Chapter 3

Fisheries Bycatch of Chondrichthyes

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Abstract

This chapter reviews the current state of knowledge about global chondrichthyes bycatch, including how the combination of biological characteristics of these species and the impact of different fishing methods reflect their vulnerability to bycatch. Specifically, it summarizes the present status of elasmobranchs and chimaeras bycatch worldwide. Following this, it illustrates the main ecological consequences behind such incidental captures. Hence, it provides a description of how chondrichthyes bycatch occurs across broad fishing gear categories. Moreover, it outlines potential mitigation options available to reduce bycatch. As such, the main technical measures tested and applied in different fishing practices are listed. In addition, an overview about which are the current management measures implemented at international level to ensure long-term conservation of cartilaginous fish is reported. Then, two case studies summarize how chondrichthyes bycatch occurred in some of the most exploited fishing areas. Finally, the chapter ends with relevant considerations about potential for new research needed to monitor and reduce chondrichthyes bycatch.

Keywords: bycatch, fisheries, chondrichthyes, fishing gears, mitigation measures

1. Introduction

The unintentional catch of non-target species or bycatch occurring in fisheries represents one of the major threats to long-lived marine species worldwide. In this context, chondrichthyes are thought to be particularly vulnerable to bycatch due to their biological characteristics that include long life spans, late age at maturity, larger size at birth and low reproductive rates [1–3]. Historically, despite the high value of some cartilaginous fish products (e.g. shark fin market), sharks and their relatives have often been considered as low-value marketed fish, mainly landed as bycatch of other more profitable species (e.g. tuna and tuna-like species [4, 5]). Due to the high level of exploitation, they are now considered among the most threatened marine animals worldwide. Indeed, based on The International Union for Conservation of Nature (IUCN) Red List categories and modelled estimates, of the 1041 assessed species, at least 24% are predicted to be threatened worldwide [6]. According to the most recent the Food and Agriculture Organization of the United Nations (FAO) report [7], approximately 766,064 tons of chondrichthyes were caught in 2011, mainly sharks and batoids. A large portion of these catches was a result of unintentional catches. In addition, illegal and unregulated fishing activities might have increased the total catch because some cartilaginous fish are often discarded at sea without being recorded in any assessment [8–11]. Thus, fisheries bycatch is likely to have significant demographic impacts on these species. Therefore, there is an urgent need to better understand the interactions between chondrichthyes and fisheries in order to develop and apply proper tailored fisheries management strategies.

1.1. Elasmobranchs bycatch

Elasmobranchs are often taken as bycatch in fisheries targeting more valuable species (e.g. tuna and tuna-like species [4, 5]), although in some countries they are caught as target species (e.g. blue shark in the North East Atlantic). Over the last century, as a result of overexploitation, severe population declines have been documented for a number of non-target species mainly large pelagic sharks in the Mediterranean (**Figure 1** and [12, 13]) and North West Pacific [1, 10]; skates and sawfish in the Atlantic [6, 14, 15]. Such declines have been related either to a direct fishery and/or indirectly to incidental capture. According to the Food and Agriculture Organization of the United Nations (FAO), since the 1950s, landings of sharks and rays gradually increased and peaked in 2003 with more than 400,000 tons, afterwards declined by 20% [6, 7]. In contrast, recent investigations estimated a potential global catch rate of about 100 million sharks in 2000 and between 63 and 273 million sharks per year [16]. In any case, over the last decades, elasmobranch catches have been gradually dominated by rays. Due to massive exploitation and their relatively large body size, rays and skates are among the most threatened elasmobranch [6]. While several species are subjected to targeted fishing, elasmobranch catches are often illegal, unregulated, discarded and unreported to national or international management agencies. In addition, it has been estimated that approximately 50% of the global elasmobranch catches consists of individuals incidentally captured mostly in pelagic longline fisheries [11, 17]. Nevertheless, these catches still remain poorly documented. Thus, nominal annual landings do not reflect the true magnitude of fisheries-related mortality. Bycatch of sharks and rays results in a consistent number of individuals often discarded dead or dying at sea. Hence, the real number of elasmobranch discarded has generally not been reported. Based on the initially available estimates, approximately 27.0 million tons of individuals have been discarded between 1980 and 1993 [18] and about 7.3 million tons between 1998 and 2001 [4] with large uncertainties. Currently, some nations have invested in research and monitoring programmes, evaluating bycatch and discard by trained fisheries observers during commercial fishing operations [19–21]. Overall, a number of studies revealed different pattern in bycatch among gears, fisheries, fishing areas and species composition [10, 11, 22] and references there in. For sharks, pelagic longlines targeting tuna and tuna-like species reflect the highest global shark bycatch ratio and one of the largest discard ratio [23, 24].

