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Assessing the current status of *Hexanchus griseus* in the Mediterranean Sea using local ecological knowledge

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ABSTRACT

Fishermen from 9 countries distributed throughout the Mediterranean Sea were interviewed between May and December 2019 with the aim of compiling information about the current impact of fisheries on a large deep-water shark species, the bluntnose sixgill shark (*Hexanchus griseus*). A total of 382 professional fishermen belonging to 6 different gears (bottom trawling, bottom longline, drifting longline, trammel nets, gillnets and polyvalent) took part in the study. Bottom trawlers were the most interviewed fishermen (n = 148) and the best fleet coverage was obtained for bottom longline (38.89%). Results showed most captures of *H. griseus* occur in the Western and Central Mediterranean Sea, particularly during the warm months of the year and most commonly by bottom trawlers and bottom longliners. At-vessel mortality (AVM) was rather low in all gears but a slightly higher degree of individual mortality is suggested in trammel and gillnets. The population trend of *H. griseus* in the Mediterranean Sea could not be inferred from the interviews as answers were highly variable, but the overall trend in some countries may suggest this species is showing signs of population decrease. The results of this study are mostly aligned with the latest IUCN assessment but also recommend reviewing the current status of *H. griseus* in the Mediterranean basin. Further empirical research on post-release mortality would also be advisable to implement measures that help reduce this source of mortality.

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1. Introduction

Sharks and their relatives are possibly facing the largest crisis of their 420-million-year history [77]. Despite playing a key role in the structure and function of marine communities [52,66], many shark populations have severely declined due to intense fishing worldwide [33,54,96]. It has been estimated that the median population biomass of sharks captured by fisheries had declined between 81% and 89% since fishing began [25] and large sharks in particular can suffer strong population declines even with light fishing pressure [43]. These declines have raised worldwide concern over the status of sharks and their survival greatly depends on science-based legislation, which can establish sensible catch quotas for commercial species and effective protection for those species of concern [69]. Nonetheless, catch quotas are not applied everywhere. This is the case of the Mediterranean Sea, where indirect measures to control fishing effort do not exist except for the bluefin tuna (*Thunnus thynnus*), the only fish species regulated by a Total Allowable Catch (TAC) [21].

The Mediterranean Sea represents a hot spot for elasmobranchs but they are exposed to multiple threats such as habitat loss and degradation, pollution, eutrophication, climate change, invasion by alien species and most importantly, intense fishing [20,67]. Most elasmobranchs inhabiting the Mediterranean Sea are demersal and many of them are the bycatch of demersal fisheries, particularly bottom trawling [88], though some species can also be caught by longlines [13,49] and nets operating in shallower waters [86]. Demersal sharks share the same life traits as their pelagic counterparts; they also follow a K-selected life history strategy, characterised by slow growth, late sexual maturity, long life spans, low fecundity and a low capacity for population increase [71,82]. Detailed studies on the distribution and abundance fluctuations of demersal sharks tend to be focused on the most common species [88], such as the small-sized *Scyliorhinus canicula* and *Galeus melastomus* [17,30,51,75], while little information is compiled about other larger species [22].

The Bluntnose sixgill shark (*Hexanchus griseus*) is a common shark in the Mediterranean Sea and is the biggest member of the Hexanchidae family, reaching up to 500 cm total length (TL) [39]. In Southern African waters, males mature at about 310 cm TL and females are mature at 420 cm TL [35], while in the Mediterranean Sea this species is believed to reach maturity at a slightly smaller size. This was first suggested by Capapé et al. [16] and later reported by Vella & Vella [93], who estimated the maturity size for males and females at about 270 and 400 cm TL. *Hexanchus griseus* is a deep-water species living over insular, continental shelves and upper slopes [24] which can be found at depths of up to 2500 m [64], even though it has also been reported at 200 m from the surface off southern Sicily and between Tunisia and Malta [42]. It is also a common bycatch species that is mainly captured by both bottom and mid-water trawlers but also by gillnets, trammel nets, longlines, handlines and traps [78]. Mislabelling is not rare in this species and this shark is sometimes sold under the common names of other sharks [48]. *Hexanchus griseus* is currently assessed as "Least Concern" in the Mediterranean Sea by the International Union for Conservation of Nature (IUCN), though the fact that it can get caught by this wide range of fishing gears, in addition to counting on little international protection, makes monitoring its population trend important for its preservation, especially under the current degree of fishing pressure [78] and also considering this is a highly migratory species, according to the 1982 Convention on the Law of the Sea [89]. Species that can move over long distances are more likely to move through different jurisdictional boundaries [53], getting exposed to being caught by fisheries in the process and so complicating conservation efforts. It is without a doubt reasonable to prioritize conservation measures aimed at protecting and preserving threatened species, but neglecting non-threatened species can bring about undesirable scenarios that could have been avoided. Unfortunately, this was the case for the blue shark (*Prionace glauca*) in the Mediterranean Sea, a shark that had been assessed as "Vulnerable" in 2006 [19], "Near Threatened" in 2009 [81] and changed to "Critically Endangered" in 2016 [32].

A practical method to obtain high-quality and low-cost information [2] about the abundance and population trends of a given species is using the Local Ecological Knowledge (LEK) held by 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" ([10]: 1252). Integrating LEK in the management of marine resources often leads to increased participation, compromise, responsibility and empowerment of stakeholders [9,55]. Therefore, the combination of LEK with scientific assessments has the potential to improve management schemes [8,23,45,76].

To this end, this study aimed at compiling new up-to-date information about the abundance and population status of *H. griseus* in the Mediterranean Sea using fishermen's LEK from 9 different countries. Most specifically, the study focused on looking into several features related to captures of *H. griseus* in every sampling port from each country as well as analysing the fishermen's impressions regarding the population trend of this species. Finally, the results obtained in the study were used to discuss the suitability of the IUCN's latest Mediterranean assessment for *H. griseus* [78] in the present.

2. Material and methods

2.1. Study area

The study was conducted by researchers from a total of 9 (Albania, Cyprus, France (South), Greece, Italy, Libya (East), Montenegro, Spain (Northeast) and Tunisia) of the 21 countries that have coastline in the Mediterranean Sea, allowing the study to cover part of the Western, Central and Eastern basin along with a part of the Adriatic Sea (Fig. 1). Countries were selected according to their location in the basin, fleet volume and composition and total landings. Given the fact that in most cases there was only one researcher per country, only certain ports of each country were sampled except in Montenegro, which was the only country sampled in its totality. In Italy, all sampled ports were in Sicily except for one, the fleet of which operated in the Tyrrhenian Sea, whereas the fleet of the remaining sampled ports operated mostly in the Ionian Sea and the Tyrrhenian Sea. No Italian ports were sampled in the Adriatic Sea. Altogether, the ports sampled in this study fell within the GFCM geographical subareas 6, 7, 9, 10, 13, 14, 16, 18, 19, 21, 22 and 25.

