

# Literature, social media and citizen science surveys identify relevant areas for *Carcharhinus* species conservation in the Mediterranean Sea

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## Abstract

Sharks support ecosystem health, but their populations are facing severe declines worldwide. Knowledge gaps on shark distribution and the negative human perception of them still represent a barrier to the implementation of effective wide-scale conservation measures. Here we used shark catches and sightings reported in the scientific literature and social media platforms to 1) depict the distribution of *Carcharhinus* species in the Mediterranean Sea, 2) identify potential hotspots for their conservation and 3) evaluate people's attitude toward shark protection. In addition, we administered 112 questionnaires in one of the very few shark-diving spots of the Mediterranean Sea to assess the potential role of sustainable shark-tourism activities in enhancing people's self-perceived knowledge of sharks and supporting positive attitudes toward their conservation. The main findings show that social media content represents a valuable integration of literature to identify potential conservation hotspots for shark populations. Social data mining reported a general shift towards positive perceptions of sharks in recent years, whilst negative attitudes still prevailed in postings shared by fishers. Moreover, we found that shark diving activities may further improve tourist perceptions of sharks and increase diver willingness to support conservation measures. By integrating different data sources, this study provides essential information for improving our understanding of human and ecological dimensions of shark conservation, a necessary step towards specific and efficient protection policies.

## 1. INTRODUCTION

Sharks play crucial and diverse roles in ecosystem health and stability, but they are facing a rapid population decline worldwide mostly due to fishing activities and, to a lesser extent, habitat degradation and climate

change (Dulvy et al., 2021). More than one-third of the species are considered at risk of extinction globally (Dulvy et al., 2021), with more than 70% of pelagic populations depleted during the last five decades (Pacoureau et al., 2021), and coastal reef sharks facing local extinction in 20% of Pacific, Western Atlantic and Western Indian Oceans' areas (McNeil et al., 2020). All this suggests a widespread shark decline that has gone undocumented until now and is even more evident inside the Mediterranean Sea, a well-recognized extinction hotspot for elasmobranchs (Ferretti et al., 2008). In this basin, more than half of the species have been included in the threatened categories of the IUCN Red List (VU: Vulnerable; EN: Endangered; CR: Critically Endangered; (Dulvy et al., 2016), but are still frequently by-caught, deliberately fished and even sold off in the marketplaces (Milazzo et al. 2021).

Several constraints still hamper the implementation of effective management strategies required to reach informed shark conservation actions, both at global and regional scales. Among these, are the underestimation of elasmobranch catches, with regional fishery statistics often reporting aggregated data from various fishery sectors, the lack of fishery-independent data on abundance and distribution of shark species, the poor preparation of fishers and officials on how to identify, handle and release sharks, the little development of ecotourism activities promoting non-consumptive uses of sharks (Mazzoldi et al., 2019; Jorgensen et al., 2022). Moreover, about 20% of the Mediterranean shark species are classified by the IUCN as Data Deficient (DD), which means that their actual conservation status could be anything from Least Concern to Critically Endangered, or even locally Extinct (Walls and Dulvy, 2021), with this lack of information hampering the development of efficient conservation actions. This is particularly evident for large-bodied migratory species of the genus *Carcharhinus*, whose spatio-temporal distribution patterns in the Mediterranean Sea are poorly understood due to their rarity and elusive behaviour. The genus *Carcharhinus* includes 25 species distributed in tropical and temperate coastal areas worldwide (Garrick, 1982). In the Mediterranean Sea, we lack reliable data on their distribution, stock conditions and fishing pressure, likely also because of the very similar morphological patterns making them not readily identifiable at the species level (Dudgeon et al., 2012). According to the last regional IUCN report, six *Carcharhinus* species (hereafter also called "requiem sharks") are present in the Mediterranean waters: five of them (*C.*

*altimus*, *C. brachyurus*, *C. limbatus*, *C. brevipinna* and *C. obscurus*) classified as DD, and one (*C. plumbeus*) as EN (Dulvy et al., 2016). However, when taking into account additional biological and ecological traits (i.e., maximum body size, median depth, and reproductive strategy), the conservation status of *C. brachyurus*, *C. altimus* and *C. obscurus* shifted to Critically Endangered, and that of *C. limbatus* to Endangered in the Mediterranean Sea (Walls and Dulvy, 2021). Therefore, addressing gaps in the knowledge of these poorly known species is strongly needed to build effective conservation strategies and to put into practice efficient management actions.

In this regard, cost-effective methods relying on citizen science tools and public engagement for data acquisition are rapidly emerging as valuable sources for scientific research (Di Minin et al., 2015; Giovos et al., 2018, 2019; Bargnesi et al., 2020). Among these, social media data mining represents a growing opportunity for wildlife data collection and may provide crucial information for conservation science (Shiffman et al., 2018; Di Minin et al., 2015; Toivonen et al., 2019; Fink et al., 2020; Jaric et al., 2020). As multimedia material on shark sightings increases, social media platforms are increasingly used to gather useful information on occurrences and spatio-temporal patterns of threats for rare and elusive species, which are often difficult to monitor across their distribution range (Boldrocchi et al., 2021; Taklis et al., 2020; Kabasakal and Bilecenoğlu, 2020; Panayiotou et al., 2020; Giovos et al., 2016, 2018, 2021). In addition to this, sentiment analyses from social media data may allow evaluating changes in people's feelings towards species historically perceived as dangerous and still suffering a culture-driven negative image (Neff and Hueter, 2013). The latter aspect might be important for driving successful protection policies, as there is increasing evidence that public attitudes towards wildlife may influence the efficacy of management measures and represent a prerequisite for building successful conservation strategies (Friedrich et al., 2014; Mazzoldi et al., 2019).

The public perception of sharks is gradually changing, and a shift towards pro-conservation attitudes has been recently documented on a global scale (Giovos et al., 2021). At present, raising awareness campaigns by non-governmental organizations, which push for the adoption of international agreements or specific national legislation, are contributing to increasing public interest in shark conservation (Jeffries, 2019).

However, a more direct personal experience through participation in wild tourism activities, such as watching sharks in their natural habitats using snorkel or scuba gear (i.e. shark tourism), is likely more beneficial to enhance tour participants' perceptions and promote pro-conservation attitudes (Friedrich et al., 2014; MacDonald and Wester, 2021; Gallagher et al., 2015; Gonzales-Mantilla et al., 2022).

Shark tourism is a promising growing industry that may promote conservation issues while providing economic benefits to local communities (Cisneros-Montemayor et al., 2013; Gallagher et al., 2015). In recent years, a fast popularization of shark watching activities has occurred worldwide, with more than half a million people engaged in 89 locations spanning 29 countries (Gallagher and Hammerschlag, 2011; Cisneros-Montemayor et al., 2013). In the Mediterranean Sea, shark tourism activities are still in their infancy, with only a couple of examples recently documented in a few diving spots off the Italian and Israeli coasts (Barash et al., 2018; Cattano et al., 2021). Whilst very recent studies started to explore the economic benefits (Shamir et al. 2019) and the ecological impact of shark tourism in Mediterranean shark aggregation hotspots (Cattano et al., 2021), how shark-watching activities may provide conservation benefits by raising awareness and instilling positive attitudes of people towards shark conservation is still overlooked.

Here we used a multi-disciplinary and multi-scale approach to respond to the growing need of increasing knowledge on social-ecological dimension of shark conservation. Specifically, we 1) combined data from scientific literature and social media to investigate the historical and recent distribution of *requiem sharks*, and identify potential hotspots of occurrence in the Mediterranean Sea; 2) evaluated social-media users' attitudes toward shark conservation at the Mediterranean level; 3) assessed tourists' perceptions in a shark-tourism hotspot, to evaluate the potential of shark-watching activities in enhancing people's knowledge, attitude and support for shark conservation. The combination of these different approaches may improve our understanding of requiem shark distribution in a data-poor geographical context and inform regional policies and pro-conservation campaigns towards sustainable or non-consumptive uses of Mediterranean shark populations.