Figure 1. Common thresher shark (*Alopias vulpinus*) caught as bycatch by midwater pair trawling in the Adriatic Sea (Mediterranean Sea). Photo credit: Andrea Petetta.

Notably, blue shark (*Prionace glauca*) is the most encountered bycatch species in pelagic longline fisheries mainly around sub-tropical and temperate regions [5, 25]. This species is currently listed as Near Threatened globally, while as Critically Endangered in Europe and Mediterranean [26]. According to recent literature, this species together with other pelagic sharks is now considered a second target species in several pelagic fisheries (e.g. in the North East Atlantic [27]) and in countries where management and conservation measures are very limited (e.g. pelagic fisheries supplying shark fin in some Pacific islands [28, 29]). In contrast, for rays, trawl fisheries seem to pose the highest threat in terms of bycatch [11, 30, 31] while longline and gillnet fisheries show the highest discard ratio [11, 32]. Of particular note, in coastal trawl fisheries, rays comprise a substantial component of the bycatch and some species might be retained and sold [6, 33]. For instance, the thornback skate (*Raja clavata*) is a target species of most of inshore trawl fisheries in Europe [34]. It also dominates bycatch in offshore mixed trawl fisheries particularly targeting flatfishes and cod in the North Atlantic [34–36]. In these fisheries, a considerable number of individuals (mainly juveniles and small individuals) are generally discarded and are likely to be dead. Hence, this species has been globally and locally listed as Near Threatened [37]. Overall, there is a wide spread concern about the impact of trawl fisheries on elasmobranch in general. Given their large diversity, several species constitute considerable portions of trawl bycatch because a viable market exists for them [6, 11, 22]. In addition, misidentification is quite common in multi-species trawl fisheries, especially for those species which are partially or not target species (i.e. rays and skates) where only little information on post-capture mortality is available.

1.2. Chimaeras bycatch

Despite one species (i.e. the elephant fish *Callorhinchus milii* in New Zealand [38]), chimaeras do not seem the subject to any direct fishing pressure. Given the minimal fishery interest and very limited reported catches, official landing statistics of chimaeras are generally gather together with sharks and rays. Overall, chimaeras are occasionally taken as bycatch by deep-water trawl fisheries and by deep-water longline, and most likely discarded at sea across their geographic distribution (**Figure 2**; [39]). The occurrence of several chimaeras species in deep-water habitats and the continuous expansion of deep-water trawl fisheries raised awareness about their potential overexploitation. Although for chimaeras, very little information exists on their ecology, life history traits and behaviour; there is a growing concern about their vulnerability to population depletion [40, 41]. Like other chondrichthyes, the extent of chimaeras bycatch is poorly documented and individuals are usually discarded at sea due to scarce commercial value. For instance, the rabbitfish *Chimaera monstrosa* is probably one of the most known chimaeroid fishes. This species is often retained as bycatch in the North East Atlantic and Mediterranean Sea [41]. Even though no specific data on population trend over time are available, this species is assessed as Near Threatened due to suspected but unconfirmed declines [41, 42]. Notably, discard is a critical aspect for this species and its relatives. The soft body structure of chimaeras and the depth of capture decrease the chance of survival of individuals after being discarded.

Figure 2. Small-eyed rabbitfish (*Hydrolagus affinis*) caught as bycatch by deep-water longline in the North East Atlantic (Azores). Photo credit: Sara Bonanomi.

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Evidence of low post-capture survival suggests that rabbitfish may represent at least 10% of discarded biomass in deep-water trawl fisheries off West coast of Ireland [40]. However, due to the lack of biological information available for these species, further research is needed in order to understand the real impact of incidental captures of chimaeras across their habitats, which are the ecological implications.

