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Opportunities from citizen science for shark conservation, with a focus on the Mediterranean Sea

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Abstract
The Mediterranean Sea is a hotspot for shark conservation. A decline in large pelagic shark populations has been observed in this vast region over the last 50 years and a lack of data on the local population status of various species has been pointed out. Throughout history, the relation between people and sharks has been revolving around a mixture of mystery, fear, and attraction. Recently, however, a remunerative ecotourism industry has been growing in areas of shark aggregation globally. This growth has been accompanied by the establishment of a citizen science (CS) movement aimed to engage and recruit ecotourists in data collection for shark research. Several CS projects have generated interesting results in terms of scientific findings and public engagement. In the Mediterranean Sea, shark aggregations are not as relevant to support locally-focused CS actions on shark diving sites as in other parts of the world. However, a series of other initiatives are taking place and CS could offer an excellent opportunity for shark conservation in the Mediterranean Sea. The dramatic decline of shark populations shown in the region calls for alternative ways to collect data on species distributions and abundance. Obtaining such data to set proper conservation and management plans for sharks in the Mediterranean Sea will be possible if existing CS initiatives collaborate and coordinate, and CS is widely acknowledged and deployed as a valuable tool for public education, engagement, and scientific discovery. After providing an overview of multiple facets of the relationship between humans and sharks, we focus on the possibility of exploiting new technologies and attitudes toward sharks among some groups of ocean users to boost participatory research. CS is a great opportunity for shark science, especially for areas such as the Mediterranean Sea and for large pelagic sharks whose populations are highly impacted.

Keywords: *Crowdsourcing, image-based sightings, social networks, elasmobranchs, Facebook*

Introduction

Sharks are among the most threatened vertebrates in the ocean. Rapid and steep population depletions have been shown in several ocean regions (Dulvy et al. 2016), and the Mediterranean Sea has presented some of the most extreme population declines. Here, many species of large predatory sharks have declined by up to 96–99%, calling for urgent conservation measures (Ferretti et al. 2008). IUCN (International Union for Conservation of Nature) assessments indicated that bycatch, pollution, habitat loss and degradation, and human disturbance are the major threats affecting sharks in the Mediterranean Sea (Cavanagh & Gibson 2007; Bonanomi et al. 2017). These stressors combined with the slow population dynamics of most shark species (e.g. late maturity and low fecundity) are making the Mediterranean Sea one of the most dangerous places for sharks in the ocean (Cavanagh & Gibson 2007).

In the Mediterranean Sea, a few species of sharks are still fished to be commercially used. Examples include smooth-hounds (*Mustelus* spp.), catsharks (*Scyliorhinus* spp.), and dogfishes (*Squalus* spp.). Species that are directly targeted by fisheries such as the common smooth-hound (*Mustelus mustelus*) and the spiny dogfish

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(*Squalus achantias*) are listed as vulnerable and endangered respectively by the IUCN (Cavanagh & Gibson 2007). At the moment, there are no management measures in place for sharks in the region and some options (e.g. fishing closure in critical habitats of the northern Adriatic Sea) are urgently required to restore depleted populations (Bonanomi et al. 2018). Several other shark species, however, are part of fisheries' bycatch (Cavanagh & Gibson 2007). Bottom trawling is a widespread fishing activity in the Mediterranean Sea (Kroodsma et al. 2018) that produces abundant elasmobranch bycatch, especially demersal species, impacting their abundance, distribution and suitable habitats (Ferretti et al. 2013, 2016a). Among these species, angelsharks (*Squatina* spp.) have shown steep declines, and are now considered commercially extinct in areas where they were previously abundant and supporting dedicated fisheries (Ferretti et al. 2016a), such as the Adriatic Sea (Ferretti et al. 2013; Fortibuoni et al. 2016), the Marmara Sea (Kabasakal & Kabasakal 2014) and the Alboran Sea (Muñoz-Chapuli 1985). In the Mediterranean Sea, there are no fisheries that officially target pelagic sharks, which, nevertheless, form part of the bycatch of fisheries targeting tuna and swordfish with pelagic longlines, and small pelagic fishes with pelagic trawls (Fortuna et al. 2010). In longline fisheries, the predominant shark bycatch includes blue sharks (*Prionace glauca*), thresher sharks (*Alopias vulpinus*) and shortfin makos (*Isurus oxyrinchus*) (Megalofonou 2005). Various types of driftnet could intercept as bycatch species such as the blue shark, the thresher shark and the basking shark (*Cetorhinus maximus*) (Cavanagh & Gibson 2007). Large-scale drift netting, which is prohibited by European Union Member States, though still used illegally by EU and non-EU fishing nations, could affect a wide range of species (Camhi et al. 2009). Since sharks are top predators or high-level consumers (Cortés 1999), bycatch of these species not only affects distribution and abundance of sharks' populations but also the structure and function of marine communities (Ferretti et al. 2010).

To date, nearly 50 species of sharks have been recorded in the Mediterranean Sea, although the presence of some is now uncertain (Serena 2005). The 2016 IUCN Red List regional assessment of Mediterranean elasmobranchs includes 40 species of sharks for which the occurrence in the area has been verified (Table I; Dulvy et al. 2016). Among these, 12 are listed as Critically Endangered, six as Endangered and five as Vulnerable. Hence, 23 species (57% of the total) in the Mediterranean Sea are considered at risk of extinction. Of the remaining species, seven are either Near Threatened (2) or Least Concern (5).