## 2. Materials and methods

### 2.1 Literature review

A database on the occurrence of *Carcharhinus* species in the Mediterranean Sea was created by performing a review of the studies and grey literature published until January 2021. We searched for papers on Google Scholar, Scopus and ISI Web of Science using the following keywords: “*Carcharhinus*”, “Mediterranean Sea”, “Shark(s)”, and complemented this information with additional papers retrieved from the reference lists of the selected articles. From each publication, we noted the species name, the year and the location of the record, as well as the type of occurrence (i.e. catch or sighting). The list of considered papers is reported in the supplementary Appendix S1

### 2.2 Social media analyses and data mining

The most popular social media platforms (Youtube, Facebook, Instagram, and Twitter) were mined to find public content reporting occurrences of *Carcharhinus* species in the Mediterranean Sea. For this purpose, we manually searched posts reporting visual contents (photos and videos) of requiem sharks published until April 2021. Records of the species of interest were searched on public accounts and on groups dealing with recreational diving and fishery contents. Posts were selected and sorted into two main categories: sightings (postings where living sharks were filmed or photographed in their natural environment) and catches (postings showing sharks fished or exposed in fish markets). The information taken from the postings included the identification of the species, the date and the location of occurrence. When the postings showed a shark exposed in a fish market, we considered the sea area facing the market site as the catch locality. To give an overview of the spatial distribution of requiem shark species, approximate locations of sightings and catches were plotted on a map. Species reported in the posts were identified independently by two experienced observers. When identification at the level of species was not possible, we noted the record as *Carcharhinus* spp.

For each posting, we assigned the social media user to one of the following categories: Fisher, Tourist Environmentalist (including NGOs and MPAs), and Researcher (see Appendix S1). If the user did not belong

to any of these categories, it was classified as “Other”. To evaluate users’ perception of shark conservation, we assigned the overall attitude expressed in the posts to one of the following classes: i) positive, if the user used words like “beautiful”, “amazing”, and in general other comments whose attitude was clearly in favour of shark conservation), negative (if the user expressed fear or hate or any other sentiment that may be interpreted against shark conservation; e.g. see Pepin-Neff and Wynter, 2018), or neutral (when it was not possible to assign the post to a positive or negative attitude) (Fink et al. 2020).

## 2.3 Questionnaires structure and surveys

### 2.3.1 Study site

The questionnaire survey was carried out in Lampedusa, the main island of the Pelagie Archipelago (Strait of Sicily, southern Italy), where an MPA was established in 2002 covering more than 40 km<sup>2</sup> (Pelagie Island MPA, Fig.1). The island is a popular tourist spot, and an increasing number of divers every summer make a shark watching experience around Lampione, an islet 11 nm western from Lampedusa, where a transient aggregation of *C. plumbeus* occurs every summer (Cattano et al., 2021). From this perspective, the area represents an optimal and almost unique study site in the Mediterranean Sea to investigate the potential conservation benefits of shark tourism activities.

### 2.3.2 Questionnaire surveys

A field study was conducted between July and September in two consecutive years (2020 and 2021) to assess tourist (divers and non-divers) perceptions of sharks and to evaluate the potential of shark-watching activities in enhancing people’s knowledge, attitude and support for sharks conservation. To do so, a questionnaire was designed and administered both to divers engaged in shark tourism and non-diver tourists.

Firstly, we assessed if tourists participating in shark-watching activities (i.e. divers; n=48) showed greater self-perceived knowledge of sharks and a more positive attitude towards shark conservation compared to a control group (i.e. non-divers; n= 64). The divers were approached in the six diving centres of the island after they returned from the shark watching tour on Lampione island, while the non-diver group was haphazardly approached on the main beaches and in the harbour of Lampedusa Island. The first page

of the questionnaire included an overview of the study aims to make the respondents aware of the reason for the interview and to obtain their informed consent. The survey was structured in two main parts: the first set of questions was asked to gather demographic information of the respondents, (i.e. gender, age, origin and education level); the second group of questions was aimed to assess respondents' self-perception of their knowledge on and attitude toward sharks (see Appendix 2). Specifically, to evaluate attitudes towards sharks, respondents were asked to rate on a four-point ordinal scale (from 1='none' to 4='high') four different indicators of feeling about sharks: two positive (i.e. curiosity and happiness) and two negative (i.e. fear and repulsion) attitude indicators. To evaluate tourists' knowledge about sharks, respondents were asked to rate (from 1='no knowledge' to 4='high knowledge') their self-perceived level of knowledge of five different aspects of shark biology and ecology. Specifically, tourists were asked which was their knowledge level about "Where do sharks live", "How long sharks can live", "How do sharks reproduce", "What do sharks eat" and "What is the risk of extinction of sharks".

In addition, the questionnaire administered to the diver group contained a section of questions aimed at investigating potential changes in attitude and self-perceived knowledge after making a shark-watching experience. Specifically, respondents were asked to rate on a 5 point Likert scale their overall attitude (1=much worsened, 2=worsened, 3=not changed, 4=improved, 5=much improved) and self-perceived knowledge about sharks (1=much decreased, 2=decreased, 3=not changed, 4=increased, 5=much increased) after diving in Lampione island. In this case, respondents were also asked if they observed any sharks during their diving experience in Lampione and if they had any shark-watching experiences in the past.

Finally, we investigated the potential effect of shark-watching activities in enhancing people's willingness to actively contribute to shark conservation. Specifically, divers were asked if their propensity to give a contribution to shark conservation had increased, decreased or remained unchanged after their shark tourism experience.

## 2.4 Ethical aspects

Ethical issues are critical when using social media data and questionnaire surveys for scientific purposes, mainly when focusing on threatened species and illegal behaviours (Di Minin et al., 2021). To avoid potential risks to social users and protect their privacy during data collection, processing and publication, we collected and stored only information needed to address our research question. All content was anonymized, and this study reports only aggregated data (Di Minin et al., 2021). No private information is shared in this study.

## 2.5 Data analyses

Information on species occurrence from literature and social media data was used to build a map of *Carcharhinus* species distribution in the Mediterranean Sea. Records were divided into 2 groups according to the year of observation (i.e. before and after 2013, which is the year before the first posting we recorded on social media platforms), and were located in four main Mediterranean sectors (EM=Eastern Med, CM=Central Med, WM=Western Med and AS=Adriatic Sea). When more than one species was recorded in a single study, the records for each species were reported on the map separately.

Social media users' sentiments toward sharks were analysed by implementing Proportional Odds Ordinal Logistic Regressions (POLR, Agresti, 2002), implementing in R the function 'clmm' of the 'ordinal' package for mixed POLR (Christensen, 2018). In order to identify potential predictors of users' sentiment (negative, neutral or positive), this response variable was tested against a set of explanatory variables: the year of posting publication (considered as a numeric covariate), the category of the record (considered as a fixed factor with 2 levels: 'catch' and 'sighting'), the interaction between these two, and the category of the user posting the content (considered as a random factor: 'Fisher', 'Tourist', 'Environmentalist', 'Researcher' and 'Other'). Significance levels in the final model were calculated using likelihood ratio tests. All estimated coefficients in the final ordinal logistic regression model were exponentiated and interpreted as adjusted odds ratios (OR, i.e. adjusted for the other variables), reported together with the relative 95% confidence intervals (CI).

In order to investigate potential differences between divers' and non-divers' perception toward sharks, indicators of attitude were used to create a compound score. Indicators of negative attitude (i.e. fear



and repulsion) were firstly converted into negative values. Then the four indicators (two positives and two negatives) were summed up and the resulting score was normalized on a 0–1 scale. Before summing the single indicators, the internal coherence was checked using Chronbach's alpha coefficient. No issue with internal coherence was highlighted ( $\alpha > 0.7$ ). Concerning tourists' self-perceived knowledge about sharks, the five indicators of knowledge were used to create a compound knowledge score, by summing up and normalizing to a 0–1 scale. Also in this case, the Chronbach's alpha test did not detect any issue with internal coherence. Drivers of attitude and self-perceived knowledge scores were investigated by implementing generalized linear mixed effect models with the package glmmTMB (Mollie et al, 2017) in R. Each response variable (score) was modelled through a beta-glmm, i.e. assuming the dependent variable to be beta-distributed, being the scores bounded variables. The full models contained the following independent variables: the category of the interviewee (fixed factor with two levels: divers and non-divers) and a set of demographic predictors (gender, education level and age). Significance of predictors was checked through a Wald chisquare test, while model diagnostics was visually checked through histograms of residuals and residuals vs fitted plots, highlighting no issues of departure from normality and homogeneity of residuals (see supplementary).

In order to investigate how the attitude and self-perceived knowledge of divers can change after the shark-watching experience, we implemented POLR models. Potential predictors of attitude and self-perceived knowledge after diving in Lampione in the full models were: demographic variables (i.e. gender, age and education level), a factor about the occurrence of past experience with shark-watching (fixed factor with two levels: 'yes' and 'no') and a factor for the direct observation of sharks during their diving in Lampione (fixed factor with two levels: 'yes' and 'no'). Due to the absence of negative responses both for attitude change and self-perceived knowledge change, and to an extremely unbalanced distribution, responses were clumped into two possible categories both for the attitude (i.e. 'not changed' and 'improved') and self-perceived knowledge (i.e. 'not changed' and 'increased'). Finally, an alluvial plot has visually inspected the effect of participation in shark-watching activities on people's willingness to

contribute to shark conservation, implementing the package 'alluvial' (Bojanowski and Edwards, 2016) in R. All analyses were performed in R 3.4.4 (R Development Core Team, 2018).