2.2. Questionnaire-based surveys

Interviews with local fishermen were conducted from May to December 2019 and were often conducted at various ports within each country. Consequently, most of the GSAs featured in this study comprised more than one sampling port. However, GSAs 9 and 10 (Italy) and GSA 14 (Tunisia) only featured one port.

Considering the depth distribution of *H. griseus*, the range of fishing gears that can capture this species according to Capapé et al. [15] and Soldo et al. [78] and also the expertise of all the participating researchers, bottom trawling, bottom longline, trammel nets and gillnets were selected as the target fishing gears of this study. In many countries, some fishermen switch gears throughout the year, most usually alternating between small longlines and trammel nets or gillnets. These vessels were also considered a target and regarded as "polyvalent vessels", a term used by the GFCM to define "*all the vessels using more than one gear, with a combination of passive and active gears, none of which exceeding more than 50 per cent of the time at sea during the year*". In various Mediterranean countries, bottom longline, trammel nets and gillnets are used by Small Scale Vessels (SSV) as well. According to the EU definition, SSV have an overall length of less than 12 m and do not

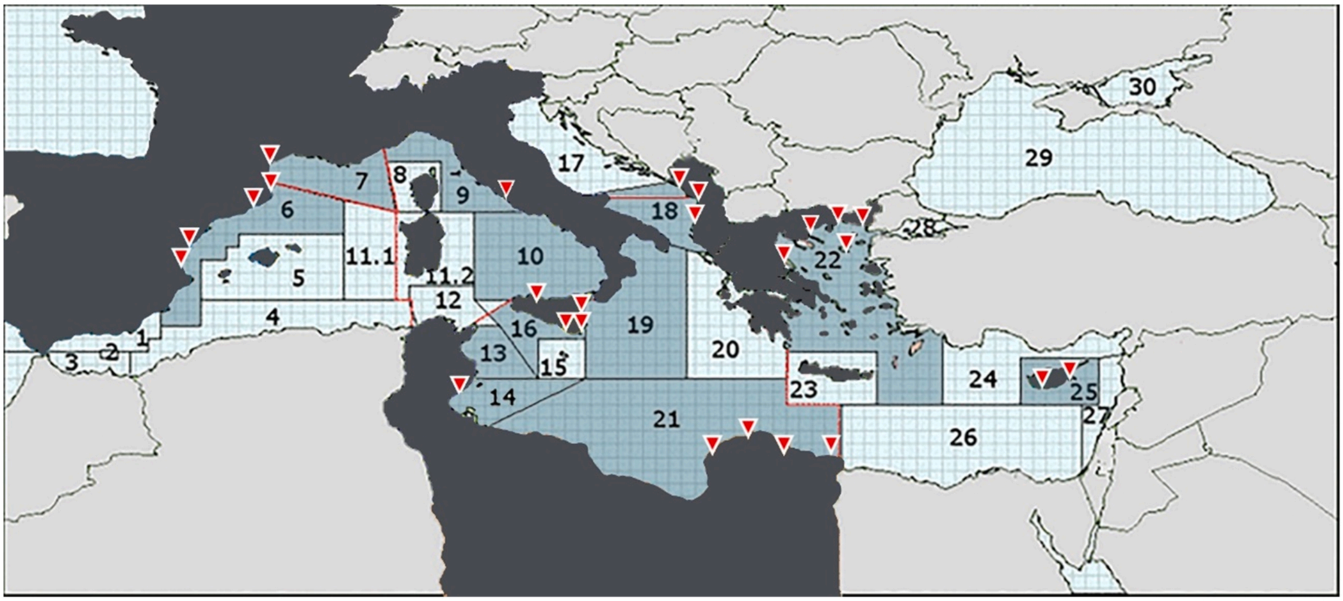

Fig. 1. Map of the Mediterranean Sea including all General Fisheries Commission for the Mediterranean Geographical subareas GSAs. All countries participating in the study are featured in black and GSAs including at least one sampling port are featured in grey. Sampling ports are shown as red pins in every country. Since some sampling ports were very close to each other, some pins represent more than one of these ports.

use towed fishing gear [38]. Although SSV can also switch gears throughout the year, the interviewed SSV in this study were not considered as such but rather the data was analysed according to the fishing gear, that is bottom longlines, trammel nets, gillnets and more than one gear (polyvalent).

The interviews were carried out using modified surveys adapted for the target species (see Annex 1). This methodology has proved to be effective in assessing the occurrence and accidental captures of other species of marine megafauna in the Spanish Mediterranean Sea [1,18,68], Italy [23] and Greece [87]. Before the beginning of the interview, the fishermen were given some identification forms and pictures of *H. griseus* as well as the other two Hexanchidae present in the Mediterranean Sea (*H. nakamurai* and *Heptanchias perlo)*. The questionnaire started with a demographic part and information regarding the fishing gear and then proceeded with a set of questions concerning biological aspects of the species, bycatch frequency, seasonality of reported captures, capture condition at the moment of being taken aboard, regarded as at-vessel mortality (AVM) and also their perception about population trend. Each interview lasted an average of 30 min, though their duration was also subject to the fisherman's availability at the moment of interviewing. Questions were laid out in a relaxed way to allow each interviewee to feel as comfortable as possible and facilitate the flow of information.

In order to assess bycatch frequency, respondents of each fishing gear were asked to report the number of *H. griseus* that had been captured both from 2018 to 2019 and from 2007 to 2017, trying to be as accurate as possible to check if the abundance and distribution of captures from 2018 to 2019 followed a similar pattern to that from 2007 to 2017. When reporting captures, respondents were always asked to give exact numbers. If exact numbers could not be obtained, respondents had to give an approximate number or interval. Nonetheless, a few answers had to be registered as "several", "a lot" or "too many". In those cases, "several" was counted as $n = 5–10$ and both "a lot" and "too many" were counted as $n > 10$. Regarding the seasonality of captures, respondents were asked to indicate the time of the year (months) they had captured *H. griseus* from 2018 to 2019 and from 2007 to 2017. A Chi-squared test [26] was carried out using IBM SPSS Statistics (Version 24) predictive analytics software to check whether captures were distributed similarly between the times of the year when the water column is stratified (May to October) and non-stratified (November to April). A Chi-square test was also used to check whether the probability of capturing *H. griseus* was due to a change in fishing effort (number of fishing months) between these two times of the year for the fishing gears that captured most individuals (bottom trawling, bottom longline and trammel and gillnets).

To assess AVM, respondents who had caught *H. griseus* at least once from 2007 to 2019 were asked whether the captured individuals were alive at the moment of either hauling the nets or pulling up the hooks. Five frequencies were given: "always", "often", "sometimes", "hardly ever" and "never". Similarly, the respondents' perception of the population trend of *H. griseus* was obtained by asking them to choose one of the following categories according to their impressions: "increasing", "stable", "decreasing" or "severely decreasing".

2.3. *Hexanchus griseus* bycatch estimations

The bycatch rate of *H. griseus* for gear z (Tz) was computed as in FAO [40]:

$$Tz = \frac{Nz}{Dz}$$

where N_z is the number of *H. griseus* caught by interviewed fishermen of gear z from 2018 to 2019 and D_z is the number of interviewed vessels of gear z.