Table I. IUCN assessments for Mediterranean shark species (Dulvy et al. 2016). CR = critically endangered; EN = endangered; VU = vulnerable; NT = near threatened; LC = least concern; DD = data deficient. Asterisks (*) mark species considered as threatened following IUCN criteria.

Species name (and family)	Common name	IUCN
Lamniformes		
Alopias vulpinus	Thresher shark	*EN
Alopias superciliosus	Bigeye thresher	*EN
Carcharias taurus	Sand tiger shark	*CR
Carcharodon carcharias	Great white shark	*CR
Cethorhinus maximus	Basking shark	*EN
Isurus oxyrinchus	Shortfin mako	*CR
Isurus paucus	Longfin mako	DD
Lamna nasus	Porbeagle shark	*CR
Odontaspis ferox	Smalltooth sand tiger	*CR
Hexanchiformes		
Hexanchus griseus	Bluntnose sixgill shark	LC
Hexanchus nakamurai	Bigeye sixgill shark	DD
Heptranchias perlo	Sharpnose sevengill shark	DD
Squaliformes		
Centroscymnus coelolepis	Portuguese dogfish	LC
Centrophorus granulosus	Gulper shark	*CR
Dalatias licha	Kitefin shark	*VU
Echinorhinus brucus	Bramble shark	*EN
Etmopterus spinax	Velvet belly lanternshark	LC
Oxynotus centrina	Angular roughshark	*CR
Somniosus rostratus	Little sleeper shark	DD
Squalus acanthias	Spiny dogfish	*EN
Squalus blainvillei	Longnose spurdog	DD
Squalus megalops	Shortnose spurdog	DD
Carcharhiniformes		
Carcharhinus altimus	Bignose shark	DD
Carcharhinus brachyurus	Bronze whaler shark	DD
Carcharhinus limbatus	Blacktip shark	DD
Carcharhinus obscurus	Dusky shark	DD
Carcharhinus plumbeus	Sandbar shark	*EN
Galeorhinus galeus	Tope shark	*VU
Galeus atlanticus	Atlantic catshark	NT
Galeus melastomus	Blackmouth catshark	LC
Mustelus asterias	Starry smoothhound	*VU
Mustelus mustelus	Smoothhound	*VU
Mustelus punctulatus	Blackspot smoothhound	*VU
Prionace glauca	Blue shark	*CR
Scyliorhinus canicula	Smallspotted catshark	LC
Scyliorhinus stellaris	Nursehound	NT
Sphyrna zygaena	Smooth hammerhead	*CR
Squatiniformes		
Squatina aculeata	Sawback angelshark	*CR
Squatina oculata	Smoothback angelshark	*CR
Squatina squatina	Angelshark	*CR

One of the most common and widespread problems in assessing the conservation status of and implementing important protection measures on sharks worldwide is the lack of data on the local status of shark populations. To date, ten species (25% of the total) are listed as data deficient in the Mediterranean Sea (Dulvy et al. 2016). Currently, sharks appear to be among the rarest and most elusive species in the Mediterranean Sea.

Scientific surveys and fisheries information are often incomplete, inadequate or absent on large sharks, especially those species that inhabit the high seas (Ferretti et al. 2008; Camhi et al. 2009). Hence new approaches are needed to obtain information on shark population abundance and distribution. Citizen science (CS), the involvement of non-professional volunteers in generating scientific knowledge (Bonney et al. 2009), is increasingly seen as a valuable option (Thiel et al. 2014). Globally, CS has already supported research on climate change, landscape ecology, rare and invasive species, disease, populations, communities and ecosystems (Dickinson et al. 2012). In the ecological sciences, CS has a long history of application, and in the last decades, information technology has facilitated the participation of a high number of people (Kobori et al. 2016). Although several CS initiatives for shark research are taking place worldwide both with a global and local scope (www.sharkpulse.org, www.eoceans.org), and focused on single species or broader taxonomic groups (Davies et al. 2013; Andrzejaczek et al. 2016; Araujo et al. 2017; Meyers et al. 2017; Norman et al. 2017), these initiatives are lagging in terms of scientific output in comparison with other similar projects on other groups of animals (Figure 1).

In the Mediterranean Sea, 33 CS initiatives on sharks have been launched since the 1980s (Table II). By reviewing these and other initiatives, here we build a case for the use of CS as an effective tool for shark monitoring and conservation in the Mediterranean Sea. We start with a description of the historical and contemporary interactions between humans and sharks; then discuss shark CS initiatives globally; describe the status and perspectives of shark CS in the Mediterranean Sea; and finally, summarize key elements of effective shark CS, providing advice for filling the gaps of data deficiency on shark species in the Mediterranean Sea.

