RESEARCH ARTICLE

A closer look at the bycatch of medium-sized and large sharks in the northern Catalan coast (north-western Mediterranean Sea): Evidence of an ongoing decline?

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Abstract

1. Historically, the Mediterranean Sea supported a rich shark fauna. Presently, however, populations of most shark species have significantly declined, largely due to intense fishing pressure.

2. Interviews with crew members of bottom trawlers, drifting longliners and bottom longliners operating off the Costa Brava (Catalonia, NE Spain) were conducted between October 2016 and July 2017 in order to gather information on the current bycatch rate of several shark species.

3. Interviews covered 41.2% of the fleet and respondents were asked for the bycatch of selected shark species—Alopias vulpinus, Cetorhinus maximus, Galeorhinus galeus, Hexanchus griseus, Isurus oxyrinchus, Mustelus spp., Prionace glauca, and Squalus acanthias—in two distinct time periods.

4. Bottom trawlers captured the highest diversity of species (eight) followed by bottom longliners (seven), and drifting longliners (three). Most respondents (89.7%) declared having captured at least one shark from 2006 to 2016 but only 56.4% declared having captured at least one shark from 2016 to 2017.

5. From 2016 to 2017, the whole fleet captured 89 specimens of H. griseus (95% confidence interval (CI) = 145, 34), 14 of G. galeus (95% CI = 30, 0), 3 of A. vulpinus (95% CI = 8, 0), 3 of I. oxyrinchus (95% CI = 8, 0), 3 of C. maximus (95% CI = 6, 0), and no Mustelus spp. The total bycatch of P. glauca and S. acanthias was uncertain due to extremely loose confidence intervals.

6. A significant decline was perceived by fishermen in the bycatch of C. maximus and S. acanthias, whereas the bycatch of H. griseus was considered to have remained stable.

7. This study suggests a dramatic reduction in the abundance of most of the medium-sized and large sharks of the Costa Brava and the likely disappearance of Mustelus spp. from the area. Only H. griseus, S. acanthias, and P. glauca are still being bycaught frequently.

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1 | INTRODUCTION

Sharks are amongst the top predators in ocean ecosystems (Dulvy et al., 2008) and potentially exercise a top-down control upon other organisms, thus having a fundamental role in the structure and function of marine communities (Myers et al., 2007; Heithaus et al., 2008; Ferretti et al., 2010). Some estimations indicate that populations of large predatory fish have been reduced by 90% worldwide over the last 50–100 years due to overexploitation (Christensen et al., 2003; Christensen et al., 2014), with sharks being highly sensitive to depletion due to their life strategies (Myers & Worm, 2005). Like most Chondrichthians, sharks are characterized by K-selected life history traits (Kabasakal, Karhan & Saknan, 2017), which results in low reproductive potential and low capacity for population increase (Pratt & Casey, 1990). Thus, sharks are more likely to be affected by intense fishing than most teleosts (Castro, Woodley & Brudek, 1999; Stevens et al., 2000). Large sharks in particular can suffer large population declines even with comparatively light fishing pressure (Ferretti et al., 2010). As a result, a large number of shark species are currently threatened worldwide due to bycatch and overfishing (Camhi et al., 2009; Hisano, Connolly & Robbins, 2011; Worm et al., 2013; Dulvy et al., 2014; Simpfendorfer & Dulvy, 2017).

The Mediterranean Sea is considered a biodiversity hot-spot for sharks (Dulvy et al., 2014). Literature published during the 19th century reported abundant populations of species such as Alopias vulpinus, Isurus oxyrinchus, Mustelus asterias, Mustelus mustelus, Prionace glauca, Scyllorhinus canicula, Scyllorhinus stellaris, and Squalus acanthias (Peris, 1862; Cisternas, 1867; Navarrete, 1898). The same sources also reported the presence of species currently uncommon such as Carcharias taurus, Cetorhinus maximus, Dalatias licha, Galeorhinus galeus, Odontaspis ferox, Oxynotus centrina, and Sphyma zygaena. Nevertheless, a growing number of studies are reporting a general decline of pelagic sharks in the Mediterranean Sea (Megalofonou, 2005; Ferretti et al., 2008; Fortibuoni et al., 2016; Colloca et al., 2020) and medium-sized and large shark species are seldom reported in the catch list of bottom trawlers operating in the western Mediterranean Sea (Massuti & Moranta, 2003; Massuti & Reñones, 2005), which suggests a severe reduction of the rich shark fauna reported by the 19th century authors (Colloca et al., 2017).