The estimation of total *H. griseus* bycatch (C_z) was calculated as,

$$Cz = \sum Tz \cdot Doz$$

where D_{oz} is the total number of registered vessels of gear z in all sampled ports of each country.

2.4. *Methodological considerations*

Given that the questionnaires were only conducted by one researcher in most countries and that adjustments were made to the economic considerations, researchers were encouraged to use their expertise and critical thinking to sample the most relevant ports and gears, trying to conduct as many interviews as possible.

In regional studies that tackle marine wildlife conservation, other factors that might not need to be contemplated at a smaller scale come into play. Although some countries are culturally very much alike, each country also has its own culture and particular mindset. Fishermen might for instance be more collaborative in certain countries than in others depending on the attitude of the researcher. Others might only decide to collaborate if they can be economically rewarded and, on some occasions, their knowledge of a fixed and pressing issue may predispose them to a higher level of engagement and cooperation. This predisposition of fishermen to collaborate is also highly related to the bond that the researcher has forged with them in other previous studies. Lastly, political and socio-economic issues can also compromise the course of a study by fostering instability, which might restrict mobility around different sampling locations.

For the purpose of the study, the official current fishing fleet statistics of every sampled port were obtained in all countries except for Libya. Since its only existing fleet counting dates back to the early 2000 s, this study excluded that source of information from the analysis as it would not be portraying the current state of the fleet. Instead, this study made use of an alternative estimation of the fleet volume provided by a local fisheries researcher who personally took a census of all active vessels of every gear in all sampling locations.

3. Results

3.1. Fleet coverage

382 professional fishermen from a total of 47 ports were interviewed. Of these 47 ports, 2 were in Albania and in Cyprus, 4 in S France, 8 in Greece, 7 in Italy, 9 in E Libya and in NE Spain, 5 in Montenegro and 1 in Tunisia. Italy was the country with the most interviews (144) from its sampled ports, followed by NE Spain (79) and Greece (50) (Fig. 2). Tunisia was fourth with a much lower number of interviewed fishermen compared to the first three countries (29), closely followed by Montenegro (22), Cyprus (19), E Libya (15), Albania (14) and, with the lowest number of interviewed fishermen, S France (10).

When split into all the fishing gears, bottom trawling (BT) had the highest number of interviewed fishermen, with a total of 149 (Fig. 3). Trammel nets (TN) had a total of 102 interviewed fishermen, followed by polyvalent vessels (PV), with 56 interviews, bottom longline (BL) (40), gillnets (GN) (22) and drifting longline (DL) (13).

Italy had the highest number of interviewed bottom trawlers (64), followed by NE Spain (43), Albania (14), Tunisia (12), Greece (8), Montenegro (6), Cyprus and E Libya (1 each) (Fig. 3). Italy was also the country with the most interviewed bottom longliners (14), followed by Greece (11), NE Spain (10) and Tunisia (5). Four drifting longliners were interviewed in Tunisia, followed by NE Spain, Cyprus and E Libya (3 interviews each). The highest number of interviewed trammel net fishermen was in Italy (65), followed by NE Spain and Greece (16 each), Tunisia (3), Cyprus and Montenegro (1 each). Greece had the highest number of interviewed gillnet fishermen (15), followed by NE Spain (3), Montenegro (2), Italy and Tunisia (1 each). Finally, the highest number of interviewed fishermen using more than one gear (polyvalent) was that of Cyprus (14), right before Montenegro (13), E Libya (11), S France (10), NE Spain and Tunisia (4 each).

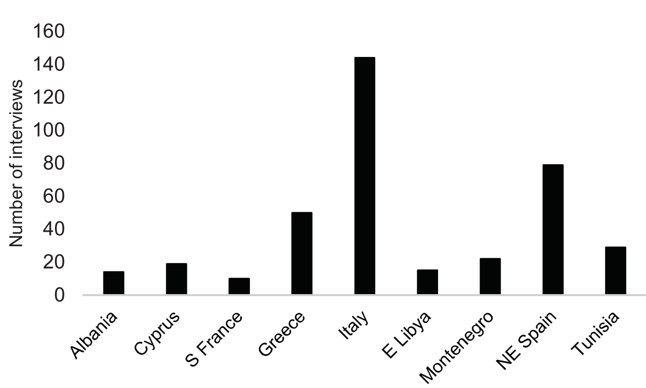

Fig. 2. Number of interviewed fishermen in the sampling ports of each country.

For the fleet coverage analysis, trammel nets and gillnets were merged into the same category and regarded as TGN, which also included the few remaining polyvalent vessels that either did not use trammel and gillnets or combined these nets with other gears, excluding traps. For further analysis, trammel and gillnets were also kept together as TGN but the remaining polyvalent vessels were treated as another category, named “other polyvalent vessels”.

For all the sampled ports in all countries, the highest fleet coverage was achieved in BL (38.89%) (Table 1). DL and BT had a total coverage of 25% and 18.72% respectively, whereas the fleet coverage for TGN (2.99%) was really low. BT had the highest fleet coverage in Cyprus (50%) and NE Spain (41.35%), followed by Montenegro (37.50%), Italy (26.78%), Albania (16.28%), Greece (7.84%), E Libya (7.14%) and Tunisia (4.72%) (Table 2). NE Spain and Italy were first and second in fleet coverage of BL, though with a much higher difference (71.43% and 18.42% respectively) and were followed by Greece (3.96%). Cyprus and NE Spain were the only two countries where the fleet coverage for DL could be obtained, and it was 33.33% for Cyprus and 20% for NE Spain. TGN had the highest coverage in S France (32.26%) and Italy (30.95%), followed by Montenegro (14.95%), NE Spain (14.84%), E Libya (3.77%) and Greece (2.15%).

3.2. Captures of *Hexanchus griseus*

According to respondents, a total of 2109 *H. griseus* were captured from 2007 to 2017 and these captures were distributed amongst 12 GSAs. GSA 6, which represents almost 2/3 of the Spanish coastline, was the geographical subarea with the most captures of *H. griseus*, with a total of 926 reported individuals (Fig. 4, top). The second GSA with the most captures of *H. griseus* was GSA 16 (Southern Sicily) (n = 292), followed by GSA 19 (Ionian Sea; n = 263), GSA 22 (Aegean Sea; n = 211), GSA 9 (Ligurian Sea and North Tyrrhenian Sea); n = 155), GSA 21 (off Libya) and GSA 25 (off Cyprus) (n = 73 each), GSA 10 (South and Central Tyrrhenian Sea; n = 70), GSA 14 (off Tunisia; n = 36), GSA 18 (Adriatic Sea; n = 8), GSA 13 (also off Tunisia; n = 3) and GSA 7 (Southern France; n = 1).

When divided by GFCM subregions, the highest number of captures of *H. griseus* from 2007 to 2017 was found in the Western basin (n = 1152). The Central basin represented the second subregion with the most captures (n = 667) and the Eastern basin hosted the lowest number of captured *H. griseus* from the three basins (n = 284). Only 8 captures were found in the Adriatic Sea.