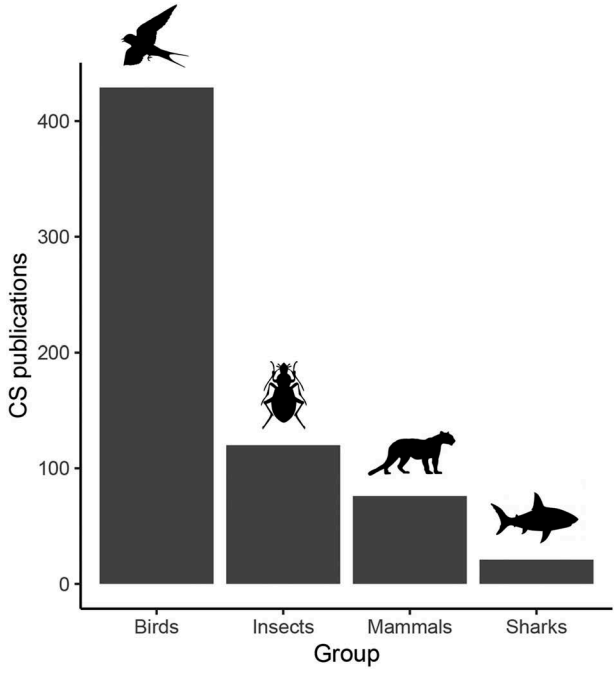

Figure 1. Number of scientific publications based on CS focusing on different groups of animals. Source: webofknowledge.com

Sharks and human society

Conservation is above all a matter of people, as laws and regulations are promulgated and managed by people, and ultimately affect people (Brown 2003). Shark CS is real people-centered action, and the relationship between humans and sharks strongly affects its future perspective. This relationship, however, is multifaceted and has a complex history. Historically, sharks have mainly been viewed negatively by the public. In ancient times, the sea was a source of myths and legends, especially in the Mediterranean area. Lamia was a shark-like children-eating sea monster in ancient Greece. Several Greek and Roman authors (e.g. Aristotele in "*Historia animalum*", Pliny the Elder in "*Naturalist Historia*", Oppians in "*Halieutica*") also reported evidence of interactions between people and big sharks, which were mostly seen as fearsome and dangerous creatures (Mojetta et al. 2018). Coastal fisheries were important activities of ancient Mediterranean populations, and evidence of the presence of sharks in the catches can be found in mosaics of roman archaeological sites (Mojetta et al. 2018). Later, the vivid imagination of the people of the Middle Ages (from 5th to 15th century) continued to populate the sea with fantastic beasts like the basilisk, tritons, and sirens (Van Duzer 2013). Often, negative connotations including fearsomeness, terror, and death, were ascribed to such creatures, thus instilling in people dread towards the sea (Gessner 1620; Aldovrandi 1642). Medieval people often observed strange animals stranded along the coasts, or while sailing, and misidentified sharks and other marine animals with those fantastic creatures. Those encounters were often reported with imaginative descriptions and drawings (Figure 2; Jonstonius 1649), and sometimes had religious connotations. An example is the story of a large sawfish (*Pristis pristis*) rostrum preserved as a relic in the Basilica del Carmine Maggiore (Naples, Italy). This is a rostrum of sawfish found stuck on a ship hull after the vessel was rescued from a storm in 1573. The sawfish blade became a relic as the fishers believed the animal prevented the ship from sinking during the storm, a sign of the Virgin Mary's intercession to the fishers who had prayed (Ferretti et al. 2016b).

Table II. Groups and initiatives related to shark CS in the Mediterranean Sea, including the country where initiatives are based and media types deployed to reach users and collect data (SN = social network; WP = web page; MA = mobile app).

n°	Name	Country	Media	Brief description
1	Angel Shark Project	Spain	SN, WP	Collection of data on angelsharks
2	Associaciò Lamna	Spain	SN, WP	Association that aims to promote research and conservation on sharks
3	Elasmocat	Spain		Collection of photos or recordings of sharks from Spain
4	Expedition Grands Requins Du Bassin Algerien	Algerie	SN	Sharks research project in Algeria
5	Ailerons	France	SN, WP	Association to protect Mediterranean sharks
6	A.P.E.C.S.	France	SN, WP	Association for the promotion of shark research and conservation
7	Corsica-Groupe de Recherche sur les Requins de Méditerranée	France	SN, WP	Research and conservation of sharks in Corse
8	Groupe Phocéen d'Etude des Requins	France	SN	Research on sharks and rays of the Mediterranean
9	Longitude 181	France	SN, WP	Shark conservation program, see *Program Requin*
10	Shark Citizen	France	SN, WP	Association promoting protection and public scientific dissemination on sharks
11	Centro Studi Squali	Italy	SN, WP	Italian research institute on sharks
12	Guppo Ricerca Italiano Squali Razze Chimere	Italy	SN, WP	Group of researchers, part of the Italian marine biology association (SIBM)
13	MEDLEM	Italy	-	Project with the aim to collect data on large Mediterranean sharks. See text for details
14	Medsharks	Italy	SN, WP	Association for research, conservation and public scientific dissemination on sharks
15	Operazione Squalo Elefante	Italy	SN	Focused on *C. maximus*
16	Progetto Stellaris	Italy	SN	Focused on *S. stellaris*
17	sharkPulse Italia	Italy	SN, WP, MA	Crowdsourcing platform collecting shark sightings from images
18	Tracking sharks for Conservation	Italy	SN, WP	Tagging program
19	WWF Italia	Italy	SN, WP	Shark conservation program, see *Safe Sharks*
20	Libyan sharks	Libya	SN	Focused on sightings collection in Libya
21	Sharklab Malta	Malta	SN, WP	Shark research center in Malta
22	Sharks and Rays in Albania*	Albania	SN	Focused on sightings collection in Albania
23	iSea	Greece	SN, WP, MA	Protection of aquatic ecosystems. Project on sharks
24	Sharks in Greece	Greece	SN, WP,	Focused on sightings' collection in Greece
25	Sharks and Rays in Gr and Cy*	Greece, Cyprus	SN	Focused on sightings' collection in Greece and Cyprus
26	Sharks and Rays in Turkey*	Turkey	SN	Focused on sightings' collection in Turkey
27	Sharks in Isreael*	Israel	SN	Focused on sightings' collection in Israel
28	CIESM Most Wanted Shark	-	WP	Focused on a list of rare sharks
29	Eastern Mediterranean Shark Club	-	SN	Focused on the eastern Mediterranean
30	Hai-Sichtungen Mittelmeer/Sharks of the Mediterranean*	-	SN	Group in German on sharks of the Mediterranean Sea
31	Reef Check Med	-	SN, WP	Generic CS marine project, but with data on sharks
32	Seawhatchers	-	WP	Generic CS marine project, but with data on sharks
33	The MECO project	-	SN, MA	Sightings' collection in the Mediterranean Sea. Related initiatives marked with asterisks (*)