The Mediterranean Sea hosts the highest proportion of threatened species due to unregulated fishing (Colloca et al., 2017). In a recent report published by the IUCN (Dulvy et al., 2016), 39 of the 73 assessed species of Chondrichthians were found to be regionally threatened in the Mediterranean Sea, with overfishing identified as the main driver of decline and local extinction. Twenty-three of these 39 species were sharks; 12 fell under the category of ‘Critically Endangered’, six were considered ‘Endangered’, and five were ‘Vulnerable.’ Furthermore, 10 species were still listed as ‘Data Deficient’. In the Spanish Mediterranean Sea, there remains a paucity of information regarding shark populations (García-Cortés & de la Serna, 2002; de la Serna et al., 2002; Massuti & Moranta, 2003; Massuti & Reñones, 2005), with recent research mostly focusing on the trophic ecology of a few species (Navarro et al., 2014; Albo-Puigserver et al., 2015; Barriá, Coll & Navarro, 2015; Barriá et al., 2015).

In general, estimating parameters such as abundance or distribution of rare species is time-consuming and requires extensive funding (Anadón et al., 2009). In this context, the local ecological knowledge (LEK) held by fishing communities, taken as “a cumulative body of knowledge, practice and belief evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment” (Berkes, Colding & Folke, 2000: p.1252) has been used to obtain information about abundance and population trends of a wide range of species (Ferguson, Williamson & Messier, 1998; Sáenz-Arroyo et al., 2005; Bender et al., 2014; Damals et al., 2015; Colloca et al., 2020), as well as other biological and ecological information (Johannes, Freeman & Hamilton, 2000; Silvano et al., 2006; Stacey et al., 2012; Giovos et al., 2019). While some scientists and managers are rather sceptical about its reliability (Shackeroft & Campbell, 2007; Brook & McLachlan, 2008), LEK has proved to be a source of high-quality and low-cost information (Anadón et al., 2009) and numerous studies working on fisheries have shown that combining scientific assessments with LEK can improve management decisions (García-Quijano, 2007; Silvano & Valbo-Jørgensen, 2008; Bender et al., 2014; Carothers et al., 2014).

The purpose of this study was to update the information about the presence of some medium-sized and large shark species inhabiting the Costa Brava, in north-eastern Spain (Figure 1) by means of LEK. Specifically, the aim was to: (i) determine which species are still commonly bycaught by bottom trawlers, bottom longliners, and drifting longliners; (ii) identify the main factors influencing the capture of each species according to the fishermen’s perception; and (iii) assess the population trend of each species according to the fisherman’s perceptions.

2 | METHODS

2.1 | Study area

The Costa Brava stretches from Portbou (42.435°N 3.174°E) to Blanes (41.651°N 2.778°E), covering up to 60 km of coastline (Figure 1). Its maritime relief is distinctive, with a narrow continental
shelf and the shelf break found just a few kilometres offshore. The continental shelf and slope are dissected by three submarine canyons (Cap de Creus, Palamós, and Blanes) from north to south (Figure 1). They represent hotspots for marine life and are used as fishing grounds, mostly by the red shrimp (*Aristeus antennatus*) and Norway lobster (*Nephrops norvegicus*) fisheries.

2.2 | Focal species

Information was collected on five species of large sharks (>200 cm standard length (SL): common thresher (*Alopias vulpinus*), basking shark (*Cetorhinus maximus*), bluntnose sixgill shark (*Hexanchus griseus*), shortfin mako (*Isurus oxyrinchus*) and blue shark (*Prionace glauca*) and several species of medium-sized sharks (90–200 cm SL: tope shark (*Galeorhinus galeus*), smooth-hounds (*Mustelus* spp.), and spiny dogfish (*Squalus acanthias*). A medium size was hereby defined as either equal or bigger than the size at maturity of *S. acanthias* in the western Mediterranean Sea, which is approximately 90 cm SL in females (Capapé & Reynaud, 2011) and therefore allowing us to exclude smaller species like catsharks (*Galeus melastomus* and *Scyliorhinus canicula*).

