giant manta (*Manta birostris*, 37%), other and unidentified rays (20%). Ray species composition is rather similar between FO and free schools, but with a larger diversity on free schools.

No mention is made here of cetaceans, of marine turtles or whale sharks[30]. In practice, tuna-dolphin association is very rarely seen in the western Indian Ocean, such that skippers do not set on dolphin schools. Sets are occasionally made on whales and on whale sharks associated with tuna schools, but these large animals either break their way out of the nets or are towed out alive. There is no evidence of mortality associated with whale sets.

30 Seabirds are not caught by purse seines.

Marine turtles are also occasionally caught in purse seine sets, but are released alive. However, cases have been occasionally observed where turtles were snagged in the old netting used as attractant material on FADs and drowned. Trials are actually being carried out using "ecological" FADs (with no netting), which should lead to elimination of this type of mortality. It should be noted that anchored FADs in the region normally use strap-bands as attractant material, and that no snagging of turtles or sharks has ever been recorded.

Another entanglement issue is related to the raft design and turtles climbing on the rafts and tangling in loose webbing. Future recommendations to IOTC will note this and support smaller flotation designs that are not attractive to turtle basking or assure that netting is tightly bound to rafts with no loose material.

With an average annual bycatch estimated at 9,588 t (3.55% of the landed tuna PS catch), purse seining is confirmed as being one of the lowest sources of fishing mortality for tuna-associated species. Tunas account for 54% of the bycatch, most of which are canned for local markets, consumed fresh or converted to fish meals and oils. Other fishes accounted for 1.2% of the catch total while sharks and rays made up only 0.36%. Another feature illustrated by Table 4 is that FO and seamount sets account for five times the bycatch of free school sets. In free-schools most of the bycatch consists of tunas, with negligible catches of other fishes, sharks, billfish and rays.

The effect of Piracy on purse seine fisheries

Figure 3 shows clearly the recent reduction of effort in the longline fisheries and redirection away from the traditional tropical grounds towards temperate regions, notably the Albacore fishery. Purse seiners carry armed guards and have resumed fishing up to the limits of the Somali EEZ, but the effect of piracy has nevertheless been considerable. Spanish and Seychelles catches have dropped by 60,000 t relative to 2005-2006 levels, while French landings have dropped by 55%.

The decrease by 40,000 t of yellowfin from French seiners is particularly spectacular. This is the result of both the reduction in the number of seiners (10 vessels from a fleet of 54 seiners have left the area) and because these boats have changed their preferred methods of targeting free schools of large yellowfin towards FAD fishing as they are obliged to fish in pairs and have had to reduce their search patterns.

		Total	SKJ		YFT		BET	
2004	FS	191,022	18,565	9.72%	168,799	88.37%	3,658	1.92%
	FO	216,226	137,882	63.77%	59,595	27.56%	18,749	8.67%
2010	FS	44,604	8,826	19.79%	31,951	71.63%	3,827	8.58%
	FO	232,435	141,797	61.01%	72,200	31.06%	18,438	7.93%

Table 5: Free-school and log-school catches (tonnes and percentages) in 2004 and 2010 (before and with piracy)

Table 5 shows clearly the reduction in tonnage of yellowfin catches due to piracy, while there was little change for skipjack and bigeye tuna. What is clear also is that skipjack catches from free-school sets are very low. While the reduction of effort on the most heavily exploited tropical tuna stocks is positive and may benefit longline fisheries in the long term, the end result is increased emphasis on FO fishing, with increased bycatch and, in particular, of juvenile yellowfin and bigeye tuna. Conversely, the proportion of skipjack in the total catch increased. Canneries in Mauritius have commented on the shift from large to small yellowfin.

Mitigation

This section looks at the possibilities for reduction of bycatch and, in particular, discards.

Pole-and-line

Bycatch species from the pole-and-line fishery are in general consumed locally and are not discarded. Baitfish therefore represent the main bycatch mortality associated with the fishery. The move from using coral head species caught by lift-nets to small pelagics with light attraction in the Maldives is certainly positive, as these resources are more resilient and less damage results to the coral reef ecosystem. Conversely, the sprats and silversides are less hardy and cannot be kept for several days (Anderson, 1996). The bait use in Maldives, at 1kg of bait caught for 8.6 kg of tunas (Anderson 2009**)** and the tuna-to-bait ratio cited by various authors for the Maldives has ranged from 7:1 to 11:1 (Gillett, R. (2012).

Improvement of bait holding techniques might reduce baitfish mortality[31]. Improvements can be made through better loading techniques, improved baitfish circulation and pumping systems, more efficient chumming and feeding and might result in less bait being used.

Longline

By far the largest incidence of bycatch and of discards in the Indian Ocean tuna fisheries studied here comes from longline fisheries. Bycatch consists of 87 species or species groups, including sharks, seabirds and turtles, many of which are listed by IUCN as being threatened or endangered. Measures to reduce seabird mortalities include use of tori lines , setting lines at night, below the waterline or along the side of the longliner (Hall, 2005), line throwers, discharging offal from areas on the vessel that discourage birds from the baited hooks, dying the bait blue, weighting branchlines and thawing baits and puncturing the swim bladders of baitfish so that baits sink faster (Bergin 1997; Furness 1999; Belda *et al.* 2001; Loekkeborg *et al.* 2001; Anderson *et al.* 2002; Loekkeborg *et al.* 2002; Robertson *et al* 2003), nylon leaders and various hook designs.