Throughout history, sharks were not only perceived as mysterious and sometimes dangerous creatures but also as pests and therefore were the object of persecution. In the XIX century, the Austro-Hungarian government rewarded fishers in the North Adriatic for killing great white sharks (*Carcharodon carcharias*) seen as competitors of their local fisheries (Faber 1883).

In the last century, the image of sharks has remained mostly negative, with detrimental implications for their conservation (Gibbs & Warren 2015; McCagh et al. 2015; Neff 2015). Shark bite incidents are low-probability high-consequence incidents with a high value for news, and thus their coverage continues to prevail over more positive pro-shark stories (Sabatier & Huveneers 2018). In movies, sharks have often been depicted as villains (Neff 2015). These negative and sensationalized narratives have been high-grossing for the movie industry but have also misinformed the public about sharks' biology and human-shark interactions (Neff & Hueter 2013). For example, the use of expressions like "shark attack", "man-eater",

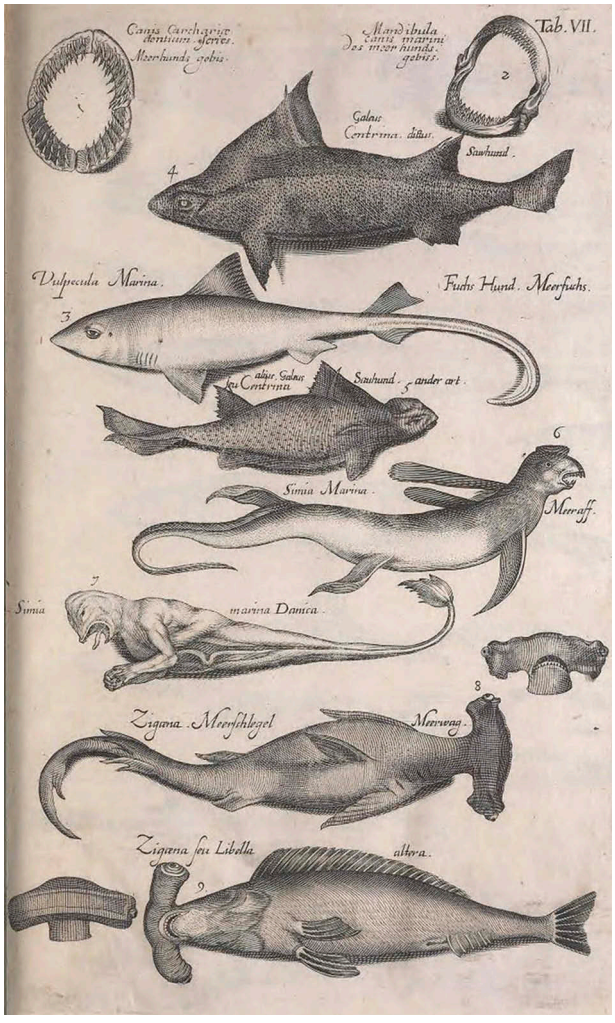

Figure 2. Drawings of sharks from the XVI century, including imaginative details such as of fantastic creatures (Jonstonius 1649).

"man-killer", "rogue", "monster" and "jaws", together with dramatized headlines and images in news reports and movies, have created a negative framing and provided sharks with a negative public image (Philpott 2002; Jacques 2010; Neff 2012, 2015; Muter et al. 2013; Neff & Hueter 2013; McCagh et al. 2015). Through an analysis of media content, Neff and Hueter (2013) concluded that using "shark attack" for describing different types of human-shark interactions has been highly inappropriate, as it has also been used for describing human-shark interactions without physical contacts with sharks like sightings and encounters. In Florida waters, out of 637 reported "shark attacks", only 11 represented fatal shark bites (Neff & Hueter 2013). Ultimately, misinformation and negative media framing of sharks and human-shark interactions are held responsible for inducing fear among the general public, thus reducing popular concern for sharks, government action to protect sharks, and proper conservation efforts for shark species. Governments often respond to reported "shark attacks" with knee-jerk policy responses (Neff & Hueter 2013). Examples include governments' decision to launch shark culling campaigns after a series of shark bite incidents which happened in 2001 in the southeastern United States during the so-called "Summer of the Shark", and after several episodes of shark bites in Western Australia between 2000 and 2014, and New South Whales in 2009 (Philpott 2002; Lynch et al. 2010; Crossley et al. 2014; Neff 2015). A recent study by Pepin-Neff and Wynter (2018) has demonstrated that perceptions that sharks intentionally "attack" people, which is a narrative typical of *Jaws* and other movies, are directly related to public fear of sharks and public support for lethal shark control policies. However, in recent times, sharks have become more popular, and there is an increasing trend in public concern for the conservation of sharks. Today, public awareness of the declining status of shark populations and of the threats sharks are facing seems to be high, at least among people with a clear interest in the marine environment (Friedrich et al. 2014).