2.3 | Questionnaire-based survey

Interviews were conducted from October 2016 to July 2017 at six of the 11 fishing ports in the area. These ports were selected because
they represented the only ones that were used as a base by either longliners or bottom trawlers. Information was compiled by interviewing fishermen with the aim of covering at least 30% of the fleet of each fishing gear.

The interviews were carried out using a modified version of the questionnaires previously used to assess the bycatch of other species of megafauna in the Spanish Mediterranean Sea (Carreras, Cardona & Aguilar, 2004; Álvarez de Quevedo et al., 2010), which were adapted for sharks. At the start of each interview, the participants were given some identification forms and pictures of each shark species and then responded verbally to a set of questions concerning biological aspects of the species, catch frequency, factors influencing their bycatch, and the population trend of the different species.

Most specifically, fishermen were asked to identify the shark species they had seen and captured and to indicate the month of the year and the fishing grounds where captures of each species had occurred over the last year (2016 to 2017) and throughout the last 10 years (2006 to 2016). Fishermen were also asked to report, as accurately as possible, the number of individuals of each species that had been captured from 2006 to 2016 and from 2016 to 2017 and to say the reason why bycatch of these species took place. Finally, fishermen were asked to give their opinion on the population trend of the focal species choosing from ‘increasing’, ‘stable’, or ‘decreasing’. For those species under any form of legal protection and whose population numbers were labelled as ‘decreasing’ in the interviews, potential factors responsible for the decline of these species were divided into three main categories: biological, fishing-induced, and other anthropogenic impacts. The combination of factors was also considered in the analysis and those that did not conform to any of these categories were classified as ‘others’.

2.4 | Fishing effort and shark bycatch estimations

The fishing fleet includes three different types of vessels using three different fishing gears (bottom trawlers, bottom longliners, and drifting longliners), so a stratified approach was used to estimate total shark bycatch (Greenwood, 1996). Fishing effort was defined as the number of months in which each vessel operated on an annual basis, as in other studies using the same approach (Carreras, Cardona & Aguilar, 2004; Álvarez de Quevedo et al., 2010). According to Spanish fishing regulations, all bottom trawlers in the region are obligated to cease fishing for 2 months at different times of the year in each port, while longline vessels are not subject to this temporal closure. During the season, every bottom trawler operates from 7 am to 6 pm, from Monday to Friday, with 2–3 tows per day of work.

Total fishing effort with gear z (Ez) was calculated as:

$$E_z = \sum_{i=1}^{n} E_{zi}$$

where Ezi is the effort from vessels from the ith port operating with gear z.

In its turn, Ez was calculated as follows:

$$E_z = E_{oz} \frac{n_z}{n_{oz}}$$

where Eoz is the effort reported by the interviewed fishermen from port i operating with gear z, noz is the number of registered vessels based in port i that used gear z, and noz the number of vessels from port i that used gear z and whose crew was interviewed. Total shark catch with gear z (Cz) was calculated as:

$$C_z = C_{oz} \frac{E_z}{E_{oz}}$$

where Coz is the number of sharks caught, as reported by fishermen with gear z; Ez is the total fishing effort with gear z; and Eoz is the effort reported by fishermen with gear z. Total shark catch by the whole fleet was the sum of the Cz values of the three gears. The 95% confidence intervals of estimated catch were calculated with the procedure detailed by Greenwood (1996) for stratified sampling.

2.5 | Fishermen’s perception on the evolution of shark populations

The questionnaires asked fishermen about their perception on the evolution of the population size of each species, with only three possible answers: increasing, stable and decreasing. A chi-squared test was carried out using IBM SPSS Statistics (Version 24) to assess whether the frequencies of the three possible answers (increase, stable, and decline) differed from those expected by chance (all three answers had the same probability by chance).

