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RESEARCH ARTICLE

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Data-mining social media platforms highlights conservation action for the Mediterranean Critically Endangered blue shark *Prionace glauca*

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Abstract

1. The Mediterranean Sea represents an area of elevated risk of extinction for sharks, where data deficiency is a pervasive problem.
2. To compensate for such a paucity of information, this study investigated the use of social media content as a complementary approach to evaluate the distribution and habitat use of the Critically Endangered blue shark *Prionace glauca* in coastal waters, as well as public perceptions of the sharks.
3. Through social media data mining a total of 146 records, comprising 158 individual blue sharks approaching Italian coastal waters, have been recorded from 2011 to 2020.
4. This study revealed that, over the past decade, blue sharks regularly visited Italian coastal habitats for extended periods of time. Differences in the temporal distribution of blue sharks by sex and size appear to be linked to reproductive activity. The higher number of adult females approaching the shore in spring and the increase in young-of-the-year (YOY) sightings in the following months possibly indicate parturition in coastal waters. Spatial analyses also showed that certain Italian coastal areas, such as those in Calabria and Puglia, were preferred coastal habitats for this species.
5. Results also indicate that social media platforms can be considered an ever-growing source of data on wildlife, which can shed light on the occurrence and distribution of endangered shark species in poorly known habitats. Furthermore, social media platforms should be used for awareness campaigns to educate the public, as this study showed that negative reactions to shark encounters remain widespread.

KEYWORDS
coastal waters, conservation, habitat use, human perception, shark ecology, social media

1 | INTRODUCTION

The Mediterranean Sea is widely recognized as an important hotspot for cartilaginous fishes (Cariani et al., 2017); however, in spite of such biodiversity, elasmobranchs face an elevated risk of extinction (Dulvy et al., 2014), with several shark species that have declined by up to 96–99% in recent years (Ferretti et al., 2008). Critical habitats need to be identified for conservation and management purposes (Bradai, Saidi & Enajjar, 2012; Moore, 2018), especially considering that the distribution of threatened elasmobranchs is not homogenous throughout the Mediterranean Sea (Coll et al., 2010; Boldrocchi et al., 2017). Data deficiency in shark ecology is also a widespread problem (Bradai, Saidi & Enajjar, 2012), as conducting ecological field studies is often very expensive (Rezzolla, Boldrocchi & Storai, 2014; Moore, 2018). New approaches are needed to compensate for such a paucity of data (Bargnesi, Lucrezi & Ferretti, 2020). Public participation and engagement in scientific research – also known as citizen science – has increasingly proven to be a rich and valuable source of information on the ecology and distribution of elusive and/or endangered species (Storai et al., 2006; Newman et al., 2012; Thiel et al., 2014; Araujo et al., 2020; Bargnesi, Lucrezi & Ferretti, 2020), as well as supplementing and validating scientific data (Davies et al., 2012; Giovos et al., 2018; Pesendorfer, Dickerson & Dragoo, 2018). The Mediterranean Sea represents a perfect case study for citizen science: not only is this region one of the most densely inhabited in the world, but its coasts are a hotspot for tourism, where interactions between humans and sharks have been particularly frequent over time (Mojetta et al., 2018). With the emergence of social media platforms, opportunities of collecting multimedia material on shark sightings have increased considerably (Araujo et al., 2019; Kabasakal & Bilecenoğlu, 2020; Taklis, Giovos & Karamanlidis, 2020), as have investigations based solely on data gathered from the internet and social media (Giovos et al., 2018; Kabasakal & Bilecenoğlu, 2020; Taklis, Giovos & Karamanlidis, 2020).

Within the Mediterranean Sea, the blue shark, *Prionace glauca* (Linnaeus, 1758), has recently been listed as Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List (Sims et al., 2016). This species is estimated to have undergone a 90% decline over three generations, primarily as a result of overfishing (Ferretti et al., 2008), and thus its protection should be prioritized (Leone et al., 2017). However, the blue shark is still threatened by direct fishing pressure, and it suffers high mortality as it also constitutes a major fishery by-catch in the Mediterranean Sea (Megalofonou, Damalas & Yannopoulos, 2005b; Biton-PorSmoguer & Lloret, 2018). At present, information on its ecology and biology mainly comes from pelagic areas where commercial fisheries operate (Garibaldi & Orsi Relini, 2000; Hemida & Capapé, 2003; Megalofonou, Damalas & De Metrio, 2009; Damalas & Megalofonou, 2010; Leone et al., 2017; Bernardini et al., 2018; Ćetković et al., 2019), leaving a gap in knowledge concerning its occurrence in coastal habitats. Thus far, observations on blue sharks in coastal waters have been documented only sporadically, and their spatio-temporal distribution and habitat use remain poorly understood (Mejuto et al., 2014; Bañón, Maño & Mucientes, 2016). Nevertheless, given that human occurrence is particularly high in coastal areas, the likelihood of shark sightings to be documented and shared through social media continues to increase significantly. Large-bodied sharks face significant risks in coastal areas because of a high exposure to anthropogenic impacts (Dulvy et al., 2014), thus understanding their behaviour in such areas is crucial for the development and implementation of management and conservation measures.

The present study investigates the occurrence of blue sharks in the coastal waters of the Italian Peninsula (Central Mediterranean) by collecting metadata from citizen scientists' contributions to social media platforms and digital grey literature over the decade 2011–2020. To address the current gap of scientific knowledge on blue shark ecology, this study aims to: (i) evaluate the spatio-temporal distribution, size, and sex segregation of blue sharks in coastal waters; (ii) identify areas of importance for the management of the species; (iii) provide an insight into the general public's attitudes to and perceptions of sharks, an essential requisite for conservation action; and (iv) validate the hypothesis that retroactively gathered opportunistic records and unsolicited observational data from citizen scientists and social media can be used to elucidate the habitat use and distribution of shark species in a poorly studied area.

2 | MATERIAL AND METHODS

2.1 | Study area

The study area covered the entire Italian coastline, which is approximately 7,468 km in length (Eurosion, 2004), and was confined to coastal waters, i.e. between the intertidal zone and an arbitrary cut-off set at approximately 100 m offshore.