## 3. RESULTS

### 3.1 Spatio-temporal distribution of catches and sightings

#### 3.1.1 Occurrences reported in the literature

We found 58 studies published between 1912 and January 2021, reporting 128 and 9 occurrences of catches and sightings, respectively, for eight different *Carcharhinus* species (Supplementary Appendix 1, Fig.1a). The temporal distribution of the records was different between the four Mediterranean sectors considered. In the western Mediterranean the majority of records dated back to before 2013, whilst only a few records were after this year. Most of the occurrences belonged to the central and eastern Mediterranean Sea and were more recent; the latest published record in the Adriatic Sea dated back to before 2013.

The vast majority of literature records dealt with catches of requiem sharks. These catch events mostly occurred in North African countries (n=35, most of them in the Gulf of Gabès, Tunisia) and along the eastern Mediterranean coast (18 records mainly along the Syrian, Lebanese and Turkish coasts).

The species most frequently reported (i.e. the number of literature records in which a species appeared) was *C. plumbeus*, representing the 55.3% (n=47) of the records (Supplementary Fig. S1a), followed by the copper shark *C. brachyurus* (14.1% of the records, n=12) and the spinner shark *C. brevipinna* with 11.8% of records (n=10). The other five species were present with less than seven records each. The occurrence of *C. plumbeus* was ubiquitous, but sightings after 2013 were reported only in Lampione island (south Italy), and along the Israeli, Turkish (Boncuk Bay) and Lebanon coasts (Dana island). The only other sighting reported in the literature concerned an individual of the spinner shark *C. brevipinna* in Boncuk Bay (Turkey). The highest number of *Carcharhinus* species (n=7) was recorded in the eastern Mediterranean (EM sector, Fig. 1) whilst a single species was reported in the Adriatic Sea (*C. plumbeus*).

#### 3.1.2 Occurrences reported on social media

We found 120 posts (66 with photos and 54 with videos) providing information on the occurrence of four *Carcharhinus* species along the Mediterranean coast. Specifically, 60 records reported *C. plumbeus*, 18 *C. obscurus*, 2 *C. brevipinna* and 2 *C. brachyurus*. In 36 postings it was not possible to identify sharks at the species level (in these cases each record was classified as *Carcharhinus* spp.), whilst two postings reported two different species in the same record. Overall, social media postings reported 58 catch events (either caught during fishing or traded at fish markets), and 62 sighting events. Requiem shark species occurred mainly in the eastern and central sectors of the Mediterranean Sea, and in the Adriatic Sea. Most of the reported catches occurred along the Mediterranean Turkish coasts (n=25), whilst all sightings were recorded on the Italian, Turkish and Israeli coasts and concerned the sandbar shark *C. plumbeus*, the dusky shark *C. obscurus* or *Carcharhinus* spp. individuals (Fig.1b). Only seven records were found in the western basin: four unidentified species in Italy and France, two *C. plumbeus* in the Bonifacio channel and northern Tunisia and one *C. obscurus* in the northern Corsica (Fig. 1b).

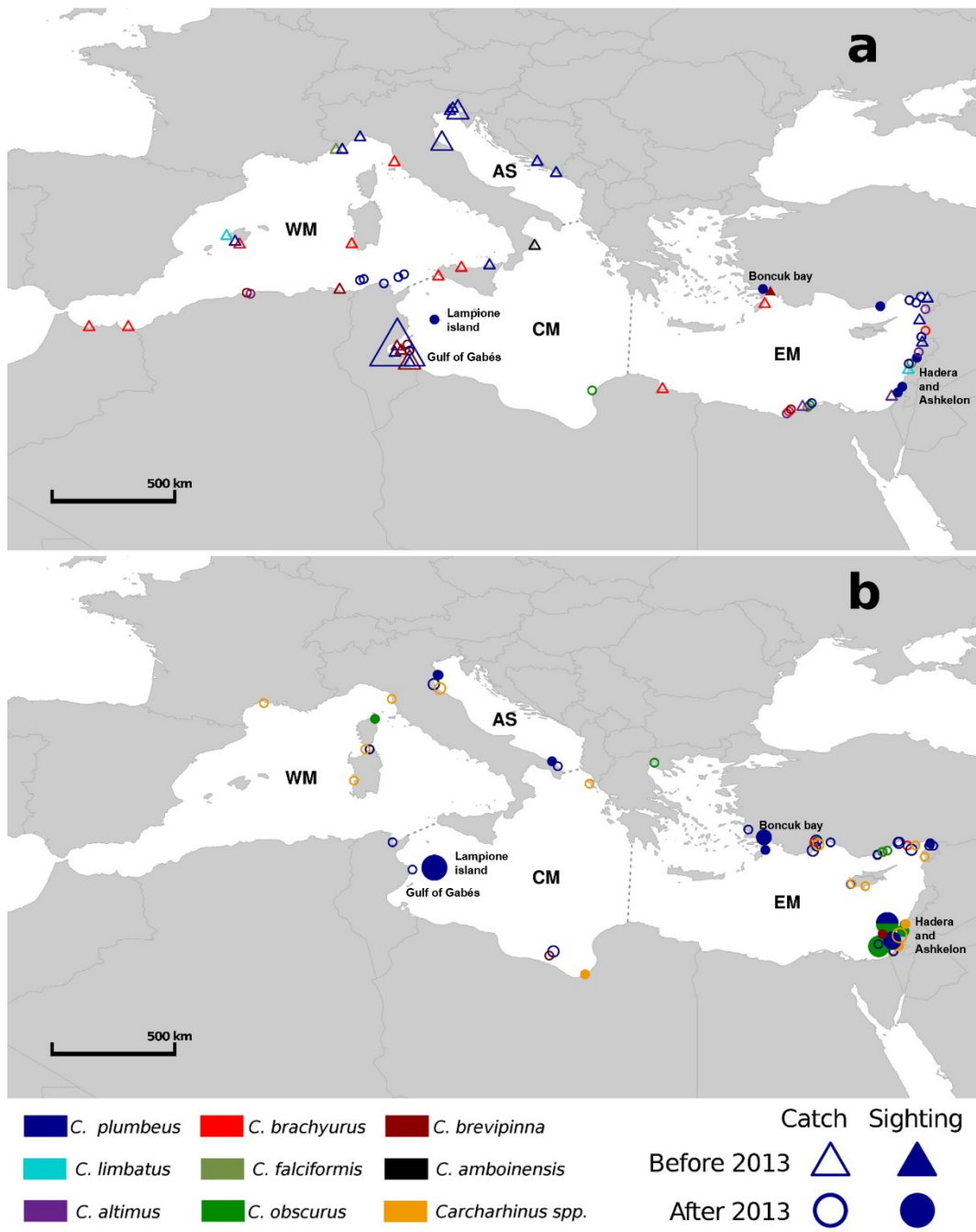


Fig. 1 - Distribution of catches (empty symbols) and sightings (filled symbols) of the eight *Carcharhinus* species reported until 2013 (triangles) and since 2013 (circles) in the scientific literature (a) and in the social media posts (b) for different sectors of the Mediterranean Sea. Colours represent the different species. The dimension of the symbols is proportional to the number of records: the number of studies conducted in the same area (min=1, max=5, for the literature map), the number of social media posts (min=1, max=18, for the social media map). Note that in very dense observation areas, jittering was added to observation coordinates to improve clarity. EM=eastern Mediterranean, CM=central Med, WM=western Med, AS=Adriatic Sea. The known shark aggregation sites (Lampione island in Italy, Boncuk bay in Turkey, Hadera and Ashkelon in Israel, and Gulf of Gabès in Tunisia) are indicated on the map.

## 3.2 Attitude and perception of social media users towards shark conservation

We deduced people attitudes towards shark conservation from 120 postings shared on Twitter (n=4), Instagram (n=43), Facebook (n=41) and YouTube (n=32). Overall, the attitude was positive in 39%, negative in 14%, and neutral in 47% of the postings, and was significantly influenced by the type of occurrence (i.e. catch or sighting) and the publication year (Table 1, Fig. 2). The postings showing *Carcharhinus* sightings and catches showed positive attitudes in 53% and 24% of the cases, respectively. Conversely, negative attitudes were significantly more frequent in postings reporting catches (27%) than in those dealing with shark sightings (only 3%; supplementary Fig. S2). The proportion of postings with negative attitudes toward sharks significantly decreased across the years. On the contrary, a positive linear relationship was found between positive attitudes and the year of the posting publication both for catches and sightings (Table XXX, Fig. 2).