Ward (2007) concluded that: "*Catch rates of several species, including sharks, were lower on nylon than on wire leaders, probably because those animals often escape by biting through the nylon leaders. High bite-off rates indicate that as many animals escape from nylon leaders as are caught on nylon leaders. The fate of escaped animals is not known, although large sharks are more likely to survive than are small animals. By contrast, catch rates of valuable bigeye tuna (Thunnus obesus) were higher on nylon than on wire leaders. Bigeye tuna are probably able to see wire leaders and avoid those hooks.*" Species able to bite-off

31 Bait use in Maldives is derived from baitfish catch and not from the quantity used in fishing. As the baitfish have low survival after capture, this is a better measure of baitfish extraction.

included sharks, and also toothed fish such as *Aleposaurus* and Wahoo. Increased costs for the replacement of hooks lost was more than compensated by the increased catch value, added to the fact that unwanted catches did not need to be dealt with.

Comparison of blue shark catches by the Fance-Réunion and Spanish fleets confirm this, with an 80% reduction in the number of sharks at haul-back for the former fleet which uses monofilament nylon leaders. However, several experiments with two leader types (wire *vs*. monofilament) demonstrate controversial results; half of them show higher bycatch level of sharks for monofilament leaders (Branstetter *et al*., 1993, Yokota *et al*., 2006).

The type of hook could also have an influence as Romanov (2010) shows that percentage of jaw-hooked fish on circle hooks is 1.33 times higher than for tuna hooks and 4 fold higher than for J-hooks. Similarly cumulative percentage of gill and gut hooked fish on circle hook is two-times lower than for tuna hook and 3.8 times lower than for J-hooks.

Table 6, below shows that, on the wire leaders used by the Portuguese fleet, a high proportion of mako, silky, whitetip and thresher sharks are dead when the lines are recovered, while 75% of blue sharks and most rays survived (Coelho *et al.* 2010). Note that, in the SEALOR observer report, most of the sharks recovered were released alive (Bach *et al.* 2008). The length of time during which a shark is on the line therefore has a marked influence on mortality.

Code	Species/Family	n	% Dead
BSH	*Prionace glauca*	2,358	24.7
SMA	*Isurus oxyrinchus*	430	56
FAL	*Carcharhinus falciformis*	31	74.2
SPZ	*Sphyrna zygaena*	25	84
BTH	*Alopias superciliosus*	19	68.4
PLS	*Dasyatis violacea*	16	0
JAM	Mobulidae	14	0

Table 6: Percentage of organisms dead at haul-back (Source Coelho et al. 2010)

Survival of the sharks after bite-off or discard alive are critical elements of ecosystem management (Boggs, 1992; Davis, 2002). There is of course no evidence that the sharks which severed the nylon leaders survived but the jaw-hooked sharks were presumably less stressed at bite-off than if they had remained on the line for many hours. Campana (2009) showed that all jaw-hooked and released blue shark survived, while sharks swallowed hook will most probably die. However, a study involving six blue sharks with old remains of fishing hooks in their bodies suffered from fibroms, stomach inflammation or inflammation of the esophageal area causing obstruction (Borucinsa *et.al.* 2002), indicating that those which are unable to dislodge embedded hooks are handicapped.

NOAA has worked for the last three years in the Gulf of Mexico (Eric Schwaab, unpublished) with “weak” circle hooks which can be straightened out by large fish but have been shown to give better yellowfin catches. These might allow some of the large sharks to escape, but blue sharks which average about 20kg in the swordfish longline fishery are unlikely to be able to straighten these hooks.

NOAA is also involved in the testing of “weak” circle hooks in the US Hawaii based longline fishery as a means to release toothed cetacean interactions while still retaining a reasonable amount of target catch. This initiative will be mandated by the agency in response to low but ecologically significant interactions with what has been determined to be a small sub-population of false killer whale (*Pseudorca crassidens*).

The use of hooks incorporating rare earth metal and magnetic deterrents[32] (Stoner *et al.* 2008, Brill *et al.* 2009) confirmed by the Australian Department of Primary Industries and Fisheries and James Cook University on a variety of shark species may offer even better prospects of reducing longline shark catches.

The European Union research program MADE (Mitigating adverse impacts of open ocean fisheries) is currently looking at ways to reduce bycatch and ecological interactions of purse seine and longline fisheries; primarily in the Indian and Atlantic oceans. The main objectives relative to longline fisheries is to test and propose measures to reduce the bycatch of sharks and juvenile swordfish taken by pelagic longline.

Purse seine

The ISSF[33]is coordinating studies and research cruises in the Indian, Atlantic and Pacific (EPO, WCPO) Oceans specifically to test and develop mitigation measures for purse seine fisheries operating on FADs (http://iss-foundation.org/science/projects/bycatch-reduction/). The project is contracting commercial purse seine vessels in all the tropical oceans to test avoidance, release and condition of oceanic sharks, whale shark, marine turtles, non-target finfish and undersized and juvenile yellowfin and bigeye tuna (Restrepo, 2010). An 11 day research cruise in the Indian Ocean that has been completed concentrated on the behaviour of sharks and finfish bycatch around FADs. A more extensive six week bycatch mitigation cruise is being conducted by the program during the second quarter of 2012 (Itano *et al.* 2011). A 73 day cruise has been completed in the Eastern Pacific Ocean on and Ecuadorian flag purse seiner as described in Schaefer and Fuller (2011). A 41 day ISSF research cruise in the WCPO completed in July 2012 on a US flag vessel operating north of American Samoa. This cruise is described by Hutchinson *et al.* 2012; Itano *et al.* 2012A; Itano *et al*. 2012b; and Muir *et al*. 2012) but analysed results are not yet available.