Changing the tide on the public opinion of sharks: focus on some users of the sea

Based on the analysis of the status quo regarding contemporary shark framing and its potential effects on shark conservation, a change in the public perception of sharks is a critical step for any future conservation actions. In particular, a shift from a "protect human from shark" to a "protect shark from human" perspective is necessary in order to gain public support for shark conservation, which can influence positive political decisions (Simpfendorfer et al. 2011; Muter et al. 2013). In this regard, there is evidence of a reduction in the trend of shark fin sales partly due to campaigns that aim to increase the popular concern for sharks (Dell'Apa et al. 2014). In similar initiatives, special attention ought to be paid to any group of people who have a higher chance to interact with sharks and can play a significant role in shark population dynamics. Two such groups include fishers (recreational and commercial) and ecotourists.

Fishers are one of the main groups of people who interact with sharks. Recreational and commercial fishers often catch sharks, both as target and unintentional catch. Attitude towards shark conservation in fishers has different facets. In Florida, a study on an online anglers' forum reveals that some anglers are aware that fishing certain shark species is illegal, although they believe that this practice has no effect

on shark populations and therefore requires no regulation (Shiffman et al. 2017). However, another Florida-based study has demonstrated that personal knowledge of shark conservation issues positively influences anglers' willingness to act in favour of shark conservation, particularly of endangered species (Gallagher et al. 2015). In the Mediterranean Sea, sharks, including vulnerable species, have been catch and bycatch of many fisheries, with destructive consequences (Ferretti et al. 2008, 2010; Font & Lloret 2014). However, in several situations, fishers have been willing to contribute to scientific research with verbal and media-based information on their catches and sightings (Maynou et al. 2011; McClenachan et al. 2012; Fortibuoni et al. 2016).

Shark-based ecotourism can provide significant conservation and educational benefits (Kimmel 1999). It can have high economic value in several parts of the world, especially developing countries, and can be an essential resource of support to local communities, both in terms of job provision and in terms of conservation and education (Brunnschweiler 2010; Cisneros-Montemayor et al. 2013). Coastal communities in Fiji, Palau, Maldives and the Philippines have realized the more sustainable perspective of exploiting shark species as non-consumptive tourism products rather than consumptive fishing products (Pine et al. 2007; Brunnschweiler 2010; Vianna et al. 2011; Gallagher et al. 2015). Ecotourism, however, can also have negative impacts on species, on public safety, and on the management of activities in marine areas, for example, due to feeding, chumming and excessive disturbance (Apps et al. 2015; Bradley et al. 2017; Brunnschweiler et al. 2018; Huveneers et al. 2018). In Australia, cage diving has been observed to influence the swimming behavior of white sharks, possibly impairing their fitness levels (Huveneers et al. 2018). Concerns about public safety have also been raised concerning cage diving, but no evidence of an increase in shark bite incidents has been observed related to this activity (Meyer et al. 2009).

In the Mediterranean Sea, there are a few places where large pelagic sharks can be observed in the wild, and some shark diving activities have been reported from the area (Figure 3). A shark (Small-tooth sand tiger shark, *Odontaspis ferox*) diving hotspot is operating in Beirut, Lebanon, (Gallagher & Hammerschlag 2011). Seasonal aggregations of dusky sharks (*Carcharhinus obscurus*) and sandbar sharks (*Carcharhinus plumbeus*) can be seen in Hadera (Israel) near the Orot Rabin power plant (Barash et al. 2018) where shark-diving activities have recently developed (Zemah Shamir et al. 2019). Similarly, in Lampedusa (Italy), sandbar sharks are often observed from August to September in a diving site near the small rock of Lampione (www.pelagoslampedusa.it). Bluntnose sixgill sharks (*Hexanchus griseus*) are sometimes observed in night dives near deep wrecks (www.oloturiasub.it) in the Messina strait, Italy. Several underwater encounters with blue sharks (*Prionace glauca*) have occurred in Corse (France) (www.legallais.net), but no commercial diving activity has been reported from the area. Shark diving ecotourism has development capacity mainly in the eastern Mediterranean Sea, where relatively less