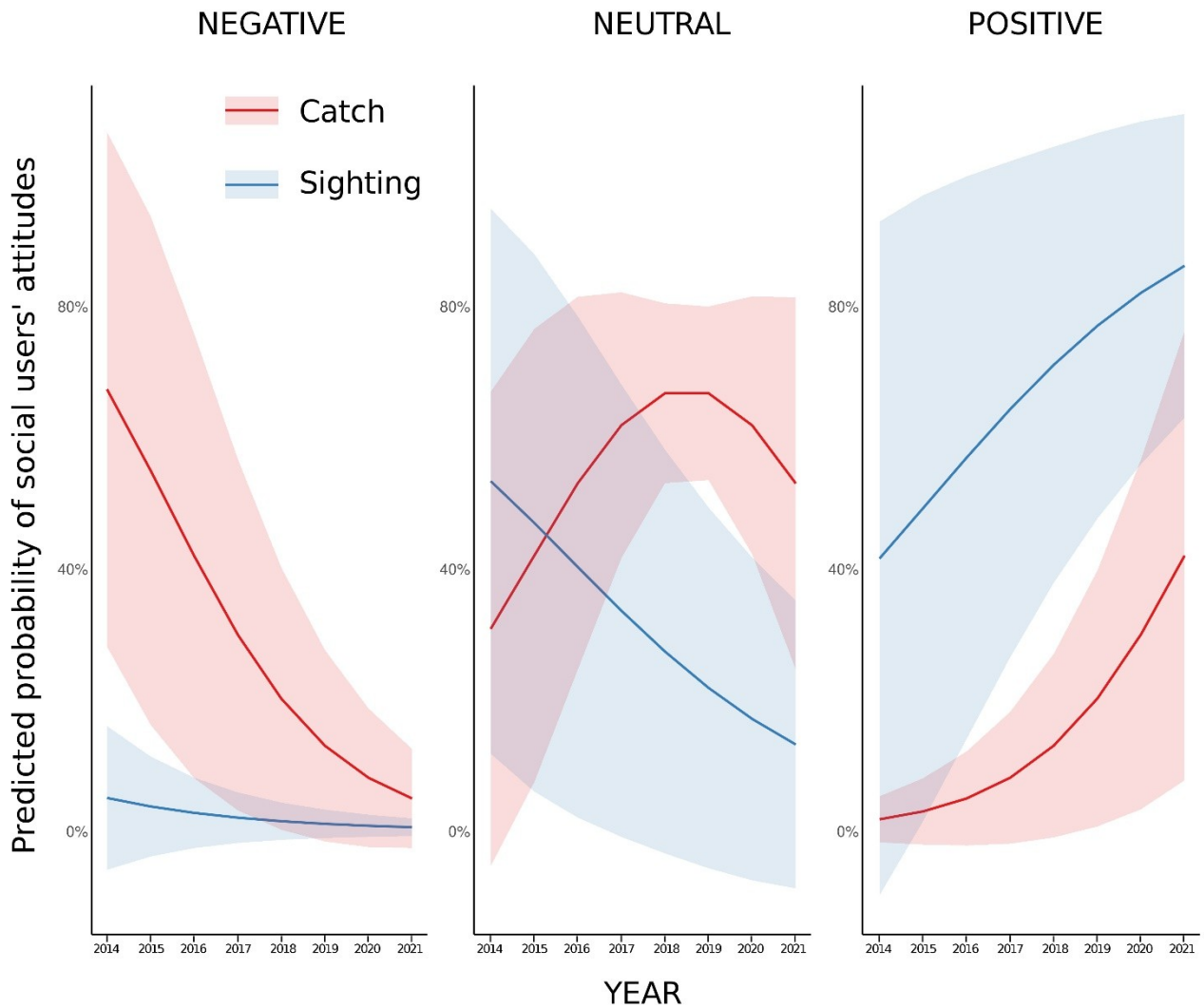


Fig.2 - POLR model predicted the percent of social users' attitudes (negative, neutral and positive) toward *Carcharhinus* species in the Mediterranean Sea, against the significant predictors identified.

Table 1 - Results from the POLR analysis on the attitude of social users toward sharks (only significant fixed predictors are reported).

Response variable	Predictor	Estimate	SE	Odds Ratio	OR 95% CI	LR Chisq	P-value
Attitudes toward sharks	Record category (catch vs sightings)	2.84	1.02	17.12	2.31 - 127.08	14.63	6.66E-04
	Year	0.43	0.12	1.54	1.21 - 1.95	14.68	6.40E-04

Attitudes toward sharks significantly changed also depending on the category of the social users. Fishers were the only users who shared content with a negative attitude. Postings shared by Tourists displayed an

equal proportion of neutral and positive attitudes, while in the case of Researchers and Environmentalists, positive attitudes were more frequent than neutral ones (Supplementary Fig. S3).

### 3.3 Self-perceived knowledge and attitude of tourists towards sharks

The questionnaire survey revealed that divers show significantly more positive attitudes toward sharks compared to non-divers (Fig. 3a;  $\chi^2=33.44$ ,  $p<0.001$ ) regardless of age, gender and education level (Supplementary Table S1). The self-perceived knowledge of sharks was significantly and positively correlated with the education level of the respondents ( $\chi^2=13.15$ ,  $p<0.001$ ) and higher (and weakly significant) in divers than in non-divers, with a non-consistent pattern across the levels of these 2 factors, thus generating a significant interaction between tourist category and education level (Fig. 3b). Highly educated divers showed the highest level of self-perceived knowledge about sharks.

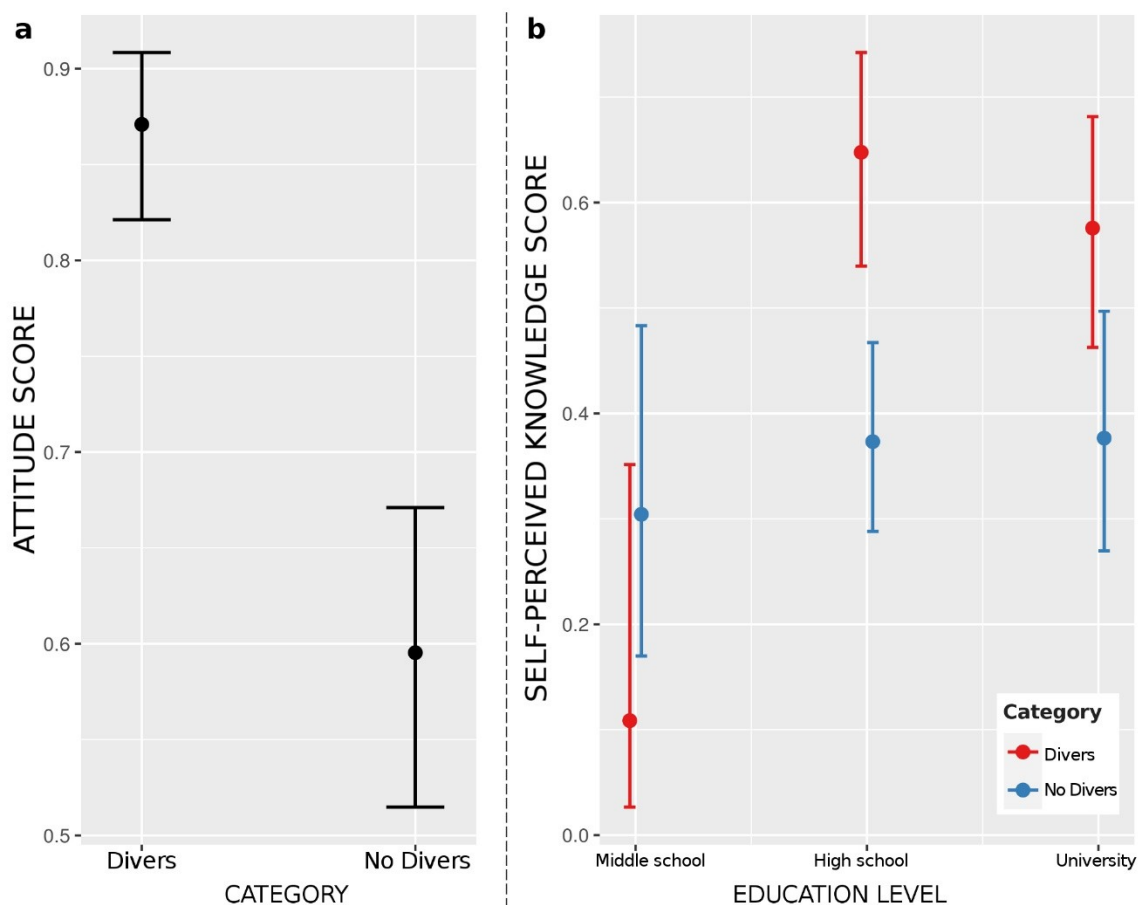




Fig.3 – Predicted values of attitude toward (a) and self-perceived knowledge (b) on sharks displayed by interviewees in relation to the significant predictors identified, respectively.