From 2018–2019, a total of 218 *H. griseus* were captured in 10 GSAs. GSA 6 was again the GSA with most captures (n = 52), followed by GSA 16 (n = 37), GSA 19 and 21 (n = 33 each), GSA 9 (16), GSA 25 (n = 14), GSA 22 (n = 13), GSAs 10 and 14 (n = 8 each) and GSA 18 (n = 5) (Fig. 4, bottom). No captures of *H. griseus* occurred either in GSA 7 or GSA 13.

The Central basin gathered most of the captures of *H. griseus* (n = 111) from 2018 to 2019. The Western basin was second in number of captures (n = 76), followed by the Eastern basin (n = 27) and the Adriatic Sea (n = 5).

From 2007–2017 and for all sampling regions, bottom trawling was the fishing gear with most captures of *H. griseus* (n = 782), followed closely by bottom longline (n = 689), trammel and gillnets (n = 515), drifting longline (n = 92) and other polyvalent vessels (n = 31), (Fig. 5). Bottom trawling also had the highest number of captured *H. griseus* from 2018 to 2019 (n = 91), followed by trammel and gillnets (n = 67), drifting longline (n = 37), bottom longline (n = 21) and other polyvalent vessels (n = 2).

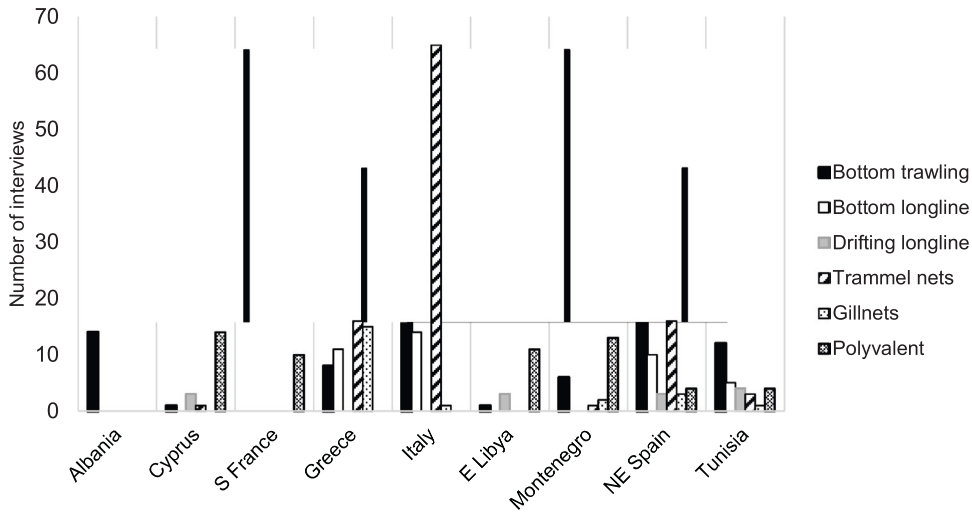

Fig. 3. Number of interviewed fishermen of each fishing gear in the sampling ports of each country.

Table 1
Number of interviewed fishing vessels of every gear in all sampled ports relative to the total fleet volume of the ports and the corresponding percentage (%). (BT=Bottom Trawling; BL=Bottom Longline; DL=Drifting Longline; TGN=Trammel and Gillnets + other polyvalent). [1]5 BL vessels from Tunisia were not included in the table since there was not enough information concerning the total fleet volume to obtain an accurate estimation. [2]4 DL from Tunisia and 3 DL from E Libya were not included in the table since there was not enough information concerning the total fleet volume to obtain an accurate estimation.

	BT	BL[1]	DL[2]	TGN
Interviewed	149	35	6	180
Total	796	90	24	6005
%	**18.72**	**38.89**	**25**	**2.99**

Table 2
Summary of the total fleet coverage of each fishing gear and for all the sampled ports in every country. Values are expressed in %. (BT=Bottom Trawling; BL=Bottom Longline; DL=Drifting Longline; TGN=Trammel and Gillnets + other polyvalent). [1]5 BL vessels from Tunisia were not included in the table since there was not enough information concerning the total fleet volume to obtain an accurate estimation. [2]4 DL from Tunisia and 3 DL from E Libya were not included in the table since there was not enough information concerning the total fleet volume to obtain an accurate estimation.

	BT	BL[1]	DL[2]	TGN
Albania	16.28	–	–	–
Cyprus	50	–	33.33	20.90
S France	–	–	–	32.26
Greece	7.84	3.96	–	2.15
Italy	26.78	18.42		30.95
E Libya	7.14	–	–	3.77
Montenegro	37.50	–	–	14.95
NE Spain	41.35	71.43	20	14.84
Tunisia	4.72	–	–	0.48

3.3. *Seasonality*

June (35.31%) and July (30.56%) were the months when most captures of *H. griseus* occurred. The lowest frequency of captures was found in December, January and February (14.24%) (Fig. 6).

The relationship between the time of the year when there is water stratification and the captures of *H. griseus* was statistically significant (χ^2 =53.06; p = 0.00). While no significant difference was found in the seasonal distribution of the fishing effort of bottom trawling (χ^2 =1.01; p = 0.32), the seasonal distribution of the fishing effort of bottom longline and trammel and gillnets was significantly different (χ^2 =5.77, p = 0.02; χ^2 =15.36, p = 0.00).

3.4. *At-vessel mortality (AVM)*

The results for bottom trawling, bottom longline and drifting longline showed *H. griseus* was usually alive when taken aboard (Fig. 7). In bottom trawling, the most frequent answer amongst interviewed fishermen was that *H. griseus* was always alive at the moment of hauling (60%), followed by sometimes alive (17.50%). The frequencies for those answers that indicated captured individuals were always or most of the time already dead, were low or very low (12.50% and 2.5%, respectively). Bottom and drifting longline shared very similar results. Like in bottom trawling, the most frequent answer in both cases was that individuals were always alive when pulling up the hook (53.85% and 50%), followed by being most of the times alive (30.77% and 30.33%). No fisherman considered that captured individuals were either always or most of the time dead when pulling up the hooks. On the other hand, the highest frequency in trammel and gillnets was found in "sometimes" (40%), being the only gears in which the probability of capturing *H. griseus* alive was as likely as capturing it dead. Capturing individuals always alive had the second-highest frequency (20%), followed by "hardly ever" (16%). Frequencies for capturing *H. griseus* alive, most of the time and never were both the same and also the lowest (12%). Finally, only four answers were obtained from fishermen using other polyvalent vessels and the frequency to which fishermen believed *H. griseus* was always, most of the time, sometimes and never alive had the same value (25%).