2.2 | Data validation

Multimedia material (videos and photos) of blue sharks in Italian coastal waters over the past decade (2011–2020) was acquired from three popular social platforms, namely YouTube (https://www.youtube.com), Facebook (https://www.facebook.com), and Instagram (https://www.instagram.com), and from digital local and/or national newspapers and blogs. Searches were conducted using selected keywords (Sullivan, Robinson & Littnan, 2019; McDavitt & Kyne, 2020) in the Italian language. A structured Boolean search (AND, OR, +) was performed using the following keywords: (i) squalo, squalo azzurro, verdesca, costa, riva, spiaggia, spiaggiato/a, spiaggiamento, cattura, porto, Italia (shark, blue shark, blue shark, coast, shore, beach, stranded, stranding, by-catch, harbour, Italy) for YouTube; (ii) #verdesca (#blue shark) for Instagram; and (iii) verdesca + Facebook (blue shark + Facebook) for Google-based searches of Facebook posts. In addition, blue shark records were searched for directly on Facebook groups (Toivonen et al., 2019) dedicated to marine biodiversity, conservation, recreational diving and recreational fishery or specifically focused on elasmobranch sightings (Bargnesi, Lucrezi & Ferretti, 2020). Only publicly available posts were retrieved because posts by private accounts could not be seen and would not comply with our ethics protocol. A cross-check validation of social media returns was carried out through Boolean search on national online newspapers using the following Italian keywords sequence: verdesca + squalo Azzurro + riva + costa (shark + blue shark + shore + coast). Cross-check validation produced between 74 and 419 raw returns, depending on the addition of date and location to the keywords sequence. Following Toivonen et al. (2019), a visual examination of raw return contents was carried out to validate records and reject false positives with misleading titles, captions or comments, or with location not pertinent to the study area. A return was considered valid if the multimedia content included a geographic location, compliant with the settings criteria, and a clear view of each individual shark, allowing for species identification. To avoid any bias in the identification process, both authors examined each record independently.

2.3 | Dataset structure

From each record, the following information was collected: (i) date and location; (ii) type of record, which included four standard categories – sightings of blue sharks swimming in inshore waters, swimming in confined areas (tourist hotspots, commercial ports, and artificial and/or natural lagoons), stranding, and by-catch; (iii) number of individuals for each record; (iv) sex of each shark, determined, when possible, by visually examining the pelvic fins for the presence of claspers in males or their absence in females; (v) life stage, classed according to Leone et al. (2017) as juvenile, with an estimated total length (ETL) of ≤120 cm, subadult, with an ETL of 120–180 cm, and adult, with an ETL of >180 cm (within the juvenile life stage, a subcategory was used to identify smaller individuals with an ETL of <80 cm, based on TL < 81.7 cm (Megalofonou, Damalas & De Metrio, 2005a), considered to be young-of-the-year (YOY) (Ćetković et al., 2019; Nosal et al., 2019), and identified with an asterisk in Table S1); and (vi) biological and/or ecological observations, including pregnancy, wounds, presence of fishing gear, professional rescue operations, etc.

2.4 | Spatial analyses

Locations of blue shark encounters recorded between 2011 and 2020 were inputted to QGIS 3.4.4 (https://www.qgis.org). If a sighting did not include an accurate Global Positioning System (GPS) position, an approximated location was used. The location was established based on the information shared by social media users and/or in web articles. To provide a visual representation of sighting hotspots, a density raster was created from a vector layer using the HEATMAP plug-in, based on kernel density estimation. A quartic kernel shape was applied, and the density was weighted by the number of sharks for each record. The resulting raster represented values for the estimated number of individuals per km^2 that are likely to occur within each grid cell. Bathymetry grids were downloaded from The General Bathymetric Chart of the Oceans (GEBCO, https://www.gebco.net).

Once possible hotspots were determined, satellite-derived monthly estimates of sea surface temperature (SST) were extracted for January–December 2017–2020, comprising more than 60% of all records collected, to determine a proxy of mean monthly SST. Monthly mean SST (°C) was derived from the GlobCOLOUR Observation Program from the Moderate Resolution Imaging Spectroradiometer (MODIS) with a spatial grid resolution of 9 km × 9 km.

2.5 | Human perception analyses

To evaluate possible changes in human perception and reaction to sharks during the study period, the headlines of digital newspapers and video content of each shark record were codified following Sabatier & Huveneers (2018) and Sullivan, Robinson & Littnan (2019), respectively. Records of stranded and dead individuals were excluded from the human perception analyses. For each record, a minimum of two articles were randomly selected, when possible, for a total of 172 articles. The content of each media item (video or article title) was classified using three categories of perception/reaction: negative (fear, hostility, or pleasure from the death of a shark, and human actions to catch and/or kill the shark); neutral (indifference, with no action or comments); and positive (empathy for the condition of the shark, and willingness and action to help and/or release the shark) (Houston, Bruskotter & Fan, 2010; Sabatier & Huveneers, 2018) (Table S2).

2.6 | Statistical analyses

Statistical significance was tested at $P = 0.05$. Simple linear regression was used to analyse the relationship between the annual number of collected records and the number of Italian social media users (data were retrieved from WeAreSocial digital reports, https://wearesocial.com/it/). Pearson's chi-square test was performed to examine the null hypothesis of an equal sex ratio (1:1 male-to-female ratio) (Megalofonou, Damalas & De Metrio, 2009). A chi-square test of independence was used to assess variations in sex ratio by size class, and to determine whether there was a statistically significant association between record type (swimming inshore event, swimming in confined waters, by-catch, stranding) with size class and sex ratio.

Seasonal variation in the frequency of blue sharks by size class and record type was also investigated with a chi-square test of independence. Simple linear regression was used to determine the relationship between the mean number of monthly shark records and the monthly SST (°C), after a square root transformation for data normalization. Finally, linear regression trendlines were fitted to the data to determine any change in the frequency of positive, negative and neutral perceptions, as well as reactions over the sampling period. Statistical analysis was performed using JMP® 14 (SAS Institute, Cary, NC, USA).

3 | RESULTS

3.1 | Social media mining

Through social media data mining, a total of 146 records comprising 158 individual blue sharks in Italian coastal waters were recorded from 2011 to 2020. Blue shark records shared by web magazines significantly decreased over the sampling period (2011–2020; $R^2 = 0.59$, $n = 10$, $P = 0.0092$), whereas records via social media (Facebook and Instagram) significantly increased ($R^2 = 0.62$, $n = 10$, $P = 0.0065$) and records via YouTube did not show any significative positive or negative trend over time (2011–2020; $R^2 = 0.02$, $n = 10$, $P > 0.05$) (Figure 1).

The overall number of blue shark records collected using social media data mining increased over time (2011–2020; $R^2 = 0.86$, $n = 10$, $P = 0.0001$). A positive linear relationship was found between the annual number of records and the number of Italian mobile social media users in 2014–2020 ($R^2 = 0.65$, $n = 7$, $P = 0.0291$). Blue shark records increased significantly with the increase in the number of Italian mobile social media users.