Several approaches are being tested that examine bycatch reduction in three stages: before arriving at a FAD (via acoustic data); on arrival and using acoustic instruments; how to remove bycatch from the encircled FAD prior to loading; release of bycatch during the loading process; and survival and condition of post-released animals. A full description of these plans that are being developed by scientists in consultation with industry are available on the ISSF website[34],

One avenue of mitigation of turtle snagging has been to promote the use of "ecological" FADs by purse seine fleets with two objectives: 1) construction from non-entangling materials to avoid marine turtle and shark meshing and 2) construction of FADs from biodegradable materials to reduce impacts of nylon and other plastics in the environment.

As is stated above, most free-school sets in the Indian Ocean are on large yellowfin and it is probable that it is the reduction in this targeting as a result of constaints on the French seiners because of piracy which has allowed the stocks of that species to recover, as well as potentially increasing the recruitment to the longline fishery. The trade-off has been more

32 Sharks are very sensitive to electric and magnetic fields.
33 International Seafood Sustainibility Foundation http://iss-foundation.org/
34 http://iss-foundation.org/science/projects/bycatch-reduction/skippers-workshops/
http://iss-foundation.org/science/projects/bycatch-reduction/fieldwork/

FAD fishing, with a corresponding increase in bycatch and in landings of skipjack and of juvenile yellowfin tuna. Purse seine bycatch levels are so low, however, that an increase in FS sets is not desirable, although there is a possibility that larger catches of juvenile yellowfin in FO sets might in the long term have a negative impact on the stocks.

This is similar to an unforeseen trade-off that is gaining increasing attention concerning the measures adopted by the IATTC to deal with dolphin by-catch in the Eastern Pacific tuna fishery (Hall 1998). Data now available indicate that the 'cost' of the spectacular reduction in dolphin mortalities achieved by the fleet has been an order of magnitude rise in the bycatch of undersized, non-usable tuna and a large increase in the mortality of sea turtles, sharks, and other fish species (Norris *et al*. 2002). These increases have arisen in part because fishers have switched from targeting their efforts on the large yellowfin tuna that associate with dolphin schools to targeting the smaller yellowfin and bigeye tuna that are unable to keep up with dolphin schools and are found around inanimate floating objects, such as logs (Norris et al. 2002). Another example of trade-off includes the high seas drift net ban that was enacted in 1992. This action, was certainly effective in reducing some forms of bycatch, but it also resulted in the rapid expansion of a longline fishery, which has by-catch problems of its own.

One regulatory mechanism that is being increasingly used by tuna RFMOs to mitigate bycatch is the mandating of full retention of target and bycatch by purse seine fleets. The idea is that purse seine captains will develop better ways and skills to avoid setting on bycatch or undersized market tuna if they will be required to load and land everything that enters the net. However, full retention must be implemented with the understanding that live release of some species is preferable to a legislative requirement to land everything (McCoy *et.al.* 2007).

Substitution of pole-and-line for purse seine fisheries

An end to FO fishing imposed through market pressures is likely to have serious consequences, including possibly the collapse of the purse seine fishery in the Indian Ocean. Sharp (1979) was the first to suggest that purse seining might be possible in the Indian Ocean for part of the year when the thermocline was sufficiently shallow and structured to keep tunas in surface waters. These conditions only exist for three to four months of the year. This situation has been confirmed by thirty years of experience. The purse seine fleet could obviously not remain inactive eight months of the year and would most likely move to other oceans unless markets are found that accept fish caught in FO sets.

The question then arises – could pole-and-line fisheries be developed to replace the 250,000-300,000 t of purse seine landings?

Pole-and-line trials in the Indian Ocean

Prior to the 1980s it was thought that purse seine fisheries were not possible in the Indian Ocean and interest for the exploitation of skipjack concentrated in livebait pole-and-line fishing which were known to work in the Maldives. The first successful enterprise in the Indian Ocean outside the Maldives was COMANIP, a Malagasy-Japanese joint venture which operated eleven boats based on Nosy Bé in the Mozambique Channel (Marcille, unpublished). This fishery collapsed for political reasons, and attempts to find bait resources failed in Mauritius, Rodrigues, St. Brandon, the Nazareth and Saya de Malha Banks (Ardill, unpublished). Two Basque boats then fished from Seychelles in 1981-82 (Cort, 1982), finding limited quantities of bait (mainly juvenile scad) for about 9 months of the year. A subsequent Seychelles-French joint venture subsequently failed. Marsac (1983) reported that Seychelles bait resources were limited and suggested the construction of bait-holding cages.

Attempts were then made to develop pole-and-line fisheries in Mozambique using Cape Verde techniques (Moreira-Rato, unpublished), and in Zanzibar (Lee, unpublished), both with FAO support. Finally, Zanzibar fishermen were taken to Maldives to learn the techniques. None of these initiatives were successful, possibly in part because of the lack of entrepreneurial skills and of investment funds, as well as the difficulties in mastering techniques of bait and tuna fishing for east African populations unfamiliar with oceanic fisheries.