3.5. *Population trend of Hexanchus griseus*

Information was gathered from 7 countries (Albania, Cyprus, Greece, Italy, E Libya, NE Spain and Tunisia) to assess the population trend of *H. griseus* according to the fishermen's perception. A clear majority of the interviewed fishermen from Albania (66.67%) and Tunisia (74.07%) considered that the population of *H. griseus* was decreasing (Fig. 8), whereas respondents from Greece and NE Spain mostly believed the population trend of this shark was stable (56.25% and 38.78%, respectively). The frequency of "increasing" was low in all countries, with Cyprus having the highest frequency for this answer (10.53%). No respondent believed populations of *H. griseus* could be increasing neither in E Libya nor in Italy. The frequency to which respondents considered populations of *H. griseus* to be severely decreasing was really low in

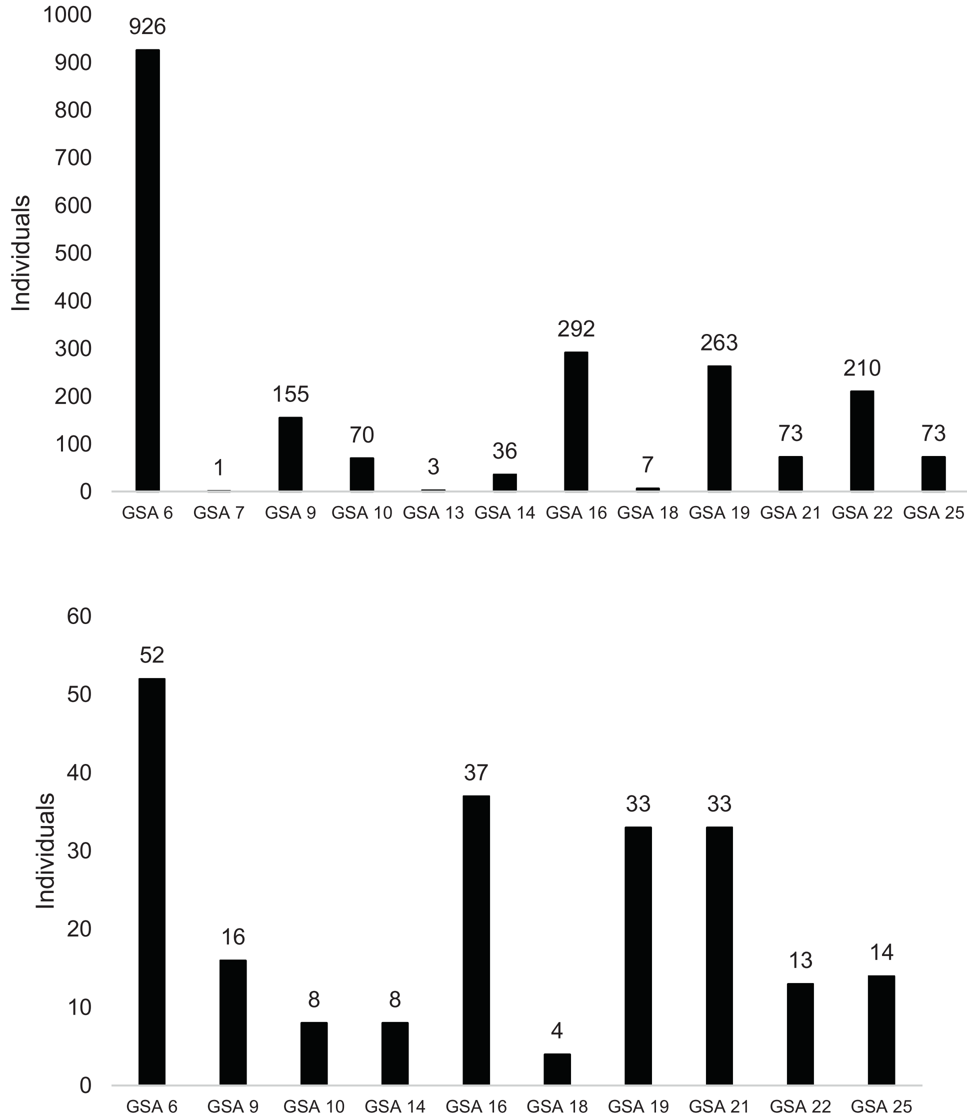

Fig. 4. Number of *H. griseus* captured by interviewed fishermen from 2007 to 2017 (top) and from 2018 to 2019 (bottom) in all GSAs with at least one capture.

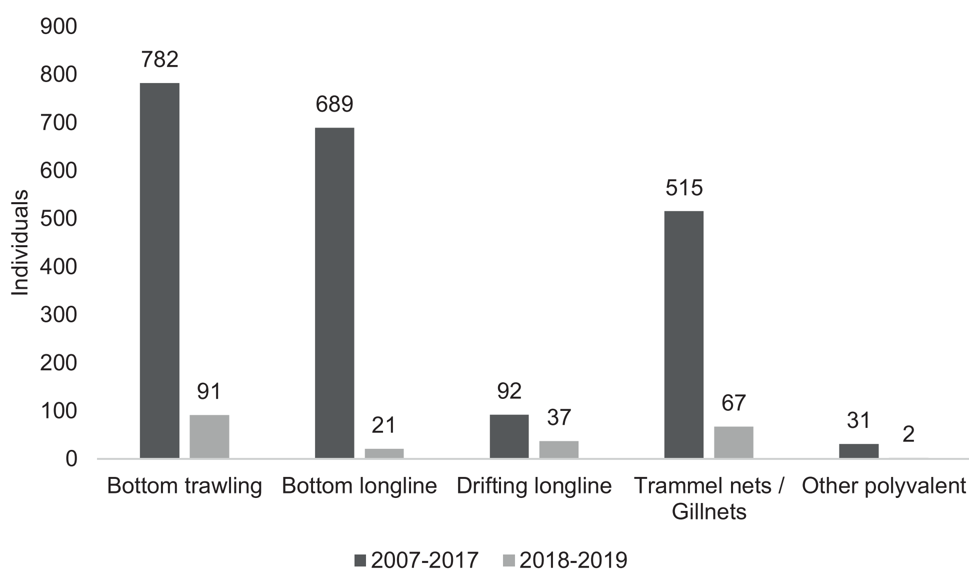

Fig. 5. Recorded captures of *H. griseus* per fishing gear from 2007 to 2017 and from 2018 to 2019 by interviewed fishermen.