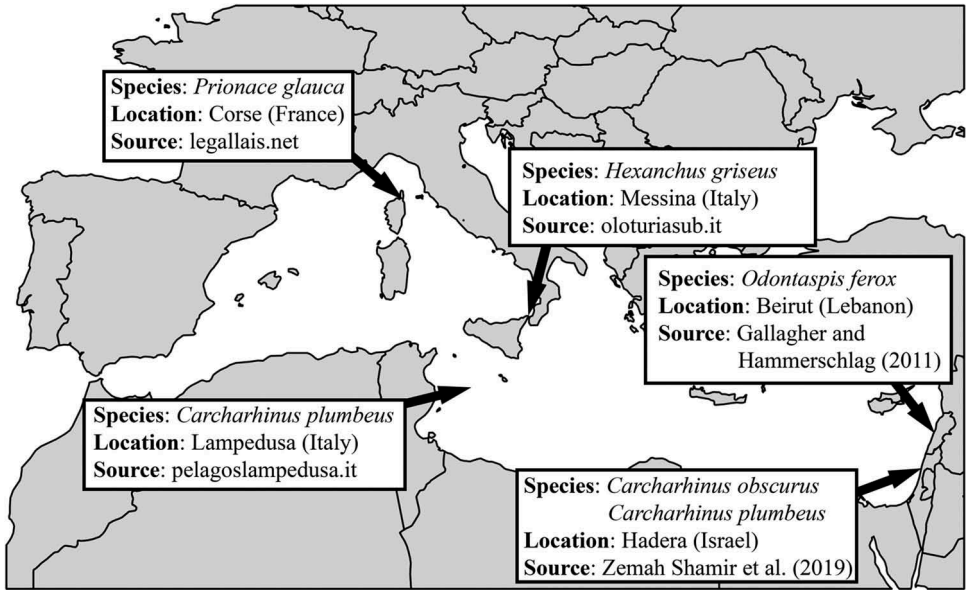

Figure 3. Diving spots in the Mediterranean Sea where shark encounters have been reported.

depleted populations of large coastal sharks still exist. Despite the economic potential of shark ecotourism in the region, the touristic intensity may cross the sustainability threshold, requiring proper control (Zemah Shamir et al. 2019).

Sharks and citizen science

Shark research has been steadily growing over the last decades. A scholarly search (webofknowledge.com) using the keyword "shark" as a topic has yielded a total of 13,066 publications. In the last five years, these publications have increased by 48% ($R^2 = 0.905$; Figure 4). Recently, laypeople have become increasingly committed to participating in the scientific process (Silvertown 2009). A scholarly search with the keyword "Citizen Science" has yielded a total of 7,563 publications. An increment of 135% has been observed over the last five years ($R^2 = 0.937$; Figure 4).

Despite the increasing trend in shark research, the recent expansion of CS has not resulted in a similar trend for shark CS. Among the published CS literature, only 20 scientific publications deal with sharks (Table III). Two of these have a global scope, and the remaining are more geographically restricted, focusing on specific regions of the world, particularly in the tropical areas of the Indo-Pacific Ocean, and the Eastern Pacific Ocean. The kind of scientific involvement citizens show in these publications is varied. For example, it can be based on observations and counts of shark individuals by scuba divers or on providing media material (e.g. photos, videos), information and knowledge on shark species by divers, fishers, and wildlife watchers. It can also be more opportunistic and based on the access and use of data accessible through databases. CS processes can result in the capture of data regarding a wide variety of shark species across geographies, through the contributions of various groups of ocean users. Trends of shark CS, however, show that this field is not being fully exploited. A large proportion (25%) of the published shark CS tends to revolve around photo identification of one species, the whale shark (*Rhincodon typus*), by scuba divers. Whale sharks are a preferred species in sharks CS initiatives because of their charisma, size, tame nature, ease of monitoring aggregations and identifying morphological characteristics, and value for the tourism industry (Andrzejaczek et al. 2016; Araujo et al. 2017; Norman et al. 2017). Among ocean users, scuba divers are the greatest contributors to shark CS; 60% of shark CS publications are from scuba divers. Scuba divers have successfully contributed to a variety of CS projects, including the study of endangered shark species such as the angelshark (*Squatina squatina*) for zoning (Meyers et al. 2017) and valid investigations on long-term distributions of the whitetip reef shark (*Triaenodon obesus*) and the grey reef shark (*Carcharhinus amblyrhynchos*) (Whitney et al. 2012; Vianna et al. 2014). Scuba divers are generally considered ideal citizen scientists, thanks to some key characteristics such as the ability to access and monitor underwater environments, a general commitment to protect the ecosystems scuba diving depends on, and a desire to grow and to learn (Lucrezi et al. 2018b).

Fishers also contribute to shark CS (eight papers published), while CS initiatives involving other ocean users tend to be scarce (two papers published). An

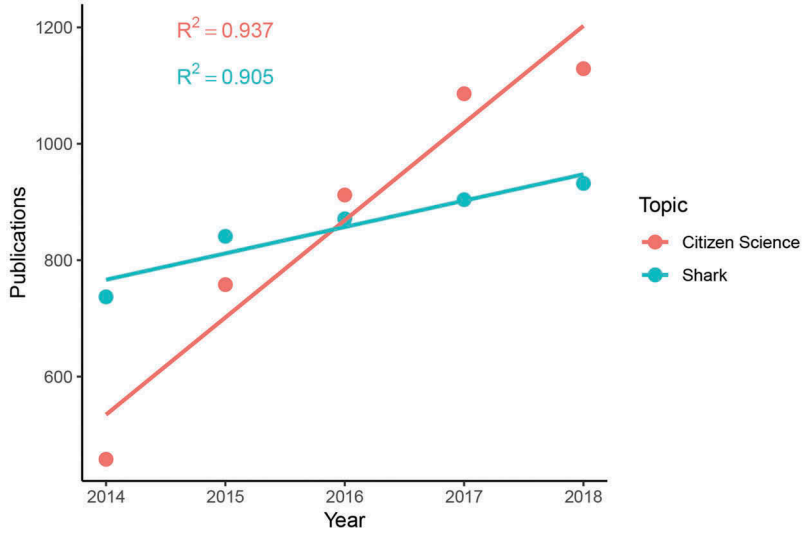

Figure 4. Trends of scientific publications on the topic "citizen science" and "shark" between 2014 and 2018.