In the context of the IOC Regional Tuna Tagging Project, surveys demonstrated the general paucity of oceanic bait resources, other than off the coast of Oman. The RTTP tagged over 150,000 fish using schools associated with the tagging platform, without bait. These operations obviously did not attain commercial catch rates but bait was found near Mafia Island (Tanzania), the Oman coast, the Nosy Bé area in Madagascar and Seychelles (in diminishing order) (J-P Hallier, *pers.comm*. 2012).

While there is obviously some potential for expansion of the pole-and-line catch in the Indian Ocean, the process is likely to take a long time and to require substantial investment and technical support. Making up the shortfall in cannery supply in the event of a collapse of the purse seine fishery is certainly completely unrealistic. There is little chance that pole and line fishing can develop in the western Indian Ocean given limited baitfish resources unless a huge differential in landed price for pole and line caught tuna develops which is unlikely.

Carbon footprint of tuna fisheries

The issue of fuel consumption and carbon footprint is becoming increasingly relevant, both in operational costs and with respect to Global warming. Pelagic fisheries (tuna and small pelagic seining) are among the most efficient in relation to fuel consumption, particularly in compared to trawling. Nevertheless, there are significant differences between gears and fishing methods.

No studies have been published on the Indian Ocean, but there have been several concerning the Pacific Ocean tuna fisheries.

Thrane (2009) estimated the carbon footprint for tuna fisheries. The figure arrived at for purse seiners was 1.15 – 5.27 kg CO^2/kg of landed tuna, while that for longliners was 6.64 – 8.86 kg CO^2/kg. The parameters used for pole-and-line do not seem to equate to those found in the Maldives. Gillett (2011) however, estimates that in the Solomon Islands 588 litres of fuel are used per tonne of pole-and-line tuna and 306 litres of fuel per tonne of FAD-associated purse seine tuna, i.e. nearly half the amount used in pole-and-line fishing. The search time for seiners in targeting free-schools is much greater than the steaming time in moving from one FAD to the next, particularly as FADs are now mostly equipped with GPS transponders that give an accurate position fix to the fishing vessel. The use of "supply" tenders by the Spanish fleet probably makes for an even greater difference, as these boats have very low power compared to the seiners.

In a separate study, purse seine gear, was found to burn, on average, 368 litres of fuel per live weight tonne of landings, while longline burned on average 1,070 and pole and line 1,490 litres per tonne (Tydmers *et al*. 2011).

A sample of landings and fuel burn from two facilities in the South of the Maldives between and 2011 gave an average ranging from less than 100 litres per tonne of tuna in 2006 to close to 300 litres in 2011with a regularly increasing trend (M. Shiham Adam, *pers. comm.*), i.e. roughly equivalent to the consumption of FAD-associated purse seiners and a quarter of the burn reported by Tydemers for the Atlantic. Such low consumption figures may be specific to the Maldives, however, where much of the pole-and-line fishing is conducted on FAD-associated schools and day trips with little time spent searcing searching for free-swimming schools.

Conclusions

Stock status

The IOTC species Working Parties have determined that, of the stocks exploited by the export-oriented fisheries, only albacore are currently being fished at above MSY, and swordfish is above, but close to MSY. Yellowfin and bigeye tuna which had historically been heavily exploited have now recovered and skipjack, the stock which is the most robust to exploitation, has an abundance which is above that at which the biomass would produce MSY.

IUCN lists most of the sharks, rays, marine turtles and seabirds caught in association with tuna fisheries as being near threatened, vulnerable or endangered, such that mitigation of these mortalities is a priority.

Bycatch and discards

This study shows that, in the Indian Ocean tuna fisheries, purse seine effort on free schools results in the lowest bycatch levels, while producing over 80% of higher value yellowfin and bigeye tuna. Floating object sets result in nearly five times the amount of bycatch, with skipjack constituting nearly 70% of the target catch albeit with nearly 28% in numbers of small yellowfin and bigeye tuna. The juvenile yellowfin and bigeye proportion may contribute to growth overfishing and secondary interaction as they recruit or would have recruited into with the high value longline sashimi fishery.

In both FS and FO sets, the main bycatch species are neritic tunas (54%), followed by finfish and cartilaginous fish. Catches of the neritic tunas are modest compared to those of targeted coastal fisheries in the Indian Ocean. From the estimated annual catches, the annual catch of no single non target species is more than 1,000t. Where the finfish are concerned, most of the species are abundant, short-lived, reproduce early and have pan-oceanic distribution. The sharks, mainly silky and oceanic whitetip, are thus the primary subject of concern.

In the FAD fishery, marine turtles and sharks are occasionally snagged but the industry is developing “ecological” FADs which should eliminate these mortalities.

Pole-and-line bycatch, at 11.6% of the target catches for bycatch alone, is much higher than the purse seine FO rates. The baitfish, however, are typically species low in the food chain with rapid turnover. The target species have a bi-modal size distribution, with a large proportion at small sizes which have a lower conversion factor for canning. However, this fishery produces the highest proportion of skipjack.

It was noted that the surface fisheries (purse seine and pole-and-line) discard very little fish.