3.2 | Sex ratio, size classes, and record type

Of the 63 specimens for which sex was determined, 17 were identified as male (27%) and 46 were identified as female (73%). Overall, the number of females was statistically greater than the number of males ($\chi^2 = 13.4$, $df = 1$, $P = 0.0003$).

A total of 56 blue sharks were classified as juveniles, 30 of which were YOY, and there were 52 subadults and 50 adults (Figure 2). For adults, the number of females was greater than the number of males ($\chi^2 = 6.53$, $df = 1$, $P = 0.01$), whereas this was not the case for subadults ($\chi^2 = 2.89$, $df = 1$, $P = 0.09$) and juveniles ($\chi^2 = 4.0$, $df = 1$, $P = 0.05$).

Of all records, 47.9% ($n = 70$) included events describing blue sharks approaching the shore, whereas 11.6% ($n = 17$) occurred in confined waters, 26% ($n = 38$) were stranding events, and 14.4% ($n = 21$) were by-catch. There were statistically significant differences in the size composition of blue sharks by record type ($\chi^2 = 22.37$, $df = 6$, $P = 0.001$), with significantly more juveniles involved in 'by-catch' events, subadults involved in 'swimming inshore' events, and adults involved in 'stranding' events (Figure 3). No significant variation was found in the overall sex ratio by record type ($\chi^2 = 1.64$, $df = 3$, $P = 0.65$).

3.3 | Temporal analyses

A monthly temporal distribution of blue sharks approaching Italian coastal waters over the sampling period is shown in Figure S1. During autumn and winter, the frequency of encounters was lowest (10.6 ± 6.0% and 10.9 ± 6.0%, respectively), whereas this was highest in spring (42.6 ± 15.5%) and summer (46.9 ± 16.1%) (Figure S2). However, as effort relating to social media posts could not be accounted for, no statistical analyses were carried out.

When analysing the seasonal distribution of blue sharks by size class, the chi-square test showed a significant difference among

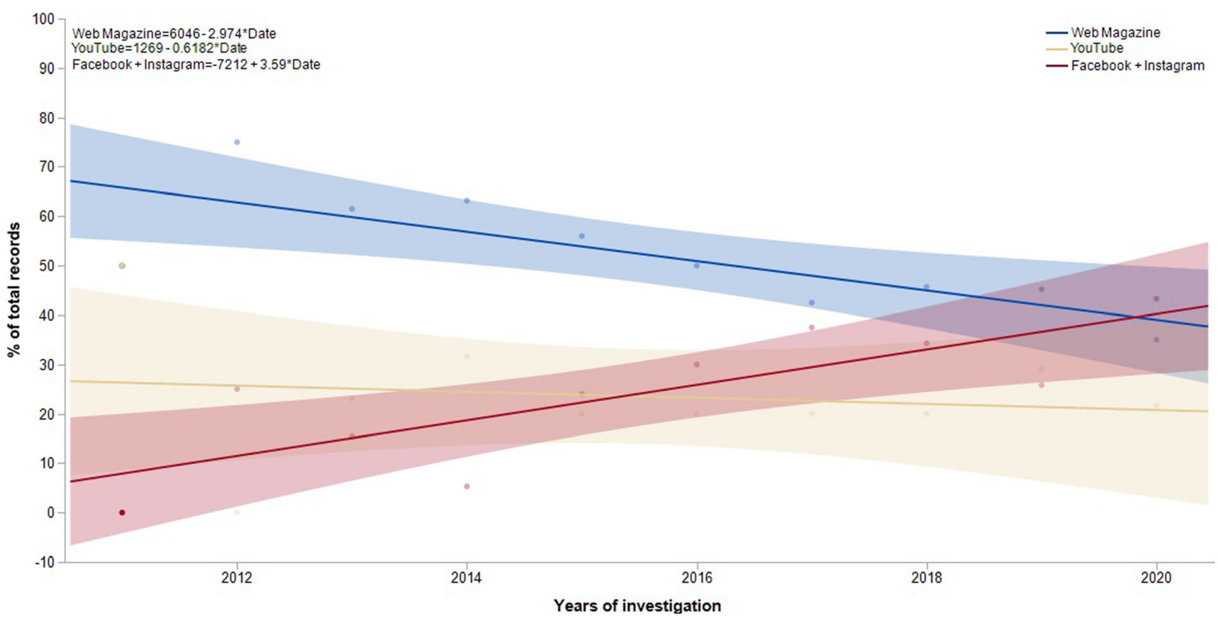

FIGURE 1 Temporal distribution of blue shark records collected from web magazine ($R^2 = 0.59$, $n = 10$, $P = 0.0092$), social media (Facebook and Instagram, $R^2 = 0.62$, $n = 10$, $P = 0.0065$), and YouTube ($R^2 = 0.02$, $n = 10$, $P > 0.05$) in 2011–2020