Table III. List of contributions in shark CS studies by users including fishers and divers. Asterisks (*) mark contribution from the Mediterranean Sea.

n°	Species	Study Type	Area	User Type	Reference
1	*Cethorhinus maximus**	Distribution, size	Mediterranean Sea	Fishers, others	Mancusi et al. 2005
2	*Cethorhinus maximus*	Temporal dynamics	UK	Fishers, others	Witt et al. 2012
3	*Manta alfredi*	Temporal abundance	Lady Elliot Island (AUS)	Divers	Jaine et al. 2012
4	*Triaenodon obesus*	Habitat use	Hawaii	Divers	Whitney et al. 2012
5	*Rhincodon typus*	Mark-recapture	Maldives	Divers	Davies et al. 2013
6	*Carcharhinus amblyrhynchos*	CS data validation	Palau	Divers	Vianna et al. 2014
7	Several species	Temporal trends	Cocos Islands	Divers	White et al. 2015
8	*Rhincodon typus*	Connectivity	Indian Ocean	Divers	Andrzejaczek et al. 2016
9	*Rhincodon typus*	Demographics, distribution	Philippines	Divers	Araujo et al. 2017
10	*Prionace glauca**	Pollution report	Spain	Fishers	Colmenero et al. 2017
11	*Squatina squatina**	Sightings	Croatia	Fishers	Holcer & Lazar 2017
12	*Rhincodon typus*	Demographics, distribution	Global	Divers	
13	*Squatina squatina*	Demographics, distribution	Canary Islands	Divers	Meyers et al. 2017
14	Sharks in general	Evaluation of shark sanctuaries	Global	Divers	Ward-Paige & Worm 2017
15	*Hexanchus nakamurai**	Sighting	Albania	Fishers	Bakiu et al. 2018
16	*R. Rhinobatos; G. cemiculus**	Distribution	Aegean Sea	Fishers	Giovos et al. 2018
17	*Rhincodon typus*	Population dynamics, habitat use	Philippines	Divers	McCoy et al. 2018
18	*Oxynotus centrina**	Sighting	Malta	Fishers	Koehler 2018
19	Several species	Distribution	Thailand	Divers	Ward-Paige et al. 2018
20	*Squatina sp.**	Distribution	Mediterranean Sea	Fishers	Giovos et al. 2019

example pertains to the UK initiative of the Marine Conservation Society for monitoring the basking shark (*Cetorhinus maximus*). The initiative began in 1987 involving several kinds of ocean users (e.g. sailors, nature watchers, fishers) and led to the creation of an extensive database. This database later merged with other data collected by the Cornwall Wildlife Trust, making it possible to evaluate the seasonality of shark sightings and its correlation with climatic oscillations (Witt et al. 2012). Another interesting example of fishers involved in CS comes from an Italian monitoring program of bycatch on species of conservation concern: Tracking Sharks for Conservation (http://www.tshark.org/). Within this action, fishers located in different areas of the Adriatic Sea host observers on board in order to gather as much data as possible. Sharks and skates caught during fishing operations are marked by observers on board (tagging) and then, in agreement with the captain, released. Fishers are finally requested to record and communicate the recapture of a tagged specimen.

Global shark CS tends to be based on the collection of data from public and open-access databases. While these initiatives currently represent a minor proportion (2 published papers) of the overall published shark CS, they possess enormous potential to contribute to CS and more importantly, to shark science. One instance is sharkPulse (sharkpulse.org). Launched in 2014 by researchers at Stanford University, the initiative has the aim of creating a global database of image-based sightings to gain information on distributions and abundance of shark species. Through the use of mobile and web applications, data are collected from a variety of ocean users (e.g. scuba divers, sailors, surfers, fishers and beachgoers) and outsourced from other online initiatives and repositories. These data are then organized, validated and curated by shark experts and made available online (http://sharkpulse.org). To date, sharkPulse aggregates over 12,200 records of 367 species of elasmobranchs. Another instance is eOceans (www.eoceans.org), which aims to use CS to describe social, ecological, environmental, policy and economic trends of several marine animal populations (including sharks) and human use patterns. Primarily targeting divers through structured questionnaire surveys, eOceans recently tested the importance of shark sanctuaries for shark conservation, but also the importance of creating programs that can increase public understanding and awareness of sharks, while simultaneously providing an instrument to collect baseline information (Ward-Paige & Worm

2017). Intending to collect information on shark presence and diversity from egg cases stranded on beaches or found underwater, the Shark Trust launched in 2003 the Great Eggcase Hunt. It started from a beach in Devon, and now it is a global initiative with more than 200,000 records from 22 countries (www.sharktrust.org). iNaturalist is a more general CS initiative that also involves sharks (www.inaturalist.org). Launched in 2008 and currently owned by the California Academy of Science, iNaturalist is a social network entirely dedicated to CS and naturalists and focused on all biodiversity records across taxa. It counts over 10 million observations of species (around 6,000 are on sharks). These data are public and shared with the Global Biodiversity Information Facility (GBIF).