3 | RESULTS

3.1 | Fleet coverage and occurrence of shark captures

A total of 42 full interviews were carried out and a minimum coverage of 30% was accomplished for each fishing gear—bottom trawlers (31 interviews; 40.8% of the fleet), bottom longliners (9 interviews; 45% of the fleet), and drifting longliners (2 interviews; 33.3% of the fleet; Table 1). The number of interviews for each fishing gear and fishing port are summarized in Table 1. The number of interviews for each fishing gear and fishing port are summarized in Table 1. The number of interviews for each fishing gear and fishing port are summarized in Table 1.
than 50 sharks (10.3%). From 2016 to 2017, ‘no catches’ was the most frequent answer (43.6%), followed by capturing 1–5 (38.5%), 6–10 sharks (10.3%), and more than 50 sharks (7.7%).

From 2006 to 2016, bottom trawlers captured all species targeted in this study. Bottom longliners captured seven species but did not capture Mustelus spp. Prionace glauca, A. vulpinus and I. oxyrinchus were the only three species captured by drifting longliners. From 2016 to 2017, the average number of sharks captured by the surveyed bottom trawling fleet was 1.7 individuals per vessel per year, whereas 31.1 and 29.5 sharks were captured per vessel per year by the bottom longline and the drifting longline fleets, respectively.

When these figures are extrapolated to the whole fleet, a total of 926 sharks were estimated to have been caught from 2016 to 2017 (Figure 2). Prionace glauca, S. acanthias, and H. griseus clearly dominated the catch, but the only reliable bycatch estimate was that of H. griseus ($n = 89; 95\% \text{ CI} = 145, 34$). Captures of P. glauca and S. acanthias were so variable that the 95% CI intervals of their estimates were extremely loose ($P. glauca n = 617, 95\% \text{ CI} = 1288, 0$; $S. acanthias n = 197, 95\% \text{ CI} = 486, 0$). The remaining species were rarely captured, which resulted in very low bycatch figures for G. galeus ($n = 14; 95\% \text{ CI} = 30, 0$), A. vulpinus ($n = 3; 95\% \text{ CI} = 8, 0$), I. oxyrinchus ($n = 3; 95\% \text{ CI} = 8, 0$), and C. maximus ($n = 3; 95\% \text{ CI} = 6, 0$). No captures of Mustelus spp. were reported. Bottom trawlers captured all the reported specimens of C. maximus and about 90% of G. galeus, H. griseus, and S. acanthias. The latter species were also captured sporadically by bottom longliners, while A. vulpinus and I. oxyrinchus were only captured by drifting longliners. Prionace glauca was mainly captured by bottom longliners (70.3%), although drifting longliners (27.7%) and bottom trawlers (1.98%) occasionally captured this shark too (Figure 2).

### 3.2 Fishermen’s perception on the evolution of shark populations

All gears combined, results show that respondents mainly considered sharks to be suffering a decrease in abundance over time or, to a lesser extent, to remain at a stable number of individuals (Figure 3). The distribution of answers about the population trends of A. vulpinus, G. galeus, I. oxyrinchus, and P. glauca did not depart from that expected by chance (Table 3) and hence fishermen’s answers were uninformative. The opposite was true for C. maximus and S. acanthias, both considered by respondents to be declining more often than expected by chance (Table 3). Likewise, the frequency to which respondents considered that the bycatch of H. griseus and Mustelus spp. is stable was also higher than that expected by chance (Table 3).
3.3 | Factors influencing shark captures

Respondents considered overlap between fishing grounds and shark habitat as the main reason for bycatch, followed by the attraction of sharks drawn by the fishing activity (Figure 4).

Together, they accounted for the 82.3% of all the answers given by respondents.

At the time of the study, four species were legally protected by Spanish legislation—A. vulpinus, I. oxyrinchus, C. maximus, and G. galeus—and each of them were differently affected by each factor (Figure 5). According to respondents, fishing-induced mortality was regarded as the main factor causing the decline in I. oxyrinchus (50%), whereas other anthropogenic impacts were identified as the main threat for A. vulpinus (66.7%) and C. maximus (50%). Finally, biological factors and other anthropogenic impacts, each identified by 30% of the respondents, were considered the two main threats for G. galeus.