Taking the longline fishery as a whole, reported bycatch levels are at slightly over 6% of the combined tuna and billfish catches. Indications are however that under-reporting of shark catches may be by as much as a factor of three, which would bring the bycatch level to around 19% of target catches. Observer data from the Spanish and Portuguese fleets placed discards at 14% of the total catch or 17% of the retained catch. The discards included 1.3% from predation and 3.4% from "other reasons", which might have included spoilage or high-grading. However, in the IOTC Nominal Catch data, reported shark and NTAD categories are nearly equal to target catches, indicating that the proportion of these species is much higher in temperate waters where these fleets operate, fishing with swordfish longlines. A more detailed analysis should be conducted using gear type and area stratifications.

Finally, the bait use in the fishery probably amounts to half the total catch, albeit of species which are low in the food chain and have high turnover, and often caught in a different ocean.

In the longline fisheries, with the exception of the Spanish fleet for which blue shark are a target species, sharks listed by IUCN are by far the largest component of bycatch, which places longlines as the most ecologically damaging tuna fishery.

Mitigation

Pole-and-line

Particular attention was placed on the NGO pressure on sourcing cannery raw material from FAD-free fisheries, and notably from pole-and-line. While there is obviously some potential for expansion of the pole-and-line catch in the Indian Ocean[35], the process is likely to take a long time and to require substantial investment[36] and technical support. Making up the shortfall in cannery supply in the event of a collapse of the purse seine fishery is certainly completely unrealistic. Limited baitfish resources was identified as a major constraint, as was the higher price of FAD-free fish[37]. It also costs more to catch a tonne of tuna by pole-line than by purse seine.

The main avenue for bycatch mitigation was therefore identified as being more efficient use of baitfish. Discarding of neritic tunas and the NTAD component is unlikely to happen in small-scale fisheries where bycatch is consumed.

Purse seine

A shift from FO to FS sets would result in reduced skipjack catches and increased pressure on the more sensitive yellowfin and bigeye tuna stocks, with probable interactions with longline sashimi fisheries. Because of the short FS season, purse seiners might also leave the Indian Ocean, with serious economic and social consequences in the western Indian Ocean islands.

Approaches are being tested by ISSF that examine bycatch reduction in three stages: before arriving at a FAD (via acoustic data); on arrival and using acoustic instruments; how to remove bycatch from the encircled FAD prior to loading; release of bycatch during the loading process; and survival and condition of post-released animals, as well as non entangling and biodegradable FADS appear to give the best prospects.

Longline

In longline fisheries, the mitigation measures used for seabirds appear to have resulted in marked decrease in interactions. Several shark species seem however to be heavily exploited,

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35 The pole-and-line expansion would presumably be largely in East African countries which have much more pressing nutritional problems and the bycatch could alleviate this problem (cf. bycatch of the Mozambique shrimp fisheries which is collected at sea and consumed).

36 Displacing the purse seine fleet would presumably increase capacity in other oceans.

37 This is estimated a 5-8% above purse seine prices.

with uncertain reporting of catches. A number of mitigation measures might reduce this unwanted bycatch. Chief among these would be the adoption by all fleets of monofilament nylon leaders. The results of the France/Réunion longliners would need to be confirmed and research initiated on the survival of sharks which are cut-off with circle hooks embedded in their jaw. This could probably be achieved using pop-up tags to measure long-term survival. As the Spanish fleet retains blue sharks as a target species, a special derogation may be necessary to permit the use of wire leaders for fleets targeting sharks if a ban on wire leaders were to be enacted.

Finally, the deterrent effect of magnet technology associated to hooks needs to be tested urgently on oceanic longlines.

Other ecological issues

The lowest consumption of fuel per tonne of catch is in Maldivian pole-and-line operations followed by FO seiner fisheries and FS fisheries. Longliners consume about twice as much fuel per tonne of catch as seiners (Tydmers *et al*. 2011).

Enforcement and verification

A ban on discarding dead organisms in all fleets would certainly have a positive effect in encouraging adoption of techniques leading to escapement of bycatch organisms such as undersized fish in purse seine fisheries and sharks in longline fisheries. On the smaller longliners, such a measure might pose problems in storing on board organisms (such as sharks) which might contaminate other components of the catch. A positive side to such regulations would come from the contribution of this fish to nutrition: Mauritius already takes 4,500 t of bycatch from longliners transhipping in Port Louis which is sold on the local market (Sheik Mamode, 2011).

Verification of discarding bans would usually involve observers. The purse seine fleet claims at present that the spare accommodation is fully taken up by the guards carried to counter pirate attacks and long trips in difficult conditions makes observer coverage on the Asian longline fleet very difficult. It is therefore necessary as a matter of priority to develop remote sensing monitoring devices adapted to the different fisheries.

Closing comments

Finally, it should be noted that the IUCN-CEM Fisheries Expert Group (FEG) and the European Bureau for Conservation and Development (Garcia, 2010) concluded that a fisheries management regime based on retention of all species and size groups in catches may in practice lead to less harmful ecological effects and higher sustainable production than selective targeting of particular species and sizes. At the species assemblage level, this implies that management should aim at a wide distribution of the fishing pressure to balance direct and indirect impacts across species. From that perspective, by-catch, if maintained within limits imposed by sustainability, may not be an impediment to maintenance of community structure and ecosystem stability (Zhou, 2008).