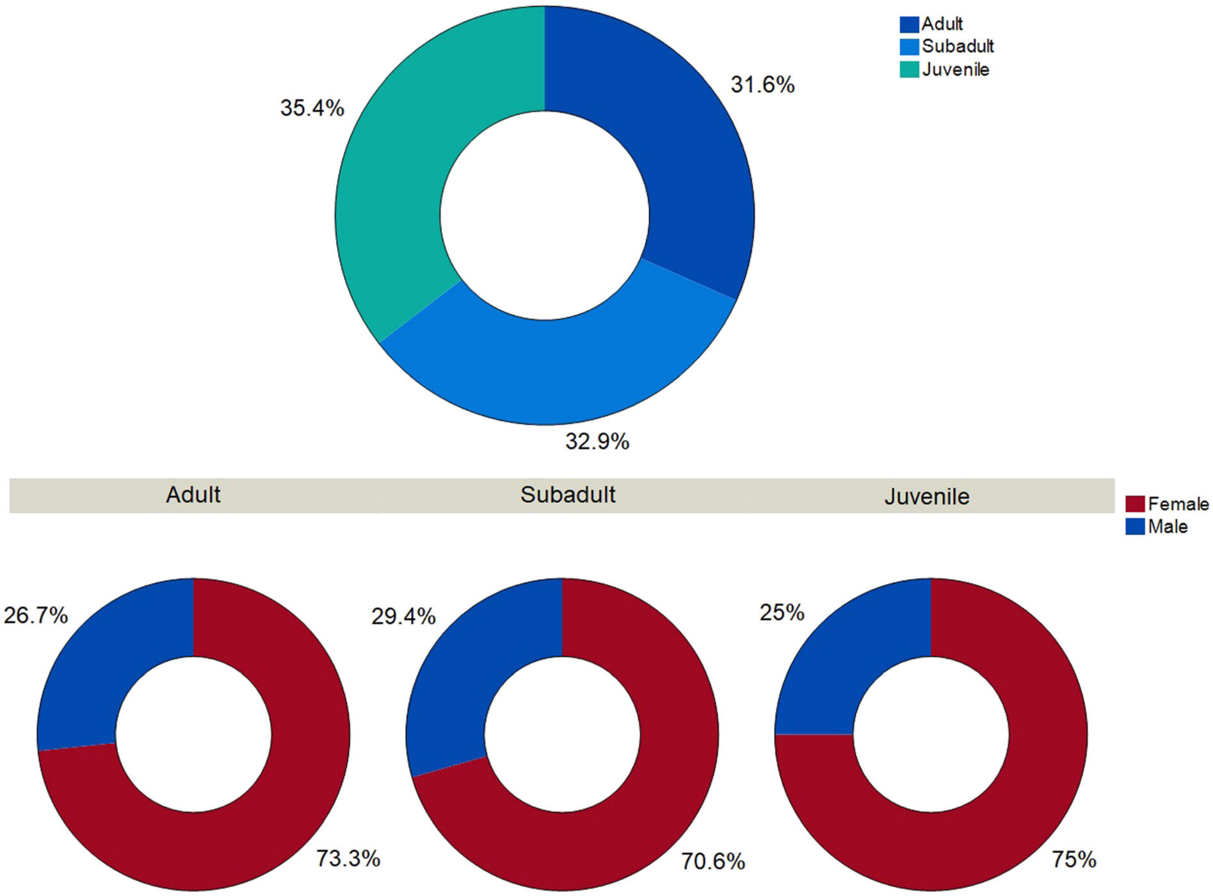

FIGURE 2 Size distribution of blue shark records ($n = 158$) and sex distribution by size class of blue sharks ($n = 63$)

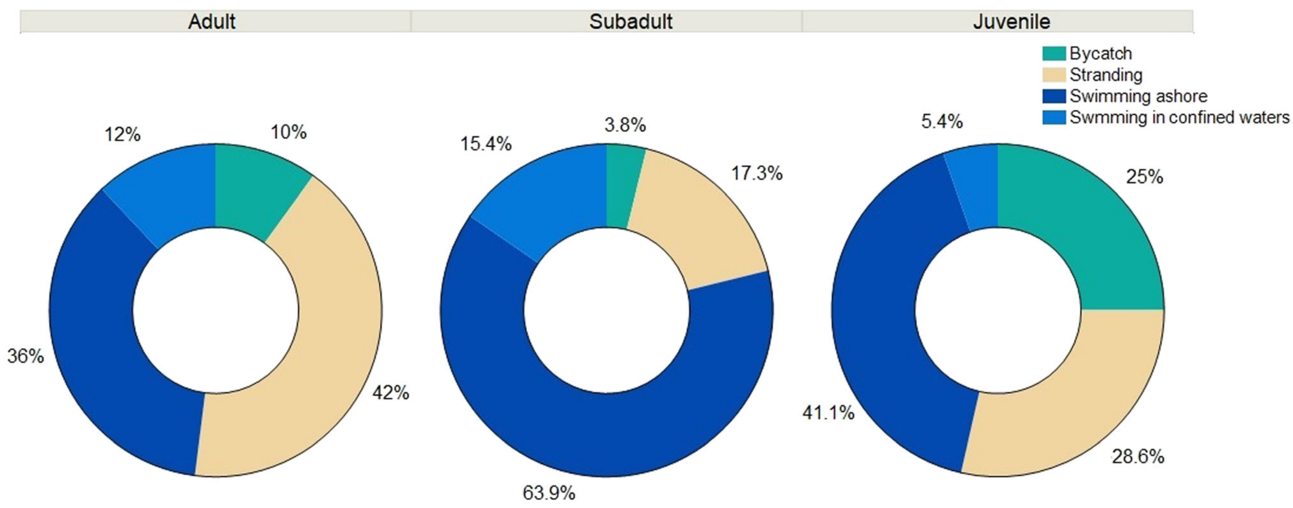

FIGURE 3 Type of records (by-catch, swimming inshore, swimming in confined waters, and stranding) per size class of blue sharks recorded from Italian coastal waters in 2011–2020

size classes by month ($\chi^2 = 42.62$, $df = 20$, $P = 0.0023$). Juveniles were not recorded in coastal habitats during December–March (Figure 4a). Their abundance increased from April to July, when they reached a peak in the monthly sightings (38.2%), and a significantly higher abundance compared with individuals from the other size classes (72.4%) (Figure 4a). From August to October, the abundance of juveniles declined from 18.2 to 3.6%. Subadults showed a similar increasing trend from January up to June, when they accounted for