Focusing on questionnaires administered to the diver group, we found that only the direct observation of sharks during the tour in Lampione produced a significant and positive change in the overall attitude ( $\chi^2=61.28$ ;  $p=0.01$ ; Table 2) and self-perceived knowledge of sharks ( $\chi^2=7.61$ ,  $p<0.01$ ; Table 2), while all other predictors considered were not significant. More than 50% of the respondents who observed sharks during the diving in Lampione displayed an enhanced perception of them after diving.

Table 2. Results from the POLR analysis on the attitude and self-perceived knowledge change in divers after participation in shark-watching activities in Lampione (only significant predictors are reported).

Response variable	Predictor	Estimate	SE	Odds Ratio	OR 95% CI	LR Chisq	P-value
Divers' attitude after diving in Lampione	Seen shark in Lampione during the diving	2.23	0.96	9.33	1.42 – 61.28	61.28	0.01
Divers' self-perceived knowledge after diving in Lampione	Seen shark in Lampione during the diving	2.15	0.86	8.64	1.61 – 46.64	7.61	5.80E-03

Conversely, the majority (>75%) of divers who did not see sharks during diving stated that their attitudes did not change after the tour to Lampione island (Fig. 4a). Similarly, almost two-thirds of the divers who encountered sharks declared an increased self-perceived knowledge of sharks, whilst tourists who did not see sharks declared that their level of knowledge was unchanged (Fig. 4b).

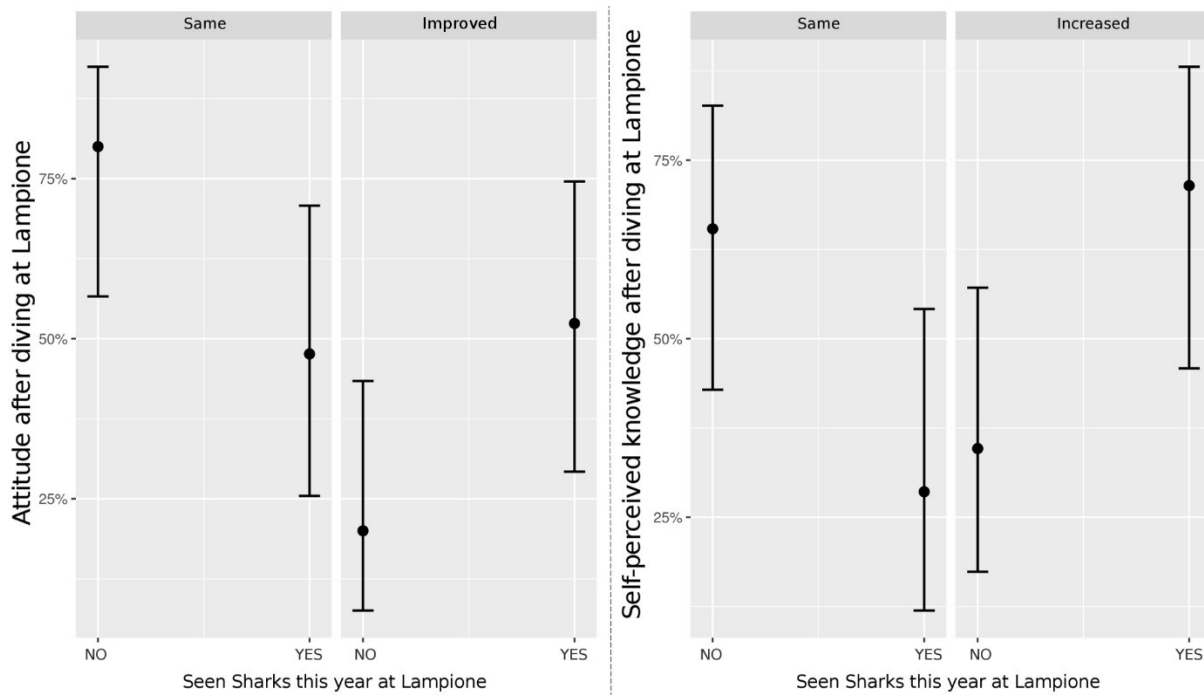


Fig. 4 -Attitude towards sharks (a) and self-perceived knowledge of sharks showed by divers who have seen or not seen sharks during the shark-watching tour in Lampione Island (Pelagie Islands MPA). For both the graphs, the first panel shows the percentage of respondents who did not change their perception/knowledge after diving, the second panel shows the percentage of respondents whose perception/knowledge ameliorated after diving.

Divers who never participated in any shark conservation programs stated that they were willing to increase their contribution to shark conservation regardless they had seen or not sharks during the shark-watching tour (Fig. 5). The majority of divers (75%) who had seen sharks during the tour in Lampione Island stated that they wanted to start contributing or increase their contribution to shark conservations (Fig. 5).

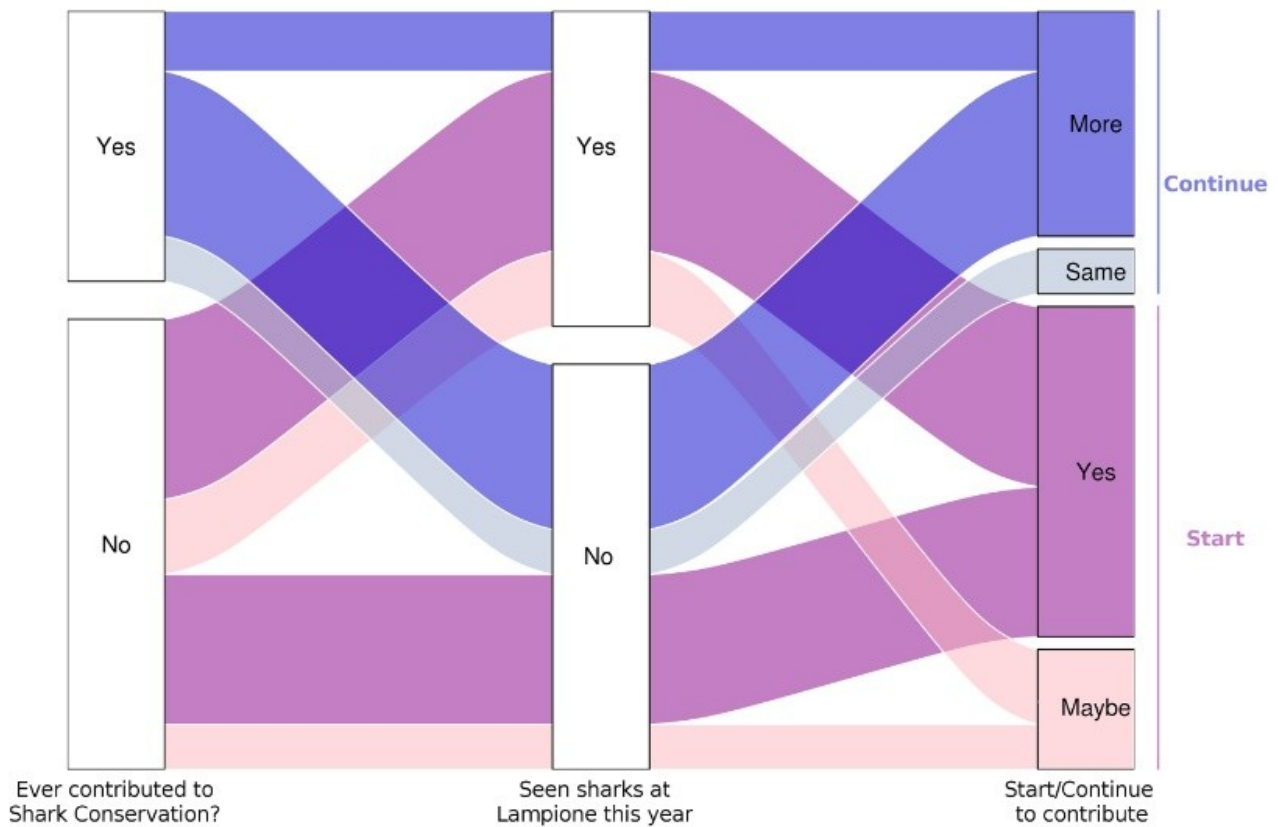


Fig. 5 - Alluvial plot showing the potential change in willingness to contribute to shark conservation displayed by interviewed divers in relation to the observation of sharks during the diving in Lampione Island (Pelagie Islands MPA) and past experience of contribution to shark conservation.