Zhou *et al.* (2010) argue that: *Globally, many fish species are overexploited, and many stocks have collapsed. This crisis, along with increasing concerns over flow-on effects on ecosystems, has caused a re-evaluation of traditional fisheries management practices, and a new ecosystem-based fisheries management (EBFM) paradigm has emerged. As part of this approach, selective fishing is widely encouraged in the belief that non-selective fishing has many adverse impacts. In particular, incidental bycatch is seen as wasteful and a negative* *feature of fishing, and methods to reduce bycatch are implemented in many fisheries. [….] However, recent advances in fishery science and ecology suggest that a selective approach may also result in undesirable impacts both to fisheries and marine ecosystems. A "balanced exploitation" approach might alleviate many of the ecological effects of fishing by avoiding intensive removal of particular components of the ecosystem, while still supporting sustainable fisheries.*

Subject to the application and verification of the bycatch mitigation measures suggested above, changes in the purse seine regime suggested by NGOs leading to a reduction in FO sets or even substitution of purse seining by pole-and-line fisheries appears not only unrealistic, but could have undesirable environmental effects.

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Appendix I

Species identified as bycatch of the different tuna fisheries in the Indian Ocean: PnL=pole-and-line; LL= longline; FS=Free school; FO=floating object school [FAD]

						Purse seine			IUCN
Common name	Species group	Family	Species name	PnL	LL	FS	FO	Sea-mount	Red list
	Fishes	Balistidae	*Abalistes stellatus*			X	X	-	
	Fishes	Belonidae	*Ablennes hians*			-	X	-	
	Fishes	Pomacentridae	*Abudefduf vaigiensis*			X	X	-	
Wahoo	Fishes	Scombridae	*Acanthocybium solandri*			X	X	X	
Lancetfish	Fishes	Alepisauridae	*Alepisaurus ferox*		X				
	Fishes	Monacanthidae	*Aluterus monoceros*			X	X	-	
Bullet tuna	Fishes	Scombridae	*Auxis rochei*		X				
Frigate tuna	Fishes	Scombridae	*Auxis thazard*		X				
Ray's bream	Fishes	Bramidae	*Brama brama*		X				
Spotted	Fishes	Balistidae	*Canthidermis*		X	X	X	-	

						Purse seine			IUCN
Common name	Species group	Family	Species name	PnL	LL	FS	FO	Sea-mount	Red list
triggerfish			*maculatus*						
	Fishes	Carangidae	*Carangoides orthogrammus*			-	X	-	
	Fishes	Carangidae	*Carangoides spp.*		X				
	Fishes	Carangidae	*Caranx sexfasciatus*			X	X	-	
Blue Damselfish	Fishes	Pomacentridae	*Chromis viridis*		X				
Dolfinfish	Fishes	Coryphaenidae	*Coryphaena equiselis*		X	-	X	-	
Dolfinfish	Fishes	Coryphaenidae	*Coryphaena hippurus*		X	X	X	X	
	Fishes	Nomeidae	*Cubiceps capensis*			X	-	-	
Driftfish	Fishes	Nomeidae	*Cubiceps gracilis*		X				
Mackerel scad	Fishes	Carangidae	*Decapterus macarellus*			X	X	-	
Mackerel scad	Fishes	Carangidae	*Decapterus sp.*			-	X	-	
Pufferfish	Fishes	Diodontidae	*Diodon hystrix*			X	X	X	
Pufferfish	Fishes	Diodontidae	*Diodon sp.*			X	X	X	
Rainbow runner	Fishes	Carangidae	*Elagatis bipinnulata*	X	X	X	X	X	
Shorthead Anchovy	Fishes	Engraulididae	*Encrasicholina heteroloba*	X					
Kawakawa	Fishes	Scombridae	*Euthynnus affinis*	X	X	X	X	X	
Silversides/ Hardyheads	Fishes	Atherinidae		X					
Cardinalfishes	Fishes	Apogonidae		X					
Triggerfish	Fishes	Balistidae	Family Balistidae			X	X	-	
	Fishes	Belonidae	Family Belonidae			X	X	-	
	Fishes	Bramidae	Family Bramidae			X	X	-	
Fusiliers	Fishes	Caesionidae		X					
	Fishes	Carangidae	Family Carangidae			X	X	-	
Dolphinfish	Fishes	Coryphaenidae	Family Coryphaenidae			X	X	X	
	Fishes	Echeneidae	Family Echeneidae			X	X	-	
	Fishes	Ephippidae	Family Ephippidae			-	X	-	
Flying fish	Fishes	Exocoetidae	Family Exocoetidae			X	X	-	
	Fishes	Fistularidae	Family Fistularidae			X	-	-	