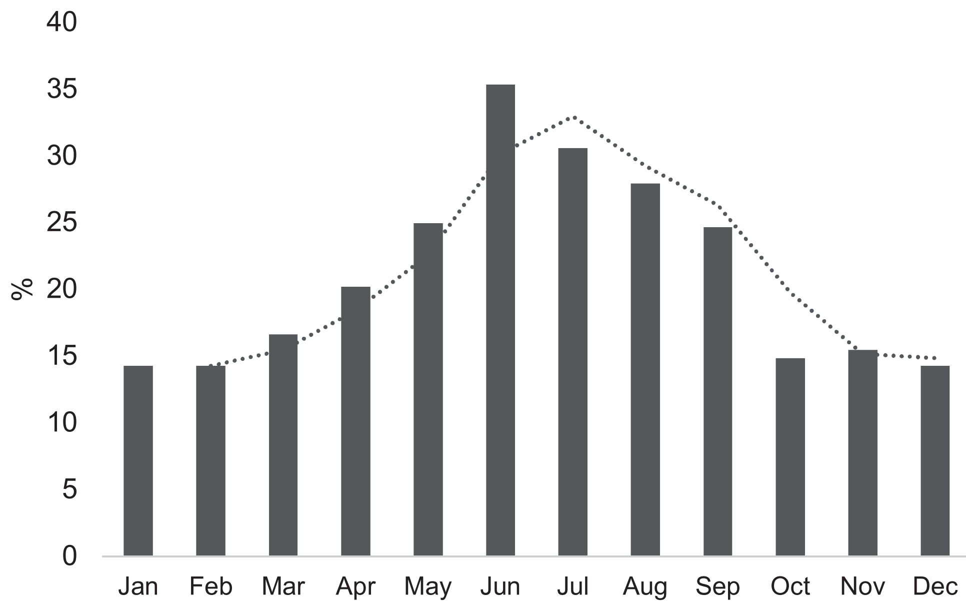

Fig. 6. Percentage (%) of captures of *H. griseus* per month by the interviewed fishermen.

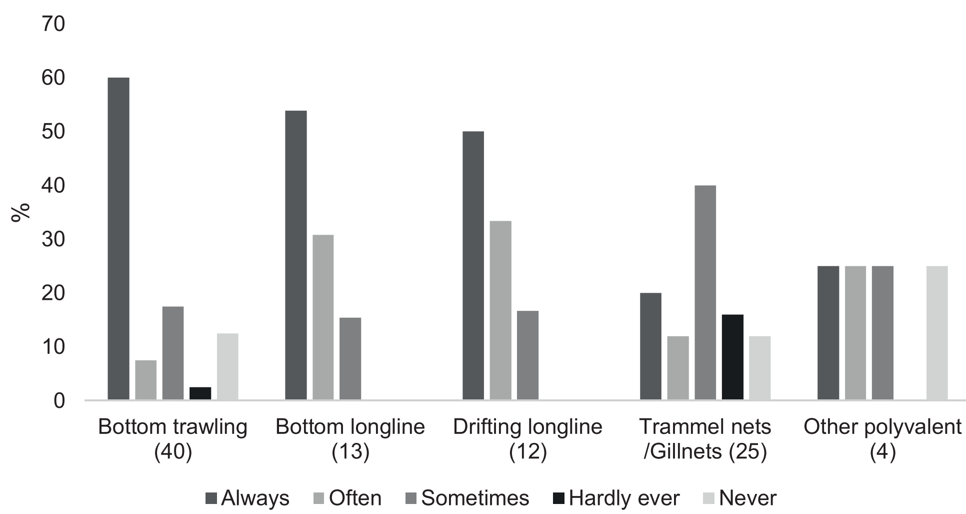

Fig. 7. Frequencies (%) of AVM in *H. griseus* (by interviewed fishermen (n) who had caught at least one *H. griseus* from 2007 to 2019).

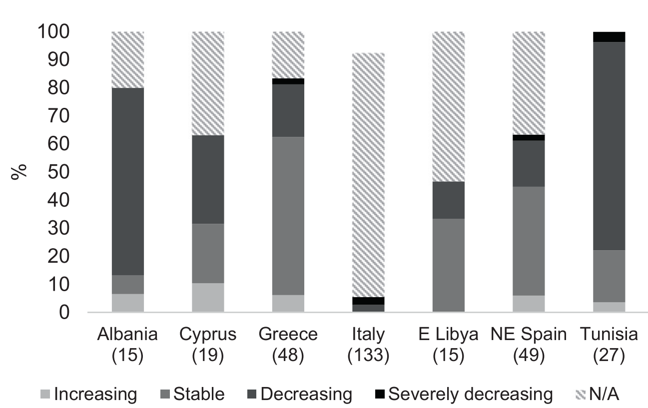

Fig. 8. Population trend of *H. griseus* according to the fishermen's perception.

Greece (2.08%), NE Spain (2.04%), Italy (2.26%) and Tunisia (3.7%), and inexistent in Albania, Cyprus and E Libya. N/A had the highest frequency in Italy (94.74%), followed by E Libya (53.33%), Cyprus (36.84%), NE Spain (36.73%), Albania (20%) and Greece (16.67%).

4. Discussion

4.1. Fleet coverage

Overall, bottom longline had the highest fleet coverage of all fishing gears but a high degree of variability in the fleet coverage was noted when broken down into each country's sampled ports. Bottom trawling, bottom longline and trammel and gillnets had the highest fleet coverage in the ports of Italy, NE Spain, Cyprus and S France. Bottom trawling had a solid fleet coverage in the ports of the first three countries (see Table 2) and was surveyed in ports of all countries except for S France. However, not much information regarding bottom trawling can be extracted from Cyprus, since such a high coverage is a result of a very small trawling fleet in the entire country (one interviewed vessel from a total of two bottom trawlers fishing in territorial waters). A significantly higher number of bottom trawlers were interviewed in the two ports sampled in Albania (n = 14), 6 bottom trawlers from a total of 16 were also interviewed in Montenegro and 11 bottom trawlers were surveyed in Tunisia.

The fleet coverage for bottom trawling in all the sampled ports in E Libya was actually higher than that of Tunisia, yet only one bottom trawler was interviewed in E Libya. We therefore believe results and interpretations concerning bottom trawling in this study were biased towards Italy and Spain, with a total of 107 interviewed bottom trawlers, as they represented the two countries which by far provided the most information about this fishing gear.

While bottom trawling and trammel and gillnets were sampled in almost all countries included in this study (except for S France and Albania, respectively), interviews with bottom and drifting longliners were only carried out in a few countries. The reason why some gears were not surveyed in certain countries had two main explanations: sometimes, researchers in charge of the interviews had to prioritize sampling the most relevant fishing gears for the study. Other times, some fishing gears were not part of the actual fleet of some sampled ports.

The major shortcoming concerning fleet coverage and data collection originated in Libya. This was ascribed to the ongoing period of national instability, which hindered the researcher's fieldwork in the region by not being able to get to the capital and its surroundings due to the constant outbreaks of violence. Libya's situation perfectly exemplifies those fortuitous events that may occur when doing broad-scale multinational studies and can have an impact on the course of it. For safety reasons, this study only used data from E Libya. Only a few vessels, mostly polyvalent, were interviewed in the Libyan ports and no estimation of the fleet coverage could be made for drifting longline due to the lack of an actual reliable fleet volume estimation in those ports. This was another added problem occurring in Libya but also in Tunisia, where coverage values for bottom and drifting longline could not be obtained either.