## 4. DISCUSSION

By combining scientific literature, social media and questionnaire surveys, this study identified conservation hotspot areas for *Carcharhinus* species in the Mediterranean Sea and shed light on people's attitudes towards sharks and on the potential role of emerging eco-tourism activities in raising people's awareness and increasing willingness to be engaged in conservation programs. This information is crucial to build effective conservation actions that may contrast the ongoing severe decline of Mediterranean threatened species, especially for coastal large-body migratory sharks like many carcharinids (Boldrocchi et al. 2021; Ferretti et al. 2008; Walls and Dulvy 2021).

### 4.1 Spatio-temporal distribution of catches and sightings

The literature survey mainly reported on catch data, whilst social media postings were equally distributed between catch and sighting events. Importantly, data from literature and social media provided information on eight *Carcharhinus* species distributed across the whole Mediterranean Sea, with their occurrences in the eastern part of the basin generally more abundant and recent than in the western part, confirming the rapid decline of large and coastal shark species in this historically exploited zone (Ferretti et al. 2008). The sandbar shark *C. plumbeus* was the most recorded species throughout the Mediterranean Sea, and the only *Carcharhinus* species reported in the Adriatic Sea, both by literature and social media data. This result is consistent with recent findings focusing on elasmobranch assemblages of different Mediterranean areas (Taklis et al. 2020; Kabasakal and Bilecenoğlu, 2020; Jambura et al. 2021). Integrating literature review and social media surveys allowed us the identification of current threat hotspots for *Carcharhinus* species, where the number of reported catches is higher than elsewhere and where conservation efforts should deserve more patrolling and enforcement, e.g., the North African coast and the eastern Mediterranean sector (Turkish, Lebanon and Syrian coasts). It is known that *Carcharhinus* species are targeted in these areas throughout the year by longline, trawling or small-scale fisheries (Bradai et al., 2018; Carpentieri et al., 2021). The sandbar sharks are targeted by artisanal fisheries in Tunisia and Libya from April to June when they may represent up to 80% of the total catches and up to 94% of elasmobranch catches by longlines (Echwikhi et al. 2014; Bradai et al. 2018; Saidi et al. 2019), with many pregnant females caught in shallow depths (Bradai et al. 2005). Another area with a high number of records from literature and social media was the Adriatic Sea, which is considered a nursery area due to the frequent catches of *C. plumbeus* neonates and juveniles mainly occurring in the northern sector (Barbato et al. 2021; Jambura et al. 2021). However, in this case, the literature records date back to before 2010, suggesting the need for updating scientific information. The vast majority of sightings of requiem shark individuals in their natural environment were recorded in two additional spots located in the Strait of Sicily (Lampione island, Pelagie island MPA) and along the Israeli coasts (Hadera and Ashqelon). In these sites, an aggregation of sandbar sharks and a mixed aggregation of the sandbar and dusky sharks have been recently described (Cattano et al. 2021; Barash et al. 2018) and the emerging shark-watching activities carried out in these spots are contributing to the increase in the number of sightings shared on social media.

## 4.2 Attitude and perception of social media users towards shark conservation

Social media postings revealed positive and neutral attitudes towards sharks. Nevertheless, the posts shared by fishers mainly dealt with catches and showed negative attitudes, suggesting an existing conflict with sharks, perceived as direct competitors. This is likely a consequence of depredation events of hooked fish or baits from fishing gear, hampering interactions of target species with fishing gears or slowing down fishing operations (Iwane et al. 2021). Fisher's perception of sharks is largely overlooked in the Mediterranean Sea, despite the crucial role of this category in building and managing effective shark conservation programs. Indeed, sharks represent a significant portion of the Mediterranean fishery by-catch (Carpentieri et al., 2021), with even a worse actual picture as existing reports considered only official landings, overlooking the impact of IUU, small-scale and recreational fishing. Despite possible geographical differences in the magnitude of this phenomenon, more efforts should be addressed to better understand the fishery impact on sharks and get a more comprehensive assessment of fishers' perceptions and attitudes towards sharks in the Mediterranean Sea. This does represent a necessary step for building and implementing more effective shark management and conservation strategies.

In order to mark a turning point in shark conservation, we need a bold change in the attitude of the general public toward them. In this respect, our analyses of social media content provided comforting indications about the positive relationship between pro-shark conservation attitudes and the year of posting publication, whilst postings with negative intent showed an opposite temporal trend. These relationships were consistent for catch and sighting events, suggesting a general ongoing positive shift in the public perception of sharks in the Mediterranean countries, as recently documented by other recent studies carried out in Greece and Italy (Giovos et al. 2021; Mazzoldi et al. 2019). The increasing positive attitudes towards sharks have been related to a growing understanding of the ecological role of these species conveyed by different sources of information, such as documentaries, the web, and books. Indeed, there is evidence that increased knowledge about sharks leads to increased concern about their protection (O'Bryhim et al. 2015). In addition, raising awareness campaigns promoted by different local and

international NGOs are contributing to gradually changing the perception of sharks from “monsters of the sea” to charismatic species (Mazzoldi et al. 2019).

### 4.3 Self-perceived knowledge and attitude of tourists towards sharks

The non-consumptive use of sharks through ecotourism activities may contribute to shark conservation, not only by decreasing catches but also by fostering positive perception and pro-conservation attitudes of the public. In this regard, our questionnaire survey revealed that: 1) diver tourists displayed more positive perception and higher knowledge of sharks than the non-diver tourists; 2) divers making a shark-watching experience showed enhanced perception and increased knowledge of sharks than the divers who did not; 3) the willingness to contribute to future shark conservation programs was high in shark-tourist divers regardless they encountered sharks in the diving spot. Despite some Mediterranean shark populations experiencing a dramatic collapse (Ferretti et al. 2008), the scarce knowledge of their spatio-temporal distribution patterns, along with insufficient information on people's perceptions and attitudes towards their conservation, might represent a barrier to the implementation of sound management and conservation programs. Indeed, a better understanding of perceptions and attitudes may provide important insights into social acceptability and potential support for conservation initiatives (Bennett 2016). Public perception of marine wildlife and pro-conservation behaviours depend on different factors (individual's interest, profession, education level, age) and there is evidence that it may influence policy preferences boosting the achievement of conservation goals (Friedrick et al. 2014; Bennett 2016; Pepin-Neff et al. 2018). Individuals with high levels of knowledge and a positive attitude toward wild animals are more likely to support conservation and avoid behaviour potentially harmful to these animals [e.g. O'Bryhim and Parson, 2015]. Yet, an individual's experience in nature may influence attitudes and motivation for personal engagement and conservation behaviour. Our findings show that divers making a shark-tourism experience declared a higher propensity to take part in future conservation programs aimed at increasing shark protection. Therefore, our results add to previous evidence from outside the Mediterranean Sea revealing the potential role of sustainable wildlife tourism in supporting conservation by fostering positive environmental attitudes and participants' knowledge of terrestrial and marine species ecology (Ardoin et al.

2015), including sharks (Ziegler et al. 2020; Apps et al. 2018; Gallagher et al. 2015; Sutcliffe and Barnes 2018).

In this context, popular shark-diving spots may represent a laboratory where testing the benefit of ecotourism for conservation (Gallagher et al. 2015). If well managed, shark tourism may have a high potential to build environmental awareness, enhance the knowledge and attitudes of tour participants and stimulate conservation support beyond tour duration (Gallagher et al. 2015; Sutcliffe and Barnes, 2018; Topelko et al. 2005; Apps et al. 2018; Gray et al. 2022). Shark-watching tours also provide economic benefits for local communities (Vianna et al. 2011, 2012; Cisneros-Montemayor et al. 2013), therefore representing an incentive for shifting the value of sharks from a fishery product to a more durable resource in many locations around the world (Gallagher et al. 2015). Moreover, shark tourism may have other indirect conservation benefits as diver operators may monitor and deter poachers and fishers engaged in illegal activities, thus extending protection also to other species.