						Purse seine			IUCN
Common name	Species group	Family	Species name	PnL	LL	FS	FO	Sea-mount	Red list
	Fishes	Molidae	Family Molidae			X	-	-	
	Fishes	Pomacentridae	Family Pomacentridae			-	X	-	
	Fishes	Scombridae	Family Scombridae			-	X	-	
	Fishes	Sphyraenidae	Family Sphyraenidae			-	X	-	
	Fishes	Tertaodontidae	Family Tetraodontidae			-	X	-	
Butterfly kingfish	Fishes	Scombridae	*Gasterochisma melanpus*		X				
Snake mackerel	Fishes	Gempylidae	*Gempylus serpens*		X				
	Fishes	Hexanthidae	*Hexanthus griseus*		X				
Skipjack	Fishes	Scombridae	*Katsuwonus pelamis*		X				
	Fishes	Kyphosidae	*Kyphosus cinerascens*			X	X	X	
	Fishes	Kyphosidae	*Kyphosus sp.*			X	X	-	
	Fishes	Kyphosidae	*Kyphosus vaigiensis*			X	X	-	
	Fishes	Tertaodontidae	*Lagocephalus lagocephalus*		X	X	X	-	
Moon fish	Fishes	Lampridae	*Lampris guttatus*		X	-	X	-	
Escolar	Fishes	Gempylidae	*Lepidocybium flavobrunneum*		X				
Fusilier Damselfish	Fishes	Pomacentridae	*Lepidozygous tapeinosoma*	X					
	Fishes	Lobotidae	*Lobotes surinamensis*			X	X	X	
Sharptail mola	Fishes	Molidae	*Masturus lanceolatus*		X	X	X	-	
Ocean sunfish	Fishes	Molidae	*Mola mola*		X	X	-	-	
	Fishes	Carangidae	*Naucrates ductor*		X	X	X	-	
	Fishes	Ephippidae	*Platax sp.*			-	X	-	
	Fishes	Ephippidae	*Platax teira*			X	X	-	
	Fishes	Echeneidae	*Remora australis*			-	X	-	
	Fishes	Echeneidae	*Remora remora*			X	X	_	
	Fishes	Echeneidae	*Remorina albescens*			-	X	X	
Oilfish	Fishes	Gempylidae	*Ruvettus pretiosus*		X	-	X	-	

						Purse seine			IUCN
Common name	Species group	Family	Species name	PnL	LL	FS	FO	Sea-mount	Red list
	Fishes	Scombridae	*Scomber japonicus*			-	X	-	
Spanish mackerel	Fishes	Scombridae	*Scomberomorus commerson*		X				
	Fishes	Scombridae	*Scomberomorus tritor*		X	-	X	-	
	Fishes	Carangidae	*Seriola rivoliana*			X	X	X	
Barracuda	Fishes	Sphyraenidae	*Sphyraena barracuda*		X	X	X	-	
Silver Sprat	Fishes	Clupeidae	*Spratelloides gracilis*	X					
Blue Sprat	Fishes	Clupeidae	*Spratelloides delicatulus*	X					
Sickle pomphret	Fishes	Bramidae	*Taractichthys steindachneri*		X				
Snoek	Fishes	Gempylidae	*Thyrsites atun*		X				
Slender ribbonfish	Fishes	Trachypteridae	*Trachipterus ishikawae*		X				
	Fishes	Belonidae	*Tylosurus crocodilus*			-	X	-	
	Fishes	Carangidae	*Uraspis helvola*			-	X	-	
	Fishes	Carangidae	*Uraspis secunda*			X	X	X	
	Fishes	Carangidae	*Uraspis sp.*			-	X	-	
	Fishes	Carangidae	*Uraspis uraspis*			X	X	-	
Swordfish	Fishes	Xiphiidae	*Xiphias gladius*		X	X	X	X	
	Fishes	Zanclidae	*Zanclus cornutus*			X	-	-	
Tunas nei	Fishes	Scombridae			X				
	Billfishes	Istiophoridae	*Family Istiophoridae*			X	X	-	
	Billfishes	Istiophoridae	*Istiophoridae nei*		X				
Sailfish	Billfishes	Istiophoridae	*Istiophorus platypterus*		X	X	X	X	
Black marlin	Billfishes	Istiophoridae	*Makaira indica*		X	X	X	-	
Blue marlin	Billfishes	Istiophoridae	*Makaira nigricans (=mazara)*		X	X	X	-	
Shortbill spearfish	Billfishes	Istiophoridae	*Tetrapturus angustirostris*		X	X	X	-	
Striped marlin	Billfishes	Istiophoridae	*Tetrapturus audax*		X	X	X	-	
Bigeye	Sharks	Alopiidae	*Alopias*		X				Vulnerable

						Purse seine			IUCN
Common name	Species group	Family	Species name	PnL	LL	FS	FO	Sea-mount	Red list
thresher shark			*superciliosus*						
Common thresher shark	Sharks	Alopiidae	*Alopias vulpinus*		X				Vulnerable
	Sharks	Carcharhinidae	*Carcharhinidae nei*		X				Vulnerable
Copper shark	Sharks	Carcharhinidae	*Carcharhinus brachyurus*		X				Near Threatened
Silky shark	Sharks	Carcharhinidae	*Carcharhinus falciformis*		X	X	X	X	Near Threatened
Galapagos shark	Sharks	Carcharhinidae	*Carcharhinus galapagensis*		X				Near Threatened
Blacktip shark	Sharks	Carcharhinidae	*Carcharhinus limbatus*		X				Near Threatened
Oceanic whitetip shark	Sharks	Carcharhinidae	*Carcharhinus longimanus*		X	X	X	-	Vulnerable
Dusky shark	Sharks	Carcharhinidae	*Carcharhinus obscurus*		X	-	X	-	Vulnerable
Dusky shark	Sharks	Carcharhinidae	*Carcharhinus obscurus*		X				Vulnerable
Sandbar shark	Sharks	Carcharhinidae	*Carcharhinus plumbeus*		X				Vulnerable
Velvet dogfish	Sharks	Centrophoridae	*Centrophorus spp*		X				Vulnerable
	Sharks	Carcharhinidae	Family Carcharhinidae			X	X	-	
	Sharks	Sphyrnidae	Family Sphyrnidae			-	X	-	
Tiger shark	Sharks	Carcharhinidae	*Galeocerdo cuvieri*		X	X	-	-	Near Threatened
Shortfin mako shark	Sharks	Lamnidae	*Isurus oxyrinchus*		X	-	X	X	Vulnerable
Longfin mako shark	Sharks	Lamnidae	*Isurus paucus*		X				Vulnerable
Mako sharks nei	Sharks	Lamnidae	*Isurus species*		X				
Porbeagle	Sharks	Lamnidae	*Lamna nasus*		X				Vulnerable
Megamouth shark	Sharks	Megachasmidae	*Megachasma pelagios*			X	-	-	Vulnerable
Blue shark	Sharks	Carcharhinidae	*Prionace giauca*		X	X	-	-	Near Threatened
Crocodile shark	Sharks	Pseudocariidae	*Pseudocarcharias kamoharai*		X				