2. Understanding the impact of fisheries bycatch on chondrichthyes

Cartilaginous fish are particularly vulnerable to overexploitation since they are slow-growing K-selected species. Evidence of their vulnerability is confirmed by the fact that poor data of sustainable target and non-target fisheries exist and only few countries have adopted specific technical strategies and management plans for these species. Overall, vulnerability to fisheries bycatch reflects intrinsic life-history traits and population parameters of chondrichthyes correlated to fisheries interactions. In this view, the following paragraphs summarize the ecological consequences beyond bycatch of chondrichthyes and the difference in species composition among different gear types.

2.1. Ecological consequences

Chondrichthyes are among the most wide-ranging apex predators and key actors in structuring ocean ecosystems [13, 43]. The incidental capture of these top predators is a result of indirect harvesting, which negatively affects trophic interactions in the marine food webs. The indirect removal of sharks and their relatives cause a number of changes in community structure and food chain such as between prey-predator and predator-competitor interactions, top-down control structuring, species replacement, increasing discard rates and scavengers density [1, 13, 44]. Several studies have demonstrated that fisheries bycatch poses a serious threat to the long-term survival of chondrichthyes in general. Due to specific life-history traits, the survival and population size of these species might be severely compromised after intense extirpation. The ability of cartilaginous fish to recover after depletion is low on average. However, incidental capture does not affect all chondrichthyes similarly. Differences in terms of long-term survival, reproductive fitness and resiliencies have been documented. Generally, elasmobranchs exhibit a relatively higher tolerance to mortality associated with bycatch compared to chimaeras. The latter together with deep sharks are the most affected and vulnerable chondrichthyes. The mortality of deep-water species is assumed to be high, given their physical characteristics (soft-bodied) and increasing physiological stress, once individuals are unintentionally caught and then immediately discarded at sea [45, 46]. Still little is known on the discard survival of these species in most fisheries. In contrast, most scientific literature is focused on large pelagic sharks. These species are suffering bycatch in many fisheries and are experiencing dramatic population declines across their geographic distribution. Of particular note, the loss of large pelagic sharks has often resulted in complex community changes and trophic cascades in the marine food web, with a consequent increase of high-level pelagic elasmobranch mesopredators. It has been documented that as commercial fisheries develop and increase, the reduction of large pelagic sharks has been observed and corresponded with an increasing trend of mesopredator like smaller sharks and rays [47, 48]. The reduction of large pelagic predators influences the abundance, distribution and behaviour of smaller long-live species, including sharks and rays. It also contributes to a decreasing natural mortality of preys having few other predators and competitor species. For instance, evidence of significant declines in large pelagic predators has led to increasing expansion and abundance of pelagic stingray (*Pteroplatytrygon violacea*) in the tropical Pacific [49]. While, other studies showed that a simultaneous removal of large sharks and elasmobranch prey species would not affect mesopredator abundance in case these species are a significant prey source for top predators [50, 51]. In addition, like other chondrichthyes, large pelagic sharks might have different species-specific bycatch survival. As previously mentioned, blue shark (*Prionace glauca*) is a major bycatch species in pelagic longline fisheries targeting tunas and billfish worldwide and it can reach up to 70% of the total catches [52, 53]. Even if this species is intensively exploited, it exhibits faster reproductive potential compared to other pelagic sharks like shortfin mako (*Isurus oxyrinchus*) and porbeagle (*Lamna nasus*) incidentally taken. Having lower fecundity and higher age at maturity, these species would appear more susceptible to bycatch mortality and would be less capable of population changes if caught in substantial numbers [48, 54]. Moreover, comparing different chondrichthyes, resilience is higher for small coastal species rather than pelagic and low for large coastal and deep-water species [55]. Given their intrinsic life-history traits, juvenile survival rather than fecundity is a crucial factor contributing to population growth rate, especially in longer-lived sharks [2, 56]. Thus, in several sharks and relatives both growth and juvenile survival might be severely affected by indirect fishing pressure.

2.2. Differences among fishing gears

Bycatch takes place in several fishing practices across the entire chondrichthyes geographic distribution. Different interactions among gear type and species composition varied according to the magnitude of fishing effort and gear selectivity. Although a multitude of gear types exists, chondrichthyes bycatch mainly occurred in four broad categories of fishing gears.