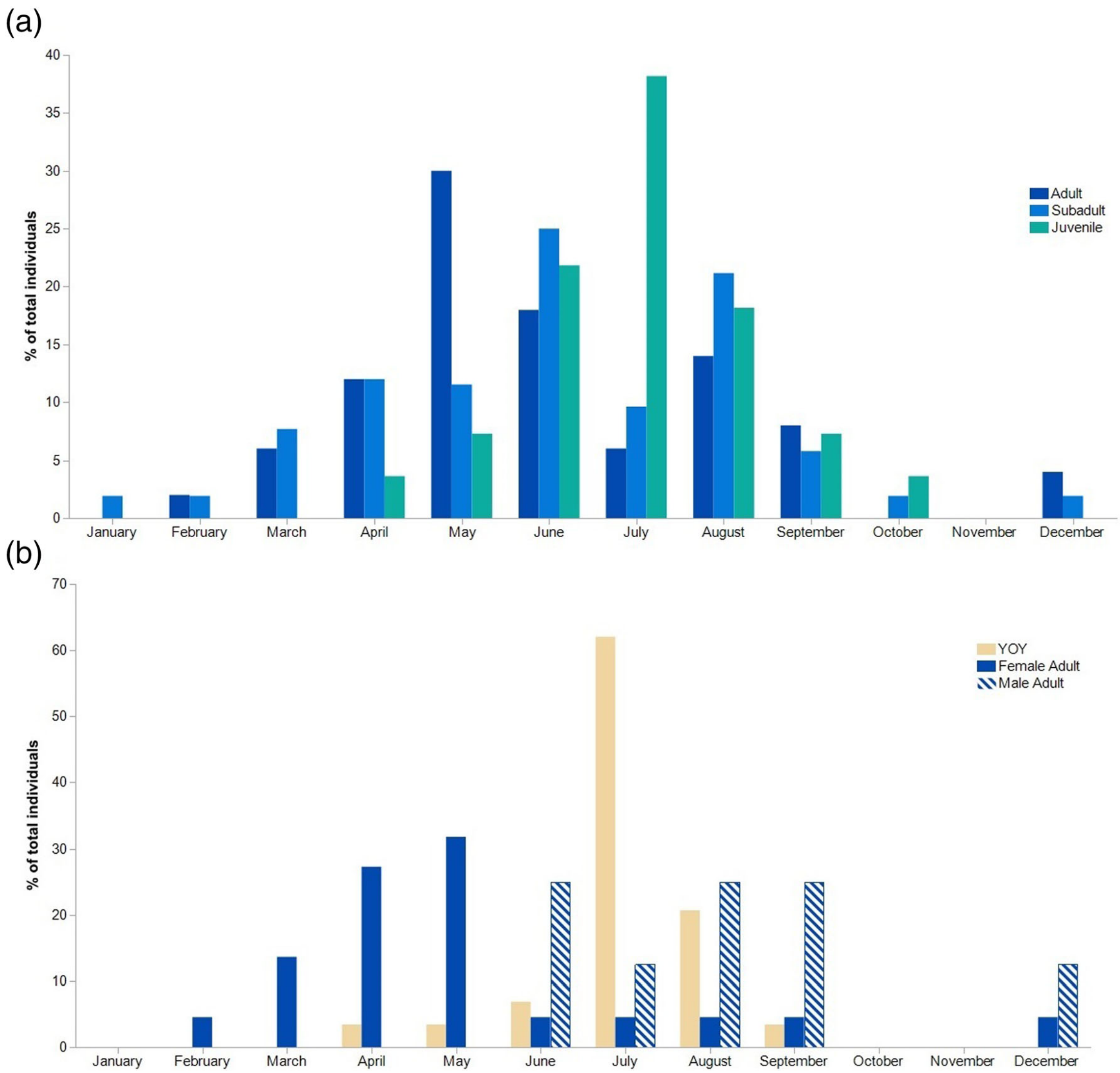

FIGURE 4 (a) Frequency of sightings by month and size class in 2011–2020 in Italian coastal waters. (b) Frequency of sightings by month of adults and young-of-the-year (YOY) in 2011–2020 in Italian coastal waters

25% of their total annual sightings, and then showed a decreasing trend from August to December (Figure 4a). Adult blue sharks approached coastal waters with an increasing trend from February to May, when they reached 30% of all yearly sightings, and accounted for 60% of all individuals recorded in May (Figure 4a). From June to December, the abundance of adults declined from 18 to 4%.

When focusing on possible reproductive activity, a significant difference was found in habitat use among YOY, male adults, and female adults ($\chi^2 = 49.31$, $df = 16$, $P < 0.0001$). Female adult sharks showed an increasing trend from February to May, when they reached a peak in frequency (87.5%) compared with both males and YOY (Figure 4b). The presence of YOY in shallow water was recorded from April to September, with an increasing trend up to July, when they reached a monthly peak in abundance (62.1%) and represented 90% of all sightings recorded in that month (Figure 4b). Adult males occurred in June–December and did not show any peak in abundance (Figure 4b).

Considering all types of events (stranding, by-catch, swimming in inshore waters, and swimming in confined waters), no significant monthly variation was found in the overall number of individuals in any group ($\chi^2 = 39.45$, $df = 30$, $P = 0.116$). No significant trend was found in the annual number of blue sharks in any group over 2011–2020 ($P > 0.05$). Stranding events showed a weak negative non-significant linear trend ($R^2 = 0.34$, $n = 10$, $P = 0.079$) (Figure S3).

3.4 | Spatial analyses

The heat map produced by combining all records collected between 2011 and 2020 indicated that the distribution of sharks was not evenly distributed throughout the survey area. Areas of high density were located along the Ionian Italian coastline and along the Calabrian coast in the Tyrrhenian Sea (Figure S4).

Juvenile blue sharks were mainly recorded in the south of Italy along the Ionian and Adriatic coasts of Puglia, Basilicata, and Calabria, with a hotspot located in the Gulf of Squillace (38°48′N, 16°37′E) (Figure 5a). Juveniles were also distributed along the Ligurian and Tuscany coasts, especially close to Piombino (42°55′N, 10°30′E). Subadult sharks displayed a similar spatial pattern, characterized by a wider distribution (Figure 5b). In the Tyrrhenian Sea, subadults ranged from Liguria (44°00′N, 8°10′E) north to the Lazio region (41°43′N, 12°17′E). Subadult sharks were also recorded from the north of Sardinia (40°55′N, 9°30′E), on the western side and Ionian coasts of Sicily (37°24′N, 15°05′E) (Figure 5b), along the Calabrian coast, and in the extreme northern Adriatic Sea (45°42′N, 13°39′E) (Figure 5b). Adult blue sharks were mainly distributed in the south of Sardinia (39°10′N, 9°06′E) and Lazio (41°43′N, 12°17′E), as well as along the coast of Ostia and around Sicily (Figure 5c). Two hotspots were recorded: in the Strait of Sicily (38°11′N, 15°35′E) and the Calabrian coast; and in the Gulf of Taranto (40°11′N, 16°47′E) (Figure 5c).

The YOY sharks were recorded mainly along the Ionian coastlines, with a hotspot extending from the Gulf of Taranto (40°12′N, 16°49′E) to the Gulf of Squillace (38°48′N, 16°37′E) (Figure 6a). Records of YOY were also collected along the Tyrrhenian coast (42°55′N, 10°31′E) (Figure 6a). Adult females were located within the Gulf of Taranto, partially overlapping with the YOY (Figure 6b), whereas adult males were distributed in the Strait of Sicily and along the Calabrian coast (Figure 6c).

When considering only the Ionian coastal waters of Puglia and Calabria, where 39.2% of blue shark records were documented, a significant positive linear relationship was found between the mean monthly SST and the monthly number of records. The number of blue sharks recorded in the Ionian coastal waters significantly increased with increasing SST ($R^2 = 0.38$, $n = 12$, $P = 0.0326$). The peak in blue shark encounters was recorded in July, with a mean SST of 26.1 °C (Figure S5). However, as effort relating to social media posts could not be accounted for, this result should be treated with a degree of caution.