						Purse seine			IUCN
Common name	Species group	Family	Species name	PnL	LL	FS	FO	Sea-mount	Red list
Whale shark	Sharks	Rhincodontidae	*Rhincodon typus*			X	X	-	Near Threatened
Scalloped hammerhead shark	Sharks	Sphyrnidae	*Sphyrna lewini*		X	X	X	-	Endangered
Smooth hammerhead shark	Sharks	Sphyrnidae	*Sphyrna zygaena*		X				Endangered
Sharks nei	Sharks	Sharks nei			X				Vulnerable
Spotted eagle ray	Rays	Myliobatidae	*Aetobatus narinari*			X	-		
	Rays	Dasyatidae	*Family Dasyatidae*			X	X	-	
	Rays	Rhinopteridae	*Family Rhinopteridae*			-	X	-	
Manta	Rays	Myliobatidae	*Manta birostris*		X	X	X	X	
Manta	Rays	Myliobatidae	*Manta sp.*			X	-	-	
Spine ray mobula	Rays	Myliobatidae	*Mobula japanica (=rancurelli)*			X	X	X	
Devil fish	Rays	Myliobatidae	*Mobula mobular*		X	X	X	-	
Devil ray	Rays	Myliobatidae	*Mobula sp.*			X	-	X	Endangered
Chilean devil ray	Rays	Myliobatidae	*Mobula tarapacana (=coilloti)*		X	X	X	X	
Pelagic stingray	Rays	Dasyatidae	*Pteroplatytrygon violacea*		X	X	X	-	
	Rays	Rays nei	Rays nei		X				
Loggerhead turtle	Turtles	Cheloniidae	*Caretta caretta*		X	-	X	-	
Green turtle	Turtles	Cheloniidae	*Chelonia mydas*		X	-	X	-	
Leatherback turtle	Turtles	Dermochelidae	*Dermochelys coriacea*		X				
Hawksbill turtle	Turtles	Cheloniidae	*Eretmochelys imbricata*			X	X	-	Critically endangered
Olive ridley turtle	Turtles	Cheloniidae	*Lepidochelys olivacea*			X	X	-	Vulnerable
Southern royal albatross	Birds	Diomedidae	*Diomedea epomorpha*		X				
Wandering albatross	Birds	Diomedidae	*Diomedea sanfordi*		X				
Cape petrel	Birds	Sulidae	*Morus capensis*		X				Endangered

						Purse seine			IUCN
Common name	Species group	Family	Species name	PnL	LL	FS	FO	Sea-mount	Red list
Petrel White chinned	Birds	Procellariidae	*Procellaria aequinoctialis*		X				
Flesh-footed shearwater	Birds	Procellariidae	*Puffinus carneipes*		X				
Buller's albatross	Birds	Diomedidae	*Thalassarche bulleri*		X				Least Concern
Shy albatross	Birds	Diomedidae	*Thalassarche cauta*		X				Near Threatened
Yellow nosed albatross	Birds	Diomedidae	*Thalassarche chlororhynchos*		X				Endangered
Grey headed albatross	Birds	Diomedidae	*Thalassarche chrysostoma*		X				Near Threatened
Black-browed albatross	Birds	Diomedidae	*Thalassarche melanophrys*		X				Endangered
White-capped albatross	Birds	Diomedidae	*Thalsssarche steadi*		X				Vulnerable
Unidentified albatrosses	Birds	Diomedidae			X				
Unidentified gannets & boobys	Birds	Procellariidae			X				
Unidentified petrels	Birds	Procellariidae			X				
Fin whale	Cetaceans	Balaenopteridae	*Balaenoptera physalus*			X	X	-	
Common dolphin	Cetaceans	Dephinidae	*Delphinus capensis*		X				Endangered
Pygmy killer whale	Cetaceans	Delphinidae	*Feresa attenuata*		X				
Risso's dolphin	Cetaceans	Delphinidae	*Grampus griseus*		X				
False killer whale	Cetaceans	Globicephalidae	*Pseudorca crassidens*		X	-	X	-	Least Concern
Spinner dolphin	Cetaceans	Delphinidae	*Stenella longirostris*		X				
	Others nei				X				