2.2.1. Longline

Longline constitutes one of the major sources of individual-chondrichthyes bycatch worldwide. Due to specific technical characteristics, this type of gear catches a significant amount of non-target species mainly cartilaginous fish. Longline comprises a main line carrying a number of hooks (between 100 and 300) on branch lines (snoods) of variable lengths (up to 9 km) and spacing. It may be set either at or near the bottom (bottom-set longline), drifting in mid-water, or near the surface (pelagic surface longline [57]). Bottom longline is generally used to catch demersal and/or deep fish (cod like, flatfish), while pelagic longline is commonly targeting large pelagic fish (tuna, swordfish and billfish). Species composition and selectivity can be affected by hook (shape, size, gap, etc.) and bait type in the longline system. Chondrichthyes bycatch may strongly increase by using smaller hooks but effects could be species-specific [58] (see Section 3). In addition, the great depths that longline can reach, long hauling and soak time severely influence bycatch mortality. Deep-water sharks and chimaeras are frequently caught as bycatch by deep-water longline and they are immediately discarded dead at sea.

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However, the portion of chondrichthyes bycatch in pelagic longline fisheries is the greatest so far. Large pelagic sharks account for more than 50% of the chondrichthyes bycatch in pelagic longline fisheries [25, 59], with blue shark accounting for the largest catches in temperate and sub-tropical areas and silky shark in the tropics, instead [5, 11].

2.2.2. Gillnet

Gillnets can entangle a variety of chondrichthyes, mainly demersal sharks and rays, in both direct and indirect fisheries. A gillnets is a single netting wall held vertically in the water column by floats on the headrope and weights on the footrope [57]. This type of gear can be held on the sea surface or at certain depth by floats to drift (driftnet), or set on the sea floor and anchored by weights (bottom gillnet). Pelagic fish, including marketed sharks, are usually caught by driftnets, while groundfish are commonly targeted by bottom gillnets. Generally, depending on the mesh size and target species, gillnets are highly selective gears. However, a number of non-target and vulnerable species can become entangled around the head or mouth as they try to escape. For chondrichthyes, the highest bycatch rate inferred by gillnets has been reported in the North Atlantic [11]. Generally, sharks and rays are the most encountered species [32]. Among sharks, Carcharhinidae and Sphyrnidae species seem to have the highest mortality rates [35], while less information on ray bycatch in gillnet fishery is available given that these species are usually discarded alive and sometimes retained on board [11].

2.2.3. Trawl

Trawl is considered the most detrimental fishing gear for numerous elasmobranches and chimaeras [60]. Several trawl fisheries exist depending on gear-species interactions and fishing area. Generally, trawl consists of one funnel shaped net either towed by one or two boats in midwater (pelagic trawling) or along the sea bottom (bottom trawling). Pelagic trawling usually target small pelagic fish (anchovies and sardine), while bottom trawling mainly catch groundfish, shellfish and shrimps. A number of factors, such as duration of the trawl, the size of the catch and sorting time can influence post-capture survival of vulnerable species like chondrichthyes [60]. Of particular note, in a contest of multi-species trawl fishery (e.g. coastal trawl fisheries in the Mediterranean), bottom trawling can cause a substantial impact by changing demersal fish assemblages, thus reducing chondrichthyes abundance and diversity [61]. Several non-target elasmobranches and chimaeras are often discarded after being caught by bottom trawl fisheries in many areas [60]. The North West Pacific, North East Atlantic and Mediterranean Sea have historically been the most exploited areas by trawl fisheries with a consequent high rate of chondrichthyes bycatch [11, 13, 62]. Recently, the trend has expanded in the Central Pacific and Southern Atlantic, but little information has been provided due to unassessed fisheries or poor research.

2.2.4. Purse seine

Compared to previous fishing gears, the interactions between chondrichthyes and purse seine are apparently limited. This type of gear is usually used to target schooling of small (anchovies and sardine) and large pelagic fish (tuna and tuna like species). However, during the detection of fish schools and encircling operations, non-target species mainly large predators attracted by high fish density might be retained within the net. Purse seine fisheries are recently posing an increasing indirect removal of large pelagic sharks in tropical and subtropical areas in the Indian and Pacific oceans [53]. In these regions, a low level of shark bycatch has been reported with a majority of juvenile of silky shark being caught [25, 63]. Nevertheless, given the growing annual tuna production in the Pacific, estimates of shark bycatch registered for purse seine are likely to increase in the near future [5, 64].