However, it is also important to assess the costs and risks associated with these tourism activities. Indeed, there is evidence that if not properly regulated, shark-watching may lead to changes in animal ecology and biology (e.g. Gallagher et al. 2015). With the recent growth of shark-diving activities in a few Mediterranean spots, quantifying and minimizing their impacts represent a research priority. A recent study on the sandbar shark aggregation in Lampione island reported that the probability of shark detection by video samplings significantly decreased in presence of more than three boats and 30 divers, thus suggesting a negative impact of elevated tourism frequentation on the shark aggregation (Cattano et al., 2021). For this reason, we encourage the early implementation of specific management measures aimed at limiting this impact, including the adoption of codes of conduct for responsible shark-watching activities and the limitation of the number of boats and divers. This precautionary approach should be applied also in the other few Mediterranean spots where elasmobranch-focused diving activities are growing, such as in Marettimo island (Egadi Island MPA, southern Italy) where a seasonal aggregation of common eagle rays has been recently described and is attracting a growing number of tourists (Grancagnolo et al. 2021).

Lampione island may be considered a suitable spot where promoting sustainable tourism activities in the Mediterranean Sea. Indeed, recent evidence showed that conservation outcomes are more evident in smaller-scale tourism sites, where sustainable tourism is perceptions, attitudes and pro-conservation behaviours are more likely to emerge (Ziegler et al. 2020).

## 5. Conclusions

Most of the existing information on the ecology and distribution of sharks in the Mediterranean Sea belongs to fishery-dependent data gathered from landing statistics, which are often reported in aggregate categories, or through experimental fishing surveys, which are cost-expensive and cannot cover wide temporal and spatial scales. Our findings add to recent evidence that literature review and social media content analysis can be complementarily used as a valid tool in conservation studies to detect the hotspot areas of migratory and elusive shark species (e.g. Boldrocchi et al. 2021; Taklis et al. 2020; Kabasakal and Bilecenoğlu 2020), whose ecology and distribution patterns are still poorly studied in the Mediterranean Sea.

Being the requiem sharks species highly migratory, the priority for their conservation is to identify critical habitats and ecological corridors to push for effective protection measures involving the governments of different countries and the international community. By updating information on the distribution of *Carcharhinus* species, this study identified some hotspot sites for requiem shark species that should deserve more attention by policymakers. The Strait of Sicily (including the Tunisian and Libyan coasts), the Adriatic Sea and the eastern coasts of the Mediterranean Sea are essential hotspot areas where these shark species aggregate in shallow waters during specific periods for reproduction (Saidi et al. 2019; Basusta et al. 2021; Barbato et al. 2021) and other purposes that are still poorly known (Cattano et al. 2021; Barash et al. 2018). The shift from extractive to non-extractive (i.e. shark-tourism) use of sharks, bans on the commercial fishing and trade of the most threatened shark species, and the institution of transboundary shark sanctuaries should be urgently promoted in these areas. In this context, the effort of GOs and NGOs might be decisive



for ameliorating people perceptions and attitudes toward shark conservation, and therefore, providing concrete support for pushing these management and conservation policies.

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# Supplementary files

**Literature, social media and citizen science surveys identify relevant areas for *Carcharhinus* species conservation in the Mediterranean Sea**

[o](#)

**Literature, social media and citizen science surveys identify conservation hotspots for *Carcharhinus* species in the Mediterranean Sea**

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Fig. S1 – Species composition in the records from literature and social media postings. For each species is also indicated the number of catches and sightings.

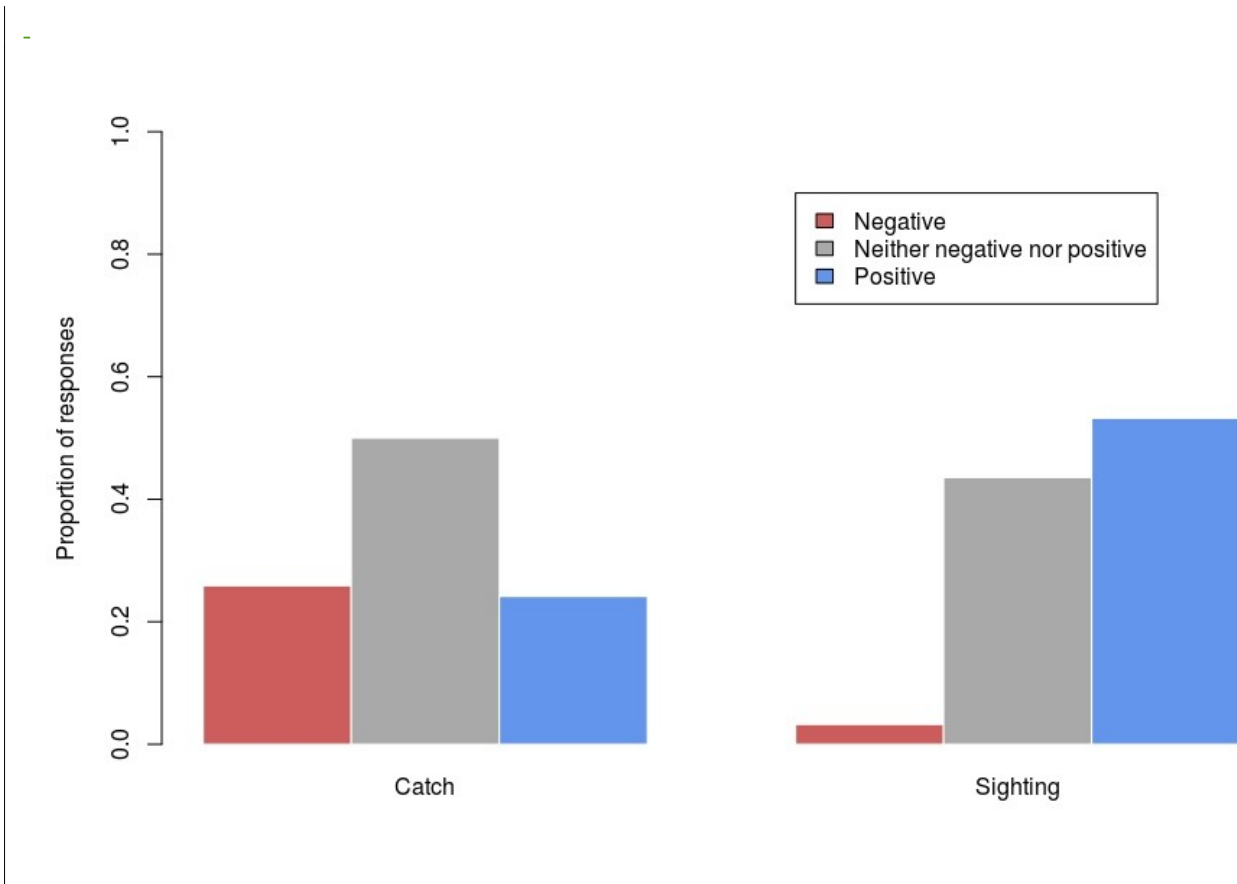


Fig. S2 - Percentage of the social media postings showing negative, neutral or positive attitudes towards shark catches and sightings