4.2. Captures

Results of this study indicated that most captures of *H. griseus* tend to occur in the Western and Central Mediterranean Sea. Whereas most captures of *H. griseus* occurred in the Central basin from 2018 to 2019, the Western basin, particularly NE Spain, gathered most of the captures from 2007 to 2017. Occasional captures of *H. griseus* have been reported in the Catalan Sea for decades ([5,61,80]) and this shark has been recently regarded as a frequent bycatch in the Costa Brava [68]. In the Central Mediterranean Sea, the Strait of Sicily has been identified as a biodiversity hotspot [31,90] and hosts a great number of shark species, including the Mediterranean white shark (*Carcharodon carcharias*) [29, 85]. *Hexanchus griseus* is also present in the area [92], with some captures being landed in Tunisian ports (where an unusual capture of a shoal of up to 21 specimens took place recently (see [7]), southern Sicily and also the Maltese fish markets [73,91]. Data coming from the Mediterranean Large Elasmobranchs Monitoring (MEDLEM) also showed that the highest number of reported captures of *H. griseus* concentrated in the Central basin, with a considerable number of these captures occurring in the Tyrrhenian Sea, and the Northern Ionian Sea [59].

The present study did not survey either GSA 12 (northern Tunisia) or GSA 15 (Malta). However, given their proximity to GSA 14 and 16 (between Sicily and Tunisia), where some captures of *H. griseus* were reported, we believe bycatch of this species might also occur in those parts of the Central basin.

In the Eastern basin, records of large sharks in Turkish waters from 1980 to 2015 confirmed *H. griseus* was the predominant species, with the vast majority of specimens being recorded in the Sea of Marmara, followed by the Aegean Sea, the Levantine Sea and a few observations from the Black Sea [57,58]. Capapé et al. [15] also compiled some records of *H. griseus* off Tukey as well as Israel between the 1970 s and the 2000 s, but the number of records of this species coming from the Eastern basin was really inferior to those coming from the Western and Central basins. In their population genetics study, Vella and Vella [92] collected 86 and 34 specimens of *H. griseus* in the Central and Western basins respectively, but only 8 were captured in the Eastern basin. Capapé et al. [15] suggested *H. griseus* could be less abundant in the Eastern basin though other possibilities were considered, like the fact that the waters were less exploited or information was not reported to the same extent as in the other basins. The results of the present study also confirm *H. griseus* was captured in the Eastern Mediterranean Sea, particularly in the Aegean Sea, but the number of captures both from 2007 to 2017 and from 2018 to 2019 was comparatively much lower than those of the Western and Central basins.

Captures of *H. griseus* also take place in the Adriatic Sea [15,27,59], although they tend to be less frequent. The Adriatic Sea has the largest shelf area of the Mediterranean Sea. Although the Southern part (GSA 18) has a much narrower shelf and a steep slope, reaching maximum depths of more than 1200 m, the Northern and Central parts (GSA 17) have a bottom depth of no more than 100 m except in Pomo/Jabuka Pit [41]. Such low depths might not constitute the most suitable habitat for benthonic species and it would be reasonable to assume captures of *H. griseus* are much less likely to occur in the Northern and Central parts of the Adriatic Sea compared to other parts of the Mediterranean Sea. A few captures of this species in the Southern Adriatic Sea and also the southern part of the Central Adriatic Sea, which is represented by Montenegro, were also reported in the present study both from 2007 to 2017 and from 2018 to 2019 indicating that occasional captures of this species continue to occur in the present.

Notwithstanding, the number of sampled GSAs amongst GFCM subregions was not equally proportioned. Whereas ports from up to five GSAs were surveyed in the Central Mediterranean Sea, three GSAs were surveyed in the Western Mediterranean Sea, two in the Eastern Mediterranean Sea and one in the Adriatic Sea. Hence, this data bias must be taken into account when making interpretations.

In all years considered in the study, bottom trawlers were responsible for capturing the highest number of *H. griseus*, although a considerable number of individuals were also captured by bottom longliners. The fact that the bycatch of *H. griseus* mostly happened in these two gears fits in with previous research done in the Mediterranean Sea [6,61]. Both bottom trawling and bottom longline target much deeper depths than the other fishing gears included in this study, consequently having a higher probability of capturing *H. griseus*.

Fewer captures occurred in those fishing gears that are deployed at the surface, though drifting longliners captured a noticeable number of *H. griseus*. The set of biological and ecological features of *H. griseus* makes it difficult to suggest why such a deep-water species can be caught so close to the surface. To the best of the authors' knowledge, the occurrence of this species in the epipelagic region of the water column has never been reported. Instead, gear modifications would be more likely to account for these captures in drifting longlines. In Spanish waters, fishermen attach weights to drifting longlines when going for *Xiphias gladius* [3]. While the mainline remains at the surface, these weights pull the hooks down to much higher depths (400–600 m), very much resembling a bottom longline but without touching the seafloor. Consequently, the chances of capturing *H. griseus* become higher than in a typical drifting longline. In this study, captures by drifting longliners mainly came from Tunisia, E Libya and Cyprus. It is known by the authors of the study that the drifting longliners from these countries can lower the hooks to much deeper waters depending on the target species. However, it remains unknown whether the interviewed drifting longliners made such modifications to the fishing gear. Results also showed there was a substantial number of *H. griseus* captured by trammel and gillnets. Bycatch of this species by nets is not a rare phenomenon [15,56] and although these gears are not as impactful as deep-water gears, the results of this study suggest they can be a significant source of bycatch for this species too.

According to the interviewed fishermen, captures of *H. griseus* were more frequent during warm months, when the water column is stratified. Seasonal shifts in habitat have been reported in *H. griseus* in the northwestern Pacific, where this shark is known to occupy deeper waters in autumn and winter than in spring (Andrews et al., 2009) and the abundance of immature individuals is greater during the summer months than in cold months relative to other months of the year [34]. These seasonal movements are usually associated with feeding, changes in the water temperature or reproduction [79]. The higher frequency of captures of *H. griseus* reported in this study during warm months could have been a result of a change in the species' depth preference and shifting to shallower waters may have increased the likelihood of being captured by more fishing gears, thus explaining why this species was more frequently captured from May to October. Nevertheless, the Chi-square test indicated that the fishing effort of some fishing gears was not equally distributed between warm and cold months. While bottom trawlers generally operate throughout the entire year, bottom longliners and fishermen using trammel and gillnets usually operate during warm months. Therefore, we believe this higher frequency of captures in warm months is more likely to respond to a change in the fishing effort by some of the fishing gears within this study.

At-vessel mortality (AVM) has been reported for a wide number of sharks [37]. However, most of the studies tend to focus on pelagic species [36,60,63], while a few studies addressing AVM of deep-water species exist [14,74]. In this study, AVM of *H. griseus* was rather low considering all gears except for polyvalent vessels, though data from the latter was limited to four vessels and no clear pattern could be inferred. Conversely, results for bottom trawling and the two longlines indicated *H. griseus* tended to be alive at the moment of capturing, agreeing with previous findings [14,83]. This low AVM was especially noticeable in individuals caught by bottom trawling nets, where 6 out of 10 interviewed fishermen believed the species was always alive when taken aboard, compared to just 1 out of 10 fishermen who believed *H. griseus* was always dead when the net was hauled. Several predictors have been suggested to influence AVM of pelagic sharks [12,50,62]. Information regarding AVM of deep-water sharks is still scarce but Brooks et al. [14] and Talwar et al. [83] also found a positive correlation between depth and AVM. In bottom trawling nets, AVM may be influenced by tow duration, catch composition and mass [37], with larger sharks being more easily captured than smaller sharks, since the latter may have a higher chance of escaping through the mesh gaps. *H. griseus* is certainly a large shark and, although it is a common bycatch in bottom trawling, the results of this study suggest it can remain alive in the trawl net before being taken aboard the vessel.