3. Mitigation options to reduce chondrichthyes bycatch

Understanding the post-capture mortality of cartilaginous fish bycatch can provide insights into their intrinsic biological traits driving mortality. This knowledge is the basis for develop and introduce management measures and technical options in order to mitigate lethal effects of capture [60, 65].

3.1. Conservation and management measures

Threatened species like chondrichthyes would significantly benefit from conservation and management measures implemented synergistically at international and national levels [66, 67]. Historically, international efforts devoted to the conservation and management of sharks have been poorly pursued [60, 68]. During the last decades, several attempts have been made at national or local levels in response to specific conservation objectives for certain species and habitats [66–68]. However, the co-operation among national authorities to encourage regional and global measures has been generally inadequate and/or inefficient. This inconsistency and this lack of uniformity mean that, today at the international level, the protection and conservation of the species of cartilaginous fish are entrusted to a set of laws that often result fragmented, duplicated or overlapping, leaving room for weaknesses and gaps. Traditionally, there have not been specific laws tailored precisely to address the bycatch phenomenon, but instead the limitation of bycatch has been one of the several aspects taken into account into wider frameworks dedicated to the management and conservation of the world's aquatic living resources [68]. However, different approaches to shark conservation and management exist, and among the international laws that protect shark species, it is easy to distinguish between fishery regulations, conservation approaches (based on listing of specific species) and habitat protection. For instance, The United Nations Convention on the Law of the Sea (UNCLOS) asks to countries members to co-operate directly or through international organizations in relation to highly migratory species (UNCLOS Articles 63 and 64). This obligation is relevant to many oceanic shark species that are listed as highly migratory species in Annex I of the United Nations Convention Law of the Sea. A particular attention is also devoted to addressing incidental issues related to bycatch. In addition, the Port State Measures Agreement (PSMA) prevents that illegal and unreported fishing, as well as bycatch caught fish, may enter international markets through ports. Since 2000, the international trade in cartilaginous fish has been regulated by The Convention on the International Trade in Endangered Species and Wild (CITES), and currently, seven species are listed in

Appendix I (endangered species, whose trade International is permitted only in exceptional cases), and 11 species are included in Appendix II (species not necessarily threatened with extinction, but whose international trade must be controlled in order to avoid an exploitation incompatible with their survival). The Appendix III may include species not necessarily threatened with extinction at the global level, and their inclusion may be decided without the agreement of other State parties, in order to generate concern on a particular species and open the door to international co-operation. Beyond the practical effects of including shark species in the CITES Appendices, the parties have repeatedly recommended improved interventions for the conservation and management of sharks, inviting the FAO Committee of Fisheries (COFI) and the regional commissions for the management of Fishing to intensify efforts, to undertake research, training, data collection and data analysis and to indicate as a priority the development of action plans for the conservation and management of sharks. Furthermore, sharks and relatives are a focus group of the Convention on Biological Diversity (CBD), which plays a critical role in habitat protection, identifying the correct strategies for both *in situ* and *ex situ* conservation, as well as delivering solid guidelines necessary for protected areas establishment [69]. Together with the management and conservation measures comes the International Plan of Action (IPOA) for the conservation and management of sharks, which it has been meant to be received as a set of technical directives for the conservation and management of sharks, to be used as guidelines by FAO member countries during the implementation of country-specific National Plans of Action. When the plan was firstly adopted in 1999, the overall knowledge available about the fishery status of shark in the world was utterly scarce and only a few countries had specific plans including fishing regulations of cartilaginous fish. Given the wide distribution of these species, it became clearer that international co-operation was a key aspect for conservation and protection of cartilaginous fish populations. The IPOA-Shark aims mainly at the conservation of sharks and at their long-term and sustainable use. The plan applies to all cartilaginous fish, including sharks, rays, skates and chimaeras and to all kind of fisheries, including commercial catches, recreational fishing, direct fishing or by-catch and others. The IPOA-Shark suggests the use of many well-known strategies of biodiversity conservation and fishery management, including a better control over access of fishing vessels to shark stocks, a decrease in fishing effort in any shark species where catch is unsustainable, the identification of vulnerable and threatened species, an improved data collection, the assessment and reporting, a sustainable use of target species and a full utilisation of dead sharks, research on little known shark species and gathering of utilization and trade data on shark species [70]. The Plan establishes not only the need to manage shark catches, but also calls for a better legislation on incidental catches, particularly in the tuna fishing sector. The plan also recommends that States that implement the Shark-plan, at least every 4 years should assess its implementation for the purpose of identifying cost-effective strategies for increasing its effectiveness, while states that determine that a Shark-plan is not necessary should review that decision on a regular basis taking into account changes in their fisheries. Finally, the IPOA-Sharks address shark conservation and management in a more comprehensive way than is achieved in the treaties previously discussed in this chapter, but one of its core problems, from a legal perspective, is that it does not create binding rights and obligations on states, because it is not a treaty or a ‘hard’ law [68].