3.5 | Human perceptions

Analyses of headlines from digital magazines ($n = 172$) over the sampling period showed that negative perceptions significantly

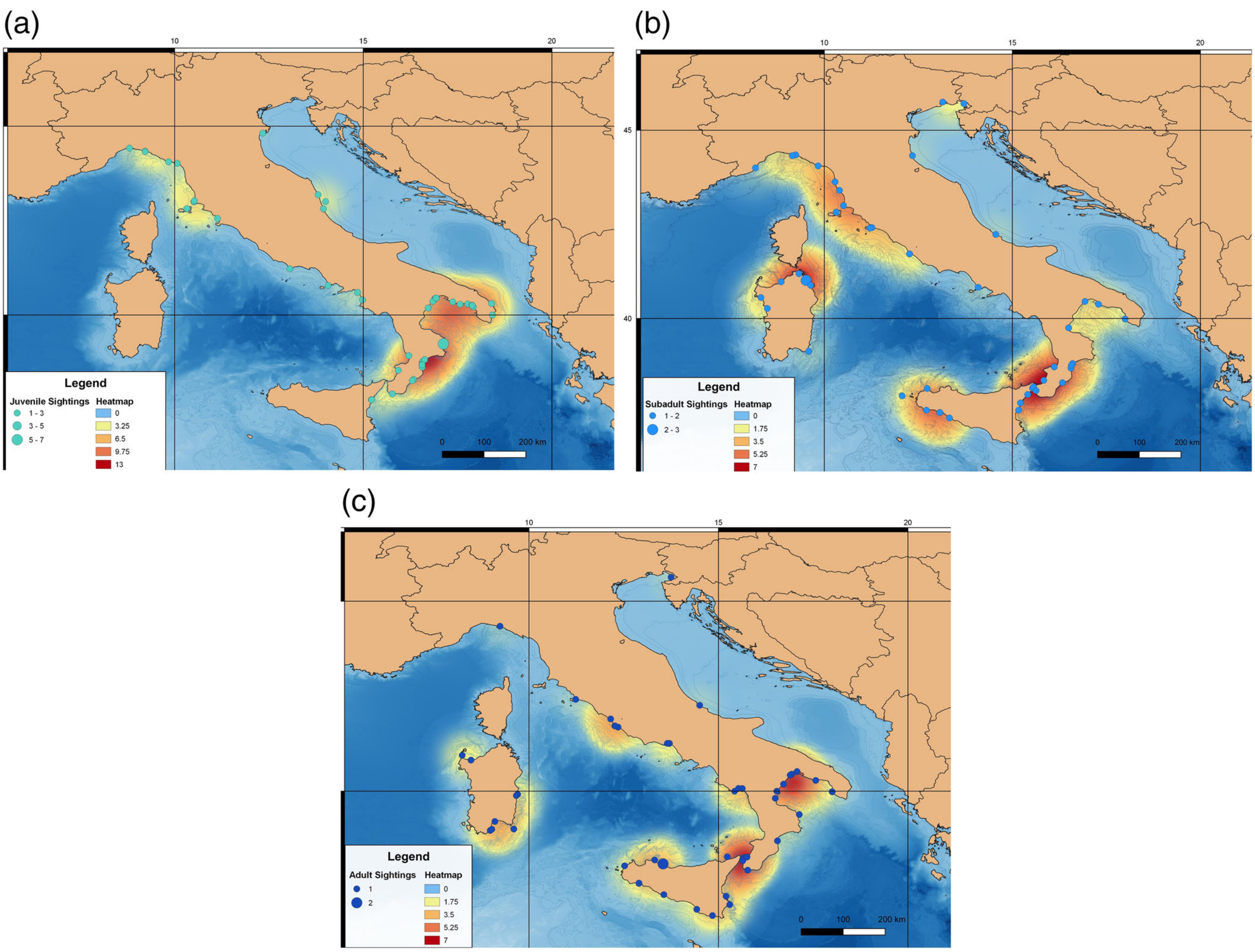

FIGURE 5 Heat map showing: (a) juvenile distribution ($n = 56$); (b) subadult distribution ($n = 52$); and (c) adult distribution ($n = 49$) along Italian coastal waters in 2011–2020