4 | DISCUSSION

The results reported here indicate that currently only P. glauca, S. acantbias and H. griseus are regularly bycaught by fishermen operating off the Costa Brava, whereas G. galeus, A. vulpinus, and...
I. oxyrinchus, C. maximus and Mustelus spp. are extremely rare. Although interview-derived data might sometimes lack accuracy or be poor if the study is poorly designed (Álvarez de Quevedo et al., 2010), questionnaire-based surveys are one of the most practical methods to assess the bycatch of rare species (Godley et al., 1998). The compilation of data using such a practical low-cost methodology provided the present study with some insight that may pave the way for future species-specific studies and encourage local and regional authorities to develop new conservation strategies in order to tackle the issues facing shark populations off the Costa Brava.

Sharks are highly vulnerable to overfishing and bycatch because of their very low rates of population increase (Camhi et al., 2009). In the Costa Brava, medium-sized and large sharks were regularly captured by fishermen in the 19th century (see Peris, 1802; Cisternas, 1867; Navarrete, 1898), but currently most of them are rarely captured by the fleet. Although the scale of bycatch is also subject to some operational factors such as the characteristics of the fishing gear, the fishing grounds, and the fishing hours (Megalofonou, 2005; Carruthers, Neilson & Smith, 2011; Oliver et al., 2015), it largely depends on shark abundance. Consequently, the decrease in both number and frequency of catches observed in this study might be indicative of an ongoing decline in shark abundance.

This study reveals bottom trawling as the fishing gear responsible for capturing the highest number of the focal shark species. Similar results have been reported in other regions of the Mediterranean Sea (Carbonell et al., 2003; Colloca et al., 2003; Yaglioglu et al., 2015; Bonanomi et al., 2018). Bradai, Saidi & Enajjar (2012) considered demersal species as the most frequently caught by trawlers but also included large pelagic species such as A. vulpinus, P. glauca, I. oxyrinchus, and C. maximus as occasional catch. Indeed, 5% of C. maximus captures in the Mediterranean Sea are reported from trawl fisheries (Mancusi et al., 2005).

Bottom longline ranked second in number of captured species, with seven reported to be bycaught from 2006 to 2016. Interestingly, P. glauca was the most commonly captured species although it is known to spend most of its time near the top of the water column (Stevens, Bradford & West, 2010). The diversity of bycaught species dropped to four from 2016 to 2017, however, and no captures of Mustelus spp. were reported from 2006 to 2016 nor between 2016 and 2017. This may suggest that Mustelus spp. have been very scarce off the Costa Brava for more than a decade, particularly considering the fact that fishers did acknowledge captures of S. acanthias, a species that shares the same habitat.

Conversely, drifting longline only captured pelagic species, namely P. glauca, A. vulpinus, and I. oxyrinchus both from 2006 to 2016 and
from 2016 to 2017, even though up to 12 species (including G. galeus, C. maximus, Mustelus spp., and H. griseus) are sometimes caught by this gear according a General Fisheries Commission for the Mediterranean report (Bradai, Saidi & Ennajar, 2012).

Concerning the estimation of the total bycatch by the entire fleet of the Costa Brava from 2016 to 2017, captures of A. vulpinus, L. oxyrinchus, C. maximus, and G. galeus were very low and the few captures of A. vulpinus and L. oxyrinchus were restricted to drifting longliners. These two species are pelagic sharks that move close to the surface and have been reported as bycatch in this gear for a long time (Casey & Kohler, 1992; Peristeraki et al., 2008; Cortés et al., 2010; Mejuto et al., 2013). The fact that only a few specimens were captured off the Costa Brava might be further evidence of the severe decline of these large predatory species in the Mediterranean Sea, already reported by Ferretti et al. (2008). Bottom trawlers were involved in all the captures of C. maximus reported in this study. C. maximus is also a pelagic species found at the top of the water column, but captures of this species can sometimes occur as some individuals get entangled in a trawl net when it is being hauled. G. galeus was mainly captured by bottom trawlers but also by bottom longliners. Again, this is as expected for this species, taking into account that this shark usually inhabits waters deeper than those of the three species before-mentioned but shallower than those of bottom-dwelling sharks, such as H. griseus, making it susceptible to being caught by both trawl nets and bottom longlines.