3.2. Technical measures applied to different fishing gears

Table 1 summarize the current technical measures adopted or proposed in different fishing gears in order to prevent and reduce chondrichthyes bycatch.

Gear type	Technical measure	References
Pelagic longline	Circle hooks	[24, 71–78]
	Bait restrictions	[71, 73, 79, 80]
	Bans on wire leaders	[81–84]
	Hook depth	[49, 85, 86]
	Temperature avoidance	[48, 87, 88]
	Reducing soak time	[4, 87, 88]
	Repellents	[89–91]
Bottom longline	Number of hooks	[92, 93]
Gillnet	Mesh size regulations	[94, 95]
	Tensioning gillnet	[96]
Trawl	Bycatch reduction devices	[97, 98]
	Filter grid	[99, 100]
Purse seine	Ecological FADs	[101, 102]
	Deterrents	[103]
	Times	[104]
	Restriction on sets on FADs and other floating objects	[105]
	Multiple FADs	[102]

Table 1. Gear types and associated technical measures.

4. Case studies

Despite indirect fisheries removal is a concern for several long-lived marine species, chondrichthyes bycatch is a noteworthy complex issue to investigate and manage. The following paragraphs summarize the current knowledge of chondrichthyes bycatch and strategies for reduction in areas where most of the research is carried out.

4.1. Chondrichthyes bycatch in the North Atlantic and potential solutions

Most of the information concerned about chondrichthyes bycatch has been reported for North Atlantic region. In this area, sharks and their relatives are both directly and indirectly taken by