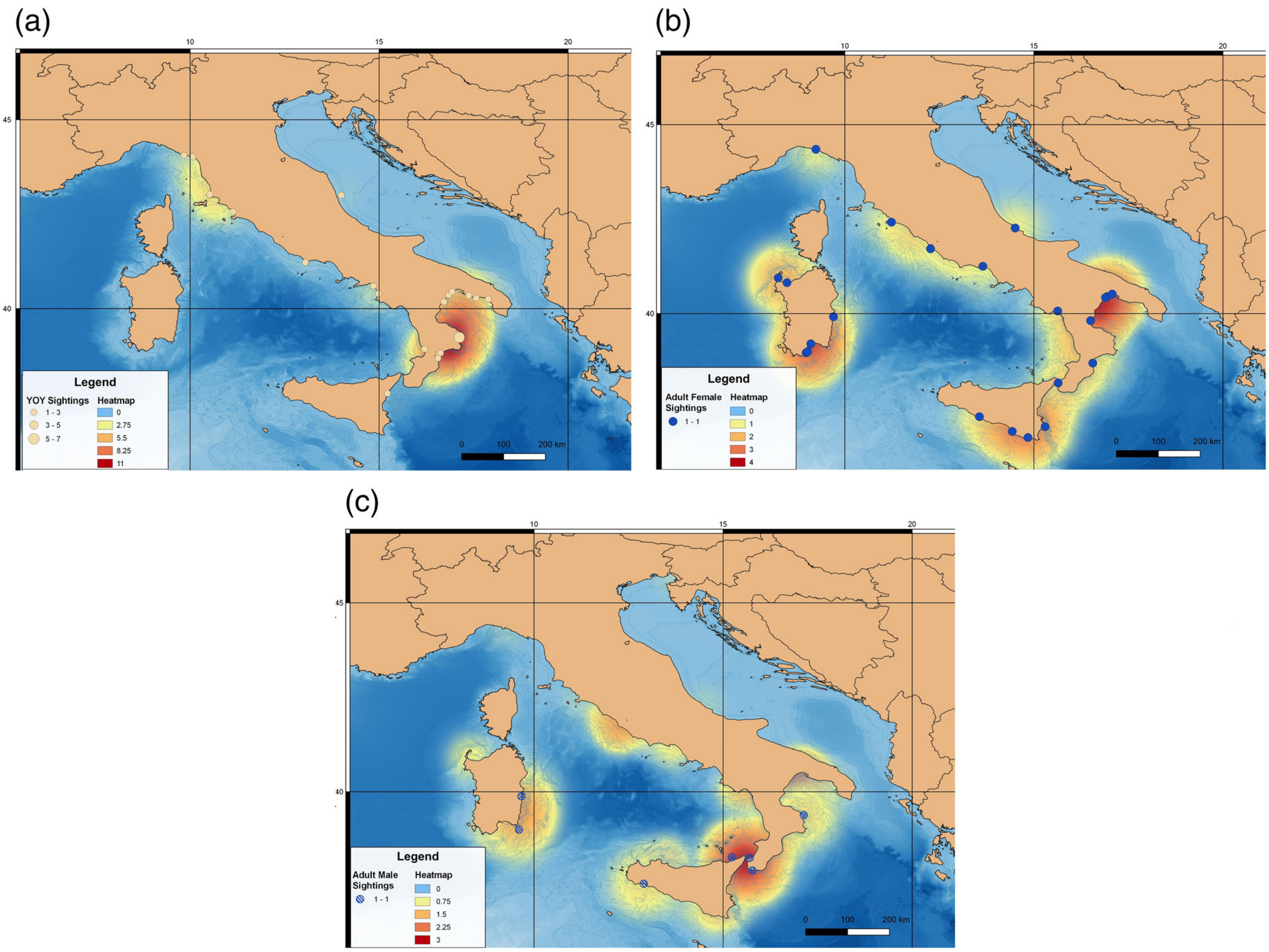

FIGURE 6 Heat map showing: (a) young-of-the-year (YOY; $n = 30$); (b) adult females ($n = 22$); and (c) adult males ($n = 7$) distribution along Italian coastal waters in 2011–2020

decreased over time ($R^2 = 0.59$, $n = 9$, $P = 0.0159$). In contrast, there was a non-significant increase in neutral perceptions over time ($R^2 = 0.31$, $n = 9$, $P > 0.05$), whereas positive perceptions did not change over time ($R^2 = 0.08$, $n = 9$, $P > 0.05$). A total of 72 videos were analysed to codify human reactions towards blue shark encounters throughout the study period. Although no statistical significance was found, negative reactions increased over time ($R^2 = 0.29$, $n = 9$, $P > 0.05$), positive reactions did not change over time ($R^2 = 0.001$, $n = 9$, $P > 0.05$), and neutral feelings decreased over time ($R^2 = 0.12$, $n = 9$, $P > 0.05$).

4 | DISCUSSION

4.1 | Social media mining

Despite an increasing number of studies on the ecology of the blue shark, most of the existing information comes from fisheries-dependent data, which are limited to areas and seasons where the fisheries operate, and are not carried out on a daily basis (Mejuto et al., 2014; Taklis, Giovos & Karamanlidis, 2020), leaving gaps in data at both temporal and spatial scales. This study showed that mining for social media content can be used as a valid, complementary, and useful approach to detect and elucidate the occurrence of a migratory and pelagic species such as the blue shark in scarcely investigated areas.

Sightings of blue sharks shared via Facebook and Instagram have increased steadily since 2010, so that social media platforms can now be considered as a primary source of opportunistic shark encounters data. Indeed, although the use of web magazines and blogs have represented an important online source of data on shark encounters in the early years of the decade, this is now declining. Moreover, the tight relationship between social media users and the number of shared records combined with the overall rapid increase of social media users worldwide suggests that social media platforms should be actively taken into account, as they might represent an ever-growing source of data on wildlife, useful for informing conservation actions (Daume & Galaz, 2016; Pace et al., 2019).

4.2 | Size, sex distribution, and record type

The distribution and habitat use of blue sharks is complex, as they display temporal and spatial segregation by sex and size, as well as broad-scale seasonal movements (Nakano & Stevens, 2008; Queiroz et al., 2012). Whereas the size and sex segregation of blue sharks has been largely described in oceanic zones (Mejuto & García-Cortés, 2005; Nakano & Stevens, 2008), little information is available from coastal areas, especially from the Mediterranean Sea (Mejuto et al., 2014; Rafrafi-Nouira et al., 2015). In this study, records of blue sharks in Italian coastal waters included individuals of all life stages, with similar size-class abundances. The sex ratio favoured females, similar to that reported from the western North Atlantic (Pratt, 1979), the eastern North Atlantic (Stevens, 1976; Henderson, Flannery & Dunne, 2001), and from Irish coastal waters, where the sex ratio was heavily biased towards females (Whelan, 1991). In contrast, findings based on longline fisheries data from the Mediterranean Sea, reported a sex ratio consistently in favour of males (Megalofonou, Damalas & De Metrio, 2009), which possibly reflects a spatial segregation of the sexes between pelagic versus coastal areas. It is worth noting, however, that because it was impossible to sex all of the individuals in the study, such conclusions should be treated with some caution.

With regards to the type of events involved in each record, juvenile blue sharks appeared to be most susceptible to by-catch. Seasonal recreational surf fishing is a common practice, which may involve shark catches (Lamberth, 2006; Kock et al., 2018). Although not primarily targeted, juveniles are more likely to end up as by-catch because of their small size compared with other size classes. Mortality rates following catch-and-release angling suggests that juvenile sharks are not immune to the impacts associated with recreational fishing (Danylchuk et al., 2014). Considering that sharks are important marine predators, it remains uncertain whether even low mortality rates for juveniles from catch-and-release recreational angling can affect population-level traits, with cascading effects through marine ecosystems (Danylchuk et al., 2014). Moreover, given that the incidence of catch-and-release angling of sharks is increasing (Danylchuk et al., 2014), more studies are needed to consider whether this angling effort is detrimental to promoting the conservation of this endangered species. Adult sharks appeared to be mostly affected by stranding events. These stranding events may be linked to reproductive activity or, as some individuals in this study had scars and wounds, could be attributable to fishing gear; it is possible that stress induced by fisheries interaction may result in shark stranding events (Williams et al., 2010). Fishes released alive after capture are often assumed to survive with minimal impacts; however, recent studies have shown that the direct effects of both targeted and incidental capture of sharks might result not only in premature parturition, but also in post-release mortality, even days after release (Gallagher et al., 2014; Adams et al., 2018). Retained fishing hooks, which are often underestimated, might also result in physical and physiological damage, with lethal consequences (Borucinska et al., 2002). Besides fishery interactions, natural causes cannot be excluded. In this study, three female blue sharks, including two that were pregnant, displayed evidence of fatal interactions with swordfish (*Xiphias gladius*). A similar report, involving an impaled pregnant blue shark, was described from the Western Mediterranean Sea (Penadés-Suay, Tomás & Aznar, 2017). Interactions between swordfish and blue sharks may be linked to both competition for food resources and predator–prey relationships (Romeo et al., 2020). Blue sharks are opportunistic feeders, whose diet includes swordfish (Markaida & Sosa-Nishizaki, 2010), and impalement might be the consequence of evasive behaviour by swordfish (Penadés-Suay, Tomás & Aznar, 2017; Romeo et al., 2020).