Not a single capture of Mustelus spp. was recorded by the interviewed fishermen from 2016 to 2017. Mustelus spp. have suffered a drastic decline in the Mediterranean Sea not only in abundance but also in terms of spatial distribution, as its distribution range has diminished in recent decades due to heavy fishing according to (Colloca et al., 2017). The absence of captures of Mustelus spp. concurs with Colloca’s findings and suggests the possibility that populations of these medium-sized sharks might no longer exist in the Costa Brava.

In the case of P. glauca and S. acanthias, the extremely high variability in all reported captures from 2016 to 2017 meant it was not possible to give a reliable estimation of their total captures. This high variability stems from the fact that only a few vessels reported captures: two for P. glauca, which reported having captured 50 and 200 individuals respectively, and one for S. acanthias, which reported having captured 90 sharks. Nonetheless, these results reveal that both species still occur in the region, although probably restricted to a few areas.

Hexanchus griseus was the most consistently bycaught shark by the fleet, yet almost exclusively by bottom trawlers. This species is most usually found on the continental slopes in the Mediterranean Sea (Stefanescu, Lloris & Rucabado, 1993; d’Onghia et al., 2004), which are precisely the main fishing grounds of the bottom trawling vessels targeting the red shrimp in the north-western Mediterranean Sea.

Respondents considered populations of A. vulpinus, C. maximus, L. oxyrinchus, S. acanthias, and G. galeus to be decreasing off the Costa Brava, but regarded populations of H. griseus, Mustelus spp., and P. glauca as stable. Numbers of P. glauca were even considered by a few fishermen, especially longliners, to be increasing. However, the distribution of the three possible answers departed from that expected by chance only for C. maximus, S. acanthias (both considered as decreasing), and H. griseus, and Mustelus spp. (both considered stable). Although illustrative, this result does not provide any science-based knowledge and could be highly biased. For instance, as of 2020, P. glauca is classified by the IUCN Red List of Threatened Species as ‘Critically Endangered’ in the Mediterranean Sea and shows a remarkable decreasing trend over the last few years contrary to what respondents have suggested in this study. But perhaps the most striking case is that of Mustelus spp., as respondents had not captured single specimen in the area for many years and hence considering the species numbers to be stable actually means that it has been rare for a long time.

Overlap between fishing grounds and species distribution has been identified in some studies as a major cause of shark bycatch (Perez & Wahrlich, 2005; Queiroz et al., 2016). Similarly, respondents in this study also acknowledged overlap as the main reason why shark bycatch occurs along with the belief that sharks get attracted to fishing activity.

Even though respondents considered there was no protected species the decline of which could be ascribed to a single factor, some factors did seem to be more relevant in explaining the dwindling numbers of some of these shark species. For example, fishermen perceived fishing-induced factors are greatly responsible for the decline of L. oxyrinchus. This coincides with other studies highlighting the dramatic decline of the species in the Mediterranean Sea (Ferretti et al., 2008; Colloca et al., 2017; Colloca et al., 2020), and moderate decline in the Atlantic Ocean (Baum et al., 2003) due to intense fishing. Other anthropogenic impacts, such as changes in water temperature due to global warming, pollution of the marine environment or water impoverishment, represented the main reasons perceived by respondents as to why C. maximus and A. vulpinus are disappearing. The results obtained for C. maximus agree with those of Sims & Reid (2002) and Cotton et al. (2005), who linked the decrease in shark catches with a decrease in the abundance of copepods and sea surface temperature respectively rather than fishing practices and thus differs from other studies that suggest C. maximus is mostly affected by overfishing (Stevens et al., 2000). Fishermen also attributed the depletion of A. vulpinus to other anthropogenic impacts, thus differing from quite a good number of studies that have considered A. vulpinus to suffer from intense fishing pressure (Baum et al., 2003; Ferretti et al., 2008; Goldman et al., 2009). Fishermen did not identify fishing as the main driver of decline for G. galeus either, as opposed to findings from other studies that attributed the depletion of this species to a long history of exploitation in target fisheries (Walker et al., 2006; Pondella & Allen, 2008). According to respondents, G. galeus seems to be declining for multiple reasons, with biological factors being much more relevant in this than in the other species. Some respondents stated that populations of G. galeus were less abundant in the Costa Brava because they had dispersed to other areas, yet no study has ever attributed the disappearance of...
G. galeus in a given area to migration to the best of our knowledge. In conclusion, although fishermen often acknowledge that sharks decline as a result of interaction with fisheries, they still blame other actors. This perceived decreasing population trend of most of them stands pretty much in line with the general decrease in the frequency of shark bycatch in the whole Mediterranean Sea reported by Maynou et al. (2011), who stated that shark bycatch had diminished since the early 1940s, coinciding with the intensification of the fishing activity.