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numerous commercial fisheries mainly tuna and billfish longline, driftnets, purse seines and shrimp trawls. Considering the North East Atlantic, spurdog (*Squalus acanthias*) constitutes a significant bycatch component of direct fisheries, mainly in shrimp trawlers and gillnet fisheries [34, 106]. In addition, a substantial number of spurdog are often discarded at sea with a relative low mortality (6%) reported for trawls [107, 108] and higher levels (55%) for gillnets [108] in this area. However, given that this species has a long history of exploitation in the North East Atlantic region; recent restrictive management measures have been adopted. For instance, only a small bycatch quota is allowed in Norwegian waters (no more than 5% by live weight of the catch retained on board and bycatch must not exceed 20% of the total landings in certain periods [34]). While, direct fishing with nets and longline has been prohibited in Swedish waters since early 2008 and effort restrictions have been applied in the mixed fisheries in the North Sea, West of Scotland and Irish Sea instead (EC 1342/2008 [34]). Furthermore, several deep-water sharks, skates and chimaeras are often taken as bycatch in mixed fisheries in the North East Atlantic. For instance, leafscale gulper shark (*Centrophorus squamosus*) and Portuguese dogfish (*Centroscymnus coelolepis*) are incidentally captured and discarded in the longline fisheries targeting black scabbardfish (*Aphanopus carbo*) in Portugal, Azores and Madeira islands [109–111]. Both species have been recently assessed as Endangered in the Red List of European marine fish [112]. According to European regulations, no directed trawl and gillnet fisheries are permitted for several deep-water sharks species in certain areas (see EC No 1568/2005 and EC No 41/2007 [34]). Only a small fraction of bycatch quota is allowed (between 3 and 10%) based on gear type and fishing area [34]. However, given that black scabbardfish and deep-water sharks apparently spatially overlap, other management measures should be introduced [109]. In contrast, many ray and skate species are usually taken as target species and bycatch in demersal fisheries for flatfish with thornback ray (*Raja clavata*) and thorny skate (*Amblyraja radiata*) accounting for 90–95% of the total skate bycatch in the North Sea and in the Barents Sea ecoregions, respectively [113, 114]. In the North West Atlantic, sharks and their relatives are generally taken in direct fisheries and also incidentally captured, mainly in USA, Canada and Mexico (Atlantic side), and with less extent in Caribbean waters [16, 115, 116]. In USA and Canada, large pelagic sharks are intensively harvested by longline fisheries. In addition, these species are the most encountered in reliable commercial landings and a large portion of these is a result of indirect fishing removal [52, 53]. While, in Mexico and Caribbean waters, sharks and rays are usually fished by artisanal fishermen, and juveniles of large species are often taken as bycatch [117]. However, regional management and conservation measures have been implemented in some fisheries. For instance, the United States National Marine Fisheries Service (NMFS) in USA and the Department of Fisheries and Oceans (DFO) in Canada have conducted observer programs to monitor commercial fishing vessels targeting tuna, swordfish and sharks. In addition, other measures including the reduction of fishing effort targeting sharks, time/area closure in certain seasons and gear restrictions have been adopted in the North Atlantic [116, 118–120]. Notably, many large pelagic sharks are overfished or in overexploitation and are often removed as bycatch in longline fisheries targeting tuna and swordfish in the North Atlantic as a whole [11, 54, 117]. Given their wide distribution and their high ability to migrate, large pelagic sharks have been usually exploited by different nations in the North Atlantic. Hence, blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*) and porbeagle (*Lamna nasus*) are among the most common caught species in the area, with blue shark having the highest bycatch and discard rates [11]. Recently, specific technical mitigation measures have been proposed and implemented in order to reduce bycatch mortality. Some authors suggested the use of circle hooks rather than J-hooks to increase post-release survival of large pelagic sharks in longline fisheries [71, 72, 120].

Overall, monitoring and management of cartilaginous fish in the North Atlantic are covered by different international advisory parties like International Commission for the Conservation of Atlantic Tunas (ICCAT), North West Atlantic Fisheries Organisation (NAFO), Inter-American Tropical Tuna Commission (IATTC). Such organisations have recently recommended a number of measures concerning the reduction of fishing mortality in fisheries directly and indirectly targeting endangered or particularly vulnerable large pelagic sharks, technical gear modifications to increase fishing selectivity, monitoring the retaining of shark fins, bycatch and discard by appropriated scientific observer programs and reporting of catch data [53].