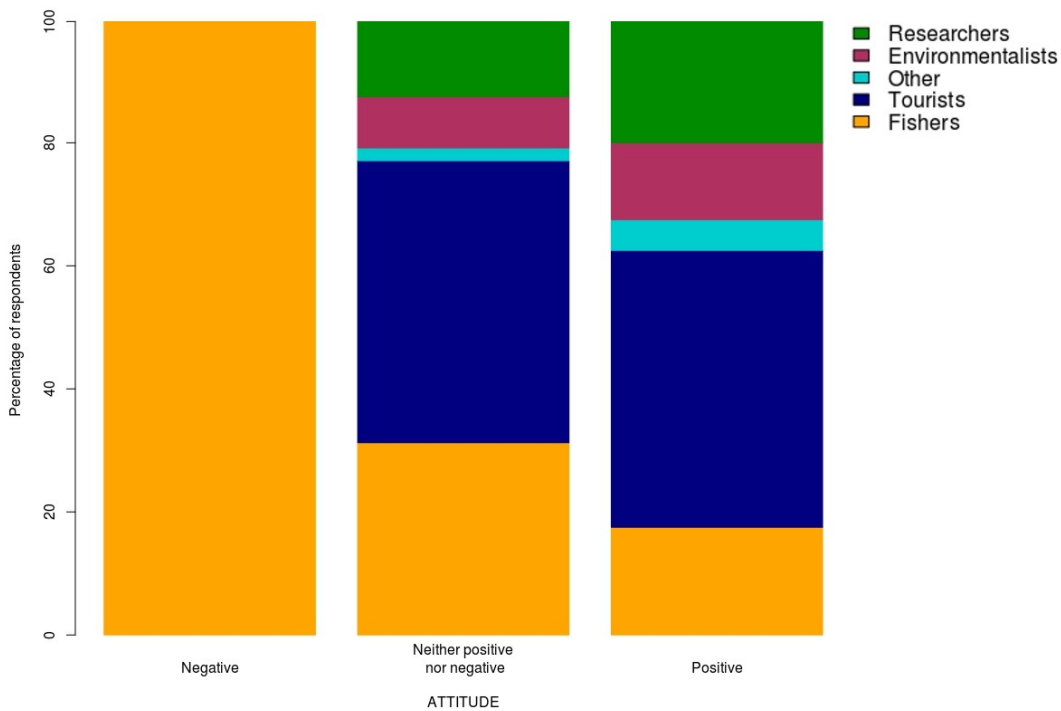
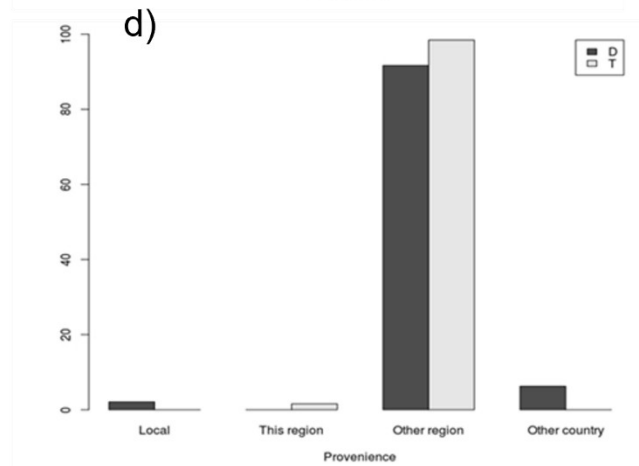
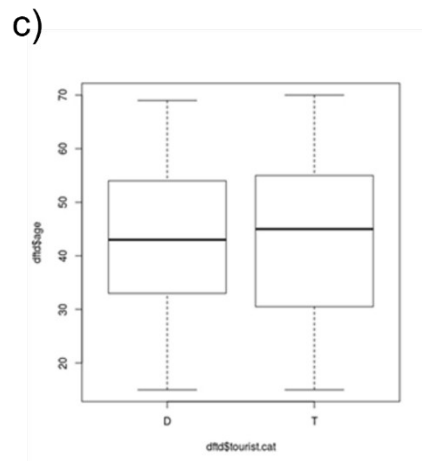
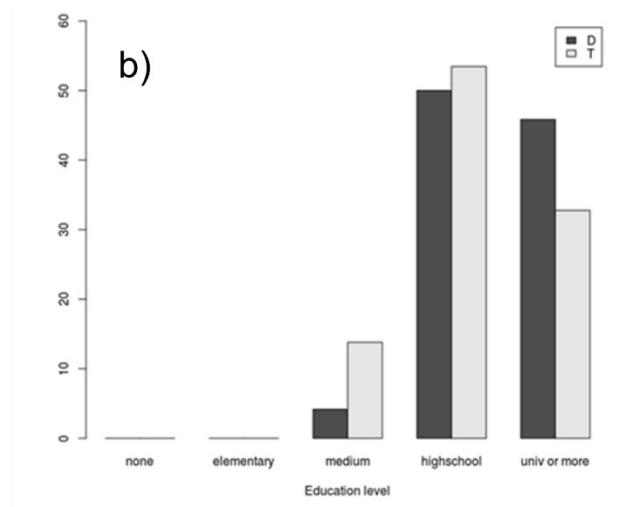
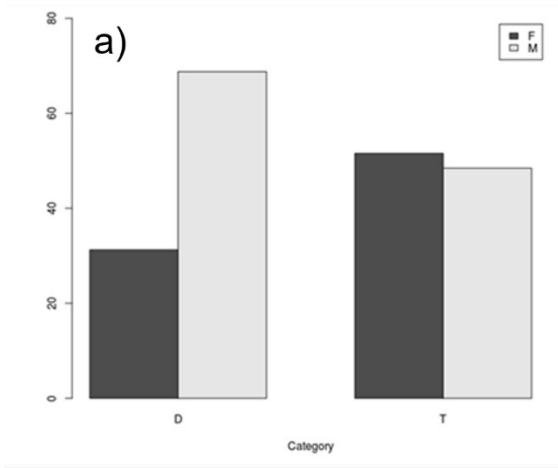


Fig. S3 - Percentage of the social media postings shared by different user categories (Fishers, Tourists, Environmentalist, and Other) showing negative, neutral or positive attitudes towards shark catches and sightings



ig. S4 – Socio-demographic information ( a) sex ; b) education level ; c) age; d) geographic provenience) relative to divers (D) and non-diver tourists (T) who participated to the questionnaire survey.



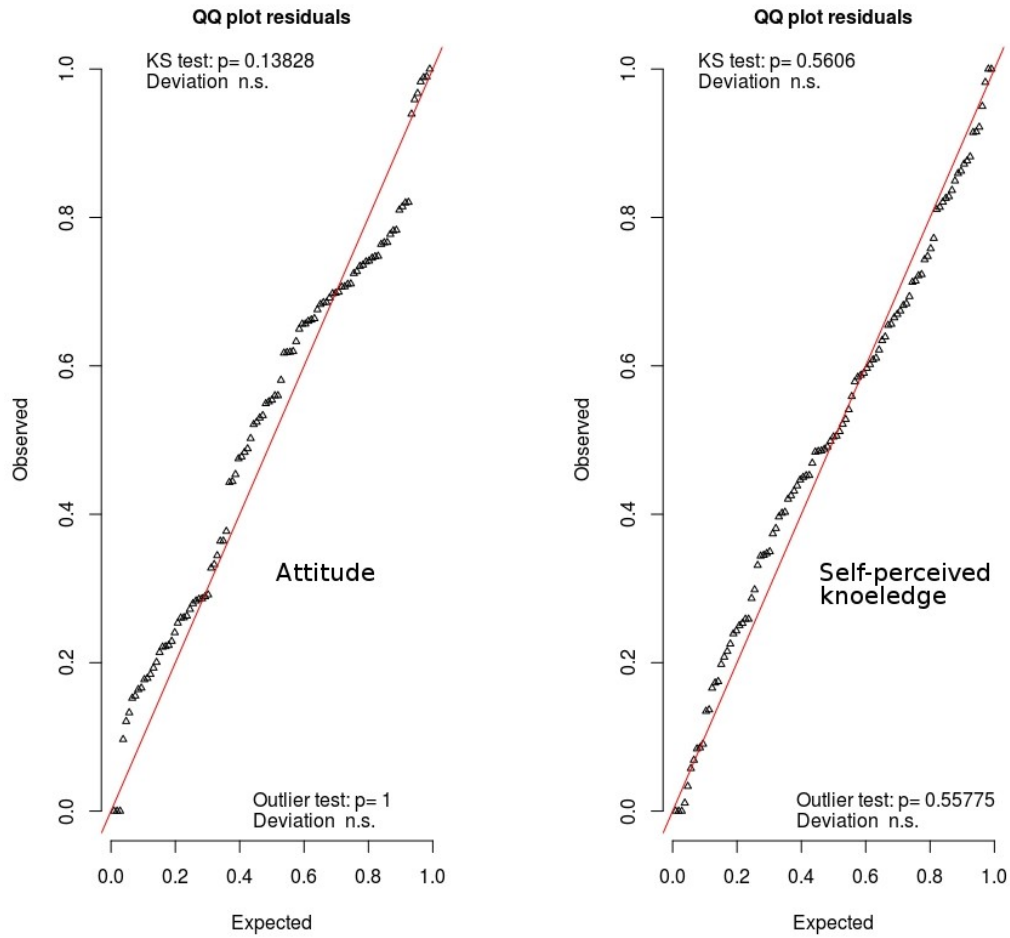


Fig. S5. Residuals vs fitted plots for the beta-GLM on Attitude (left panel) and Self-perceived knowledge (right plot)

Tab. S1. Results from the beta-GLM on attitude and self-perceived knowledge in divers and non-divers at Pelagie MPA

Response variable	Predictor	Estimate	Chi-Square	pvalue
Attitude score	Tourist category (divers vs no divers)	-1.433	33.44	7.36E-09
	Tourist category (divers vs divers)	1.48	2.793	0.094
Self-perceived knowledge	Education level	2.86	13.15	0.001
	Tourist category * Education level	-2.54	8.38	0.015