The results reported in this study support the need that some action is taken to protect all the medium-size and large shark species occurring off the Costa Brava, and not only the few species that are currently legally protected. Reducing bycatch by means of operational changes or the designation of marine protected areas (MPAs) are the only real alternatives, given the absence of directed fisheries and the often misidentification of sharks in fish markets.

Creating and implementing effective conservation strategies that could bring about biological benefits while considering socio-economic implications should be done by including the fishing sector in the decision-making process, not only for their knowledge in the field but also because many of the fishermen interviewed in this study were aware of the value of sharks as a functional group and were willing to collaborate for the simple purpose of preserving the ecosystem. Fishermen could, for instance, be trained in catch-and-release practices since sharks are sometimes still alive when bycaught. A proper handling and release of an individual might avoid post-release mortality and this could be of great importance especially for threatened species. Some studies with recreational anglers pointed out their positive attitude towards ensuring shark survival (Shiffman & Hammerschlag, 2014; McClellan Press et al., 2016). Equipping nets with Turtle Excluder Devices has proved to be an effective way of reducing elasmobranch bycatch (Belcher & Jennings, 2011; Raborn et al., 2012; Garstin, Oxenford & Maison, 2017). In the Costa Brava, a few bottom trawlers have actually started using artisanal bycatch reduction devices to avoid captures of C. maximus and H. griseus, but their effectiveness is yet to be established. Future research opportunities could be focused on assessing the impact of bycatch reduction devices in the bycatch rates of sharks by trawl nets and also exploring alternative devices that might be used by longline gears to reduce bycatch of pelagic sharks such as A. vulpinus, I. oxyrinchus, and P. glauca.

The designation of MPAs is a powerful approach to tackle the problem of biodiversity loss (Davidson & Dulvy, 2017) given the consequent range of benefits for marine wildlife (García-Charton et al., 2008). Amongst other top consumers, sharks have been used as focal species to designate MPAs given their population traits and distribution (Hooker & Gerber, 2004). Unfortunately, the limitation on data regarding spatial distribution of many shark species might lead to certain MPAs not being as effective in protecting sharks as they should be. Therefore, it is highly important to have reliable information for a given species when identifying areas of ecological importance and again fishermen could contribute to this by broadening the data baseline for many sharks. In a recent study, Giménez et al. (2020) assessed the usefulness of some current MPAs concerning the protection of certain species of demersal elasmobranchs and concluded that only a small part of them was actually relevant for the demersal shark community, since the majority of them were distributed outside the existing MPAs. This conclusion is also relevant for the species studied here, as current MPAs are too small to protect viable populations.

In any case, keeping a synergic relationship with the fishing sector can for instance engage fishermen in providing continuous data on any kind of megafauna. This has proved to be fruitful in the past in some fisheries (Ticheler, Kolding & Chanda, 1998; Obura et al., 2002; Yochum, Starr & Wendt, 2011). Data on shark abundance or distribution would be of high value especially in areas like the Costa Brava, where the status of some sharks is still far from being well-known. Fishermen could not only provide data on protected species when these got bycaught, but also on commercial species such as H. griseus, Mustelus spp., P. glauca, and S. acanthias, which are not regulated under a TAC/quota management scheme in the Mediterranean Sea. This constant flow of information coming from fishermen could help monitor the population status of such species as well, making it easier to detect changes in abundance over time and therefore allowing scientists and managers to develop conservation measures to reverse any detected decline.

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**SUPPORTING INFORMATION**

Additional supporting information may be found in the Supporting Information section at the end of this article.

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