4.2. Chondrichthyes bycatch in Mediterranean Sea and potential solutions

Although rarely targeted in Mediterranean fisheries, chondrichthyans are often caught as bycatch [121, 122]. According to [119], in the Eastern and Southern Mediterranean countries some chondrichthyan bycatch species provide an important source of cheap fishmeal. A long history of trawling in Mediterranean resulted in significant loss in number of recorded elasmobranch since 1950s [13]. Mediterranean trawls are mostly equipped with either 40 or 50 mm diamond or 40 mm square mesh codends [123]. These codends are able to release a certain amount of small chondrichthyan species [124, 125], but are certainly far from optimal. It is difficult to expect that there is going to be any further increase in mesh size in Mediterranean in near future, which is why some authors advocate using various excluder grid devices, e.g. Turtle Excluder Device (TED) [60, 66, 67, 126, 127]. So far, only one study examined the effect of inserting an excluder grid device in front of the size selective codend with the aim to reduce shark bycatch in the Western Mediterranean bottom trawl fishery [60]. The authors tested one grid with 90 mm grid bar spacing, and the results showed that the grid was not very effective in excluding *Galeus melastomus* (the only shark species tested in the study), and that reduction from 90 to 70 mm bar spacing would be much better compromise in excluding this species while maintaining the catches of commercial species. Moreover, the study performed by [128] summarized the results from the monitoring programme of accidental catches of cetaceans by Italian midwater trawlers, where highly vulnerable elasmobranch bycatch species were also monitored. According to their study, a total of 15 different species of elasmobranchs were caught in the Adriatic Sea midwater trawl fishery between July 2006 and December 2008. Sharks and rays, although not targeted, by this fishery, are highly valued and were regularly marketed. Some shark species like thintail threshers (*Alopias vulpinus*), piked dogfish (*Squalus acanthias*) and smooth hounds (*Mustelus mustelus*) were caught in relatively large numbers. Only pelagic stingrays (*Pteroplatytrygon violacea*), common stingrays (*Dasyatis pastinaca*), bull rays (*Aetomylaeus bovinus*) and common eagle rays (*Myliobatis aquila*) were regularly discarded [128]. Since the study showed seasonal and geographical variation in elasmobranch bycatch rate, the authors argued that if any mitigation measures are to be implemented in the study area, both geographical and seasonal variation must be taken into account. They also identified the North Adriatic Sea as an area where mitigation measures should be adapted first. Ref. [50] focused only on the bycatch of myliobatidae rays, common eagle ray (*Myliobatis aquila*) and bull ray (*Aetomylaeus bovinus*) in the midwater trawl fishery in the Mediterranean Sea. Bull ray catch data from the Mediterranean region are very scarce; IUCN listed this species under Data Deficient category [129]; but nonetheless, due to its life history traits it can be considered as Potentially threatened locally [50, 130]. According to [130] and references therein, the greatest threats to bull ray in Greek waters (Eastern Mediterranean) are gillnets where they are caught as a bycatch and often discarded [130]. IUCN listed common eagle ray also as data deficient, but from [131], we know that commercial demersal catches have dramatically declined in Gulf of Lion during the 1970–1995 period, what can probably be extrapolated to other Mediterranean regions. Ref. [50] noticed that the increase in the haul duration in Northern Adriatic midwater pair trawl fishery resulted in lower CPUE values for these two species, probably due to very low likelihood of catching more than few individuals per haul. They further concluded that limitation on haul duration and midwater trawl size could be beneficial, since, once discarded, it can greatly increase its chance of survival. Elasmobranch bycatch is also known to be relatively high in longline fishery [17]. A surface longline fishery targeting tuna and swordfish in the Mediterranean often incidentally captures several pelagic sharks [132]. According to [133], shark bycatch is higher in the Western than in the Eastern Mediterranean Sea, where sharks were reported to be the second most important bycatch group caught with traditional swordfish, American type and albacore longline types. The blue shark, *Prionace glauca*, was the most abundant shark bycatch species, followed by tope shark (*Galeorhinus galeus*), shortfin mako (*Isurus oxyrinchus*) and common thresher shark (*Alopias vulpinus*). The authors concluded that in any drifting longline fishery targeting large pelagic fish, many hundreds or thousands of sharks are killed in the Eastern Mediterranean each year [133]. Bottom longlines are typically catching demersal chondrichthyan species such as *Mustelus* spp., *Squalus* spp., *Torpedo* spp., *Galeus melastomus, Hexanchus griseus, Centrophorus granulosus* and several ray species such as *Raja clavata* and *Raja radula* [134–136]. Ref. [126] argued that a part of the solution for elasmobranch bycatch reduction in bottom or near bottom longlines could be the adoption of nylon gangions as opposed to the steel wires because this would allow the larger specimens to bite of the line and escape. This, however, would not reduce the bycatch of juveniles. Several technical solutions could increase the selectivity of both bottom and surface longlines, e.g. hook size and shape, reduced soaking time, fishing depth, avoidance of certain types of baits, presence of swivels, etc. [126, 127].

5. Conclusion

Chondrichthyes are among the most threatened long-lived marine species worldwide. Incidental capture is one of the main sources of mortality for these species. However, prevention and reduction of chondrichthyes bycatch are not easy tasks. Ongoing scientific research and monitoring are focused in certain areas where the actual global pattern of bycatch is no longer representative (Atlantic versus Pacific and Indian oceans). Still, scarce knowledge is available for many species, mainly for those leaving in remote environments. Hence, more information on biology, ecology and population dynamics of chondrichthyes is required to have a better understanding of species-specific bycatch composition occurring in different fishery regions. Despite cartilaginous fish are subjected to international conservation and management measures, only in few countries, advices really take place. More co-operation between fishing nations and effective recommendations is needed on both global and regional scales.

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