4.3 | Distribution and habitat use

Coastal areas are an important habitat for sharks (Knip, Heupel & Simpfendorfer, 2010), and serve a variety of ecosystem functions, including nursery and mating areas, feeding grounds, and refuges from predation risk (Speed et al., 2010; Heupel et al., 2019; Boldrocchi et al., 2020). This study revealed that blue sharks use coastal habitats for extended periods of time and consistently across years. However, although social media has the merit of being a cost-effective and easy way to explore retrospective citizen science observations, this approach also has a number of limitations (Mayer-Schönberger & Cukier, 2013). For instance, determining the temporal distribution of the overall number of blue sharks approaching the shore could not be properly assessed because of seasonal differences in the numbers of citizen science observers in coastal areas, with far more present in the summer months compared with other times of the year. Temporal, and possibly spatial, inconsistency in sighting effort between locations and seasons further highlights the potential limitations of citizen science-derived data. Therefore, although this study detected specific differences in the temporal distribution of blue sharks by sex and size, their interpretation must be undertaken with some caution. The temporal segregation by sex and size appears to be linked to reproductive activity, which is consistent with previous findings indicating that the Italian coastal waters are a breeding area for this species (Pomi, 1997; Garibaldi & Orsi Relini, 2000; Megalofonou, Damalas & De Metrio, 2009; Coelho et al., 2018; Maxwell et al., 2019). The reproduction of blue sharks is seasonal in most areas, with the breeding season occurring in late spring or summer (Pratt, 1979; Nakano, 1994). It is possible that the increasing number of adult females approaching the shore in spring could indicate parturition in coastal waters, as shown in several videos collected in this study (Table S1). This is also in accordance with findings reported from other areas (Nakano & Stevens, 2008; Mejuto et al., 2014), and with the increase of YOY sightings recorded in the following months, especially in July (Figure 4b). This hypothesis is supported by the spatial distribution analyses, which showed a partial overlap between adult female hotspots and those of YOY (Figure 6). In contrast to females, adult males did not show any seasonal peak. The presence of both adult males and subadult sharks in coastal waters might also indicate reproductive activity, as subadult females are sexually active throughout the year and are capable of storing sperm (Pratt, 1979; Nakano & Stevens, 2008).

This study showed that certain coastal areas, such as the Calabria region, including both Tyrrhenian and Ionian sides, as well as the Ionian coastline of Puglia were preferred coastal habitats for blue sharks, regardless of the life stage considered. These areas might be linked to suitable environmental conditions, including optimal SST ranges that favour a greater chance for the survival of newborns and/or high productivity that allow blue sharks to increase their body biomass in the shortest time possible (Mejuto et al., 2014). The number of sharks approaching Ionian coastal waters appeared to increase with the increase of SST up to July, when the SST reached a mean of approximately 26 °C. However, although the higher occurrence of blue sharks in certain months is likely to be driven by SST and habitat suitability, it is worth noting that the lack of information regarding effort for social media posts means that some caution should be retained so as to avoid over-interpreting this finding. Future quantitative research studies are needed to evaluate the blue shark habitat use in relation to environmental variations.

4.4 | Conservation

Veríssimo et al. (2017) and Bailleul et al. (2018) showed that blue shark populations display genetic homogeneity; therefore, any large impact at a regional scale might have serious consequences at a global scale. Shark protection and recovery is needed but requires *in situ* management actions. Reproductive areas have been considered an essential habitat for juveniles, whose protection is a vital factor in the conservation of the overall shark population (Bonfil, 1997; Cortés, 2002). Although the Mediterranean Sea has been assumed to be a breeding ground for the North Atlantic blue shark population, the protection of pelagic nursery areas has been considered unrealistic and pointless because of the overlap with fisheries fleets that would not respect *in situ* protection (Botsford, Castilla & Peterson, 1997; Baum et al., 2003; Bailleul et al., 2018). This study, however, showed that blue sharks regularly approach coastal waters, which appear to serve as important habitats at certain stages in the life history of this species, leading to new opportunities for the conservation of blue sharks. Indeed, the identification of key habitats in coastal waters, inaccessible to fisheries fleets, would allow for the planning of effective protected areas, or other forms of time–area closure, to increase the protection of this species. As shown in this study, social media mining can play a major role in data gathering, and its widespread use in the Mediterranean Sea would enable baseline information on the coastal habitat use of blue sharks in the whole basin to be collected. In this context, our results reinforce the need for a coordinated citizen science programme with the direct engagement of the general public to report sightings of blue sharks. This approach could enhance not only data collection but also community education. Addressing the gaps in knowledge on sharks is essential for sustainable conservation and management (Simpfendorfer et al., 2011). The portrayal of sharks as fearsome creatures in movies and in the media, with sensationalist headlines that amplify public fear, contribute to framing sharks negatively in the public perception (Friedrich, Jefferson & Glegg, 2014; Shiffman et al., 2020). The results presented here show that, although the negative perceptions of sharks have decreased over the last decade, giving way to a more neutral attitude, negative reactions to shark encounters remain widespread. Attitudes and knowledge towards wildlife are shaped by several factors, including personal experience, which have an important influence on environmental attitudes and pro-conservation behaviour (Miller, 2005; Bögeholz, 2006). Neff & Yang (2013) found that people living near areas frequented by sharks had positive attitudes towards them and were not negatively affected by incidental shark bites (Neff & Yang, 2013). However, when sharks are inaccessible to most of the public, negative preconceptions can spread among people, thereby limiting public support for shark conservation. In the context of raising awareness, the blue shark might represent a perfect case study to redress the knowledge gap about sharks and the misinformed perceptions of the public. Adult blue sharks, which reach a relatively large size, fall within the imagery of the 'frightening shark', but as a harmless species that regularly approaches coastal waters it has the potential to demonstrate that positive human–shark interactions can exist. With appropriate conservation initiatives, the blue shark might become an 'umbrella' species to reduce public fear against sharks and generate more positive attitudes. In this scenario, the use of social media represents a powerful tool not only as a source of data for scientists but also to deliver scientific information to the public and influence policy change. The use of social media platforms for shark conservation campaigns, in fact, have the potential to reach a huge audience and raise awareness, resulting in more appropriate pro-wildlife attitudes and reactions, and in more widespread citizen science, with a consequent increase in the monitoring activities of sharks when visiting coastal areas (Di Minin, Tenkanen & Toivonen, 2015).

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CONFLICT OF INTERESTS

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SUPPORTING INFORMATION

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

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