On the other hand, AVM was higher in trammel and gillnets compared to the other three gears. The likelihood of *H. griseus* being alive at the moment of pulling these nets could be close to 50%, represented by "sometimes" in the analysis. Some shark species can exhibit high mortality rates when captured by trammel or gillnets [28,84,95] whereas the mortality rate of other species can be much lower and that could be related to different factors [28,44], which might help explain why the mortality rate of *H. griseus* when caught by trammel and gillnets could be higher than that of bottom trawling, bottom longline and drifting longline. In any case, a deeper knowledge of how bycatch affects *H. griseus* survival could be acquired by monitoring its post-release mortality (PRM), since some individuals that are taken aboard alive may die in short term as a consequence of any physical injury, trauma and physiological stress sustained during capture and handling [65,70]. Deep-water species like *H. griseus* usually live in colder temperatures than pelagic species and the exposure to warmer temperatures may also increase their physiological stress [47,94].

Again, studies evaluating PRM tend to concentrate on pelagic sharks (Musyl and Gilman, 2019; [11]). In one of the few studies assessing PRM in deep-water sharks, a high survival rate after a trawling event was found in *Scyliorhinus canicula* [4], a fact which is totally in contrast with Talwar et al. [83], who found mortality rates ranging from 49.7% to 83% in longline-caught deep-water sharks. However, results from Barragán-Méndez et al. [4] should be interpreted with caution since they may fail to be applicable for *H. griseus*. As opposed to the small *S. canicula*, *H. griseus* is a large species, thus the response to a trawling event might be completely different. Moreover, the trawling events described in that study only lasted for 60 min, which is a much shorter time than that of a commercial trawl event. Further information is therefore needed to better understand how *H. griseus* can cope with post-release stress.

Engaging fishermen in collecting opportunistic data can generate a constant flow of useful information and training them in catch-and-release practices might also help reduce post-release mortality in *H. griseus* if they know how to properly handle and release a captured individual. Specific on-board modifications that could facilitate better handling of the captured individual may also contribute to reducing the stress of the animal, hence minimizing individual mortality. At the same time, finding new ways to reduce the bycatch of *H. griseus* remains crucial for the conservation of the species. Considering Turtle Excluder Devices (TEDs) have proved to be effective at reducing elasmobranch bycatch in trawl nets [46,72], designing and confectioning artisanal Bycatch Reduction Devices (BRDs) for large-sized sharks in such nets might also help avoid captures of *H. griseus*.

4.3. Population trend

The results of this study indicated that fishermen had different perceptions of what the population trend of *H. griseus* was depending on the sampled ports. While fishermen from ports of Greece and NE Spain (the latter by a small margin) mostly believed *H. griseus* was following a stable population trend, those from Albania, Tunisia and Cyprus claimed this species was decreasing in numbers but without doing it at an alarming pace. But perhaps the biggest outcome that could be extracted from these results is the frequency to which respondents were not able to give their interpretations regarding the status of *H. griseus* in their respective countries. That is well portrayed in the cases of E Libya, NE Spain and also Cyprus, with the latter having "n/a" as the most frequent of the answers just above "decreasing". However, the most striking case is that of Italy, where almost 9 out of 10 interviewed fishermen from the different sampled regions did not answer this question because they were totally unaware of the species' status.

The extent to which respondents from Italy and all the other regions wanted to share genuine information cannot be completely known. Nevertheless, practically all interviewed fishermen showed their willingness to collaborate and feel part of this study. Their failure to share their perceptions of the population trend of *H. griseus* might be a result of other constraints we can only speculate about, such as their unawareness of the species, which may depend on the extent to which fishermen of every country have access to information regarding the biology and conservation status of *H. griseus*.

4.4. Conclusions

Despite the data bias, the results of this study are aligned with the different inputs used in the IUCN's 2016 assessment for *H. griseus*, which altogether led to consider it a non-threatened shark species. Even though most of its accidental captures happen in deep-water gears like bottom trawling, *H. griseus* continues to be an occasional bycatch in other fisheries such as longlines, trammel nets and gillnets. Monitoring bycatch in fishing gears that occasionally capture this shark, particularly during warm months when captures are more abundant, would therefore be advisable to help preserve an optimal status of its populations in the Mediterranean Sea, especially in the Western and Central basins. Our findings also seem to indicate a certain degree of AVM in *H. griseus* when it is captured by trammel and gillnets, but AVM tends to be generally low in all the other gears. Although we reckon post-release mortality of *H. griseus* could be low given its apparent resilience when captured, further research on this topic should be done as it would certainly help both the scientific community and managing bodies understand to what extent bycatch can affect the chances of survival of every captured individual. Training fishermen in good handling practices, as well as innovating ways of reducing both on-board mortality and *H. griseus* bycatch is also of great importance for the conservation of the species. Our study highlights the importance of LEK not only for collecting valuable information but also for co-producing knowledge alongside local communities, which in turn incentivises a synergic relationship between fishermen and scientists. Therefore, conservation measures looking after keeping a sustainable relationship between fishermen and marine megafauna should welcome all sorts of insights coming from the experience of the fishing sector.

Finally, two points emerged from our results regarding the population trend of *H. griseus*: On one hand, they did not allow us to suggest any clear population trend for the whole Mediterranean Sea as the fishermen's perception varied quite significantly across sampled regions. On the other hand, they did indicate the species might be showing signs of a potential decreasing trend in certain regions from the Central and Eastern basins. Coupled with the overall elevated proportion of respondents who were not able to guess what the population trend of the species could be, we believe the "stable population trend" assigned by the IUCN in 2016 could be reviewed. In order to obtain a reliable estimation of its population trend in the Mediterranean Sea, future studies should be encouraged to compile regional-specific data on the abundance of *H. griseus*.

CRediT authorship contribution statement

Ignasi Nuez: Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – original draft, Project administration, Funding acquisition. **Ioannis Giovos**: Conceptualization, Investigation, Data curation, Writing – review & editing. **Manel Gazo:** Supervision, Writing – review & editing. **Francesco Tiralongo:** Investigation, Writing – review & editing. **Jaime Penadés-Suay:** Investigation, Writing – review & editing. **Ilija Cetkovic:** Investigation, Writing – review & editing. **Manfredi Di Lorenzo:** Investigation, Writing – review & editing. **Periklis Kleitou:** Investigation, Writing – review & editing. **Rigers Bakiu:** Investigation, Writing – review & editing. **Mohamed Nejmeddine Bradai:** Investigation, Writing – review & editing. **Sara A. A. Almabruk:** Investigation, Writing – review & editing. **Roxani Naasan Aga Spyridopoulou:** Investigation, Writing – review & editing. **Andréa Sabbio:** Investigation, Writing – review & editing.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2022.105378.

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