The perspective of shark citizen science in the Mediterranean Sea

The Mediterranean Sea is in great need of scientific efforts to establish the current trends in distribution and abundance of shark species, and CS has great potential to fulfil this role. There are some challenges to the effective implementation of shark CS in the region, such as the limited availability of shark-based ecotourism activities, and therefore of potential ecotourist volunteers in shark CS (Figure 3). Nevertheless, the Mediterranean Sea is one of the most densely populated regions on the planet and a tourism hot spot. Hence shark CS in the Mediterranean Sea can rely on a very large and diverse suite of users (such as sailors, fishers, and beachgoers) and data collection methods, resulting in initiatives holding educational and political weight. A web search of all the existing shark CS initiatives in the Mediterranean Sea has yielded a total of 33 ongoing projects (Table II). All initiatives are based on crowdsourcing of sightings and accounts on the occurrence of sharks. Nearly all initiatives use social networks to reach out to ocean users and recruit potential participants, although they have a dedicated webpage to showcase ongoing research activities and data already collected (Table II).

Only seven shark CS papers have been published for the Mediterranean Sea (Table III). This number underrepresents the actual CS effort towards shark research in the region (Table II). Reasons behind this mismatch are unclear but may include: the difficulty in managing large databases originated from crowdsourcing projects; the distrust of some scientists in the data generated through CS efforts; lack of time, people and resources for processing and publishing data, and no coordination between initiatives. These are problems generally associated with CS projects across disciplines and focal species (Lucrezi et al. 2018b). Two research papers cover the Mediterranean Sea as a whole: a study on the basking shark (*Cetorhinus maximus*), conducted with data originated from the "Large Elasmobranch Monitoring" program (MEDLEM) database (Mancusi et al. 2005), and a study on the presence and distribution of angelsharks (Chondrichthyes: Squatinidae; Giovos et al. 2019). Both studies mixed CS contribution with other research methods. MEDLEM is a survey on the presence of large elasmobranchs commenced in Italian waters in 1985 and later enlarged to other Mediterranean countries: major data have been provided by the collaboration of military authorities and research institutes, but the program also allows the contribution of professional and recreational fishers (Serena et al. 2014). The study on angelsharks was conducted mixing CS photographic reports with targeted interviews, fisheries data and bibliographic accounts (Giovos et al. 2019). The remaining five papers focus on more localized research primarily in the eastern Mediterranean Sea, with only one study in the western Mediterranean (Spain) (Table III). These papers highlight the crucial role of social networks for obtaining information on species' occurrence. Examples include records of individuals of the locally rare and endangered angelshark (*Squatina squatina*) in the North Adriatic Sea (Holcer & Lazar 2017); guitarfishes (Chondrichthyes: Rhinobatidae) in Greece (Giovos et al. 2018); angular rough shark (*Oxinotus centrina*) in Maltese waters (Koehler 2018); and bigeye sixgill shark (*Hexanchus nakamurai*), considered rare in the Mediterranean area and possibly misidentified with the bluntnose sixgill shark (*Hexanchus griseus*) (Bakiu et al. 2018). Last, published shark CS has contributed to the growing collection of evidence on the effects of plastic pollution in the Mediterranean Sea on juvenile blue sharks (Colmenero et al. 2017).

While most of the Mediterranean CS initiatives on sharks have yet to publish their data, their activities are already contributing significantly to our understanding of the distribution, abundance and behavior of shark species through their ongoing outreach effort. Videos are particularly useful. An example is a video showing the predation of a giant devil ray (*Mobula mobular*) by a shortfin mako in the Messina Strait, which was shared by several shark CS Facebook groups and projects. The video was made available online and shared by several local web news services (e.g. la Sicilia.it, letteraemme.it), often with misidentification of the shortfin mako with a great white shark (*Carcharodon carcharias*), belonging to the same family. Video shared by ocean users could also report interesting and uncommon

events: a stranded pregnant blue shark female was filmed giving birth to near 50 pups in Villapiana (Italy), and the video was published and shared online (gazzettadelsud.it).

Fifty species of sharks occur in the Mediterranean Sea, and 57% are endangered according to the IUCN. However, only ten have been the focus of investigations using CS approaches. These investigations had limited geographical scope, focusing mostly on local rather than regional scales (Table III). Local CS projects can be useful in identifying rare and uncommon species as they may have a more intense and effective focus in a given area. However, large CS networks are necessary in order to reach a consistent number of observations, as it happens for example on reef CS, where Reef Check (https://reefcheck.org) acts as aggregator of several regional and local initiatives creating a global network of local projects and succeeding in effectively creating a global snapshot on the status of tropical and temperate reefs. In order to properly analyze and assess the regional status of sharks in the Mediterranean Sea, networks are desirable since they would promote connections between various existing initiatives and between stakeholders. Global networks of local initiatives can breach linguistic barriers and thus reach more ocean users. This is an aspect particularly important in the Mediterranean Sea as the region has 22 coastal nations and 12 languages. It is also an aspect that the sharkPulse initiative is implementing through the creation of national focal points.

CS networks for shark science in the Mediterranean Sea would greatly benefit from the use of new technologies, which offer the opportunity to share detailed information quickly and effectively. Smartphones and social networks are widespread. There are 6.5 billion smartphone users around the world (Orams & Lück 2014), and the use of social networks has been rapidly increasing in the last decade. As shown in Figure 5, in coastal Mediterranean countries, the percentage of Facebook users goes between 40% and 68% of the population with a total of 250 million users (data from napoleoncat.com). This pattern reveals how new technologies are uniformly spread among people around the Mediterranean Sea, offering a tremendous opportunity for CS in the region. The use of new technologies, however, needs to be accompanied by connections with experts who can validate the records provided by volunteers. The previously mentioned case of the misidentified shortfin mako with a great white shark is just one instance of imprecise or incorrect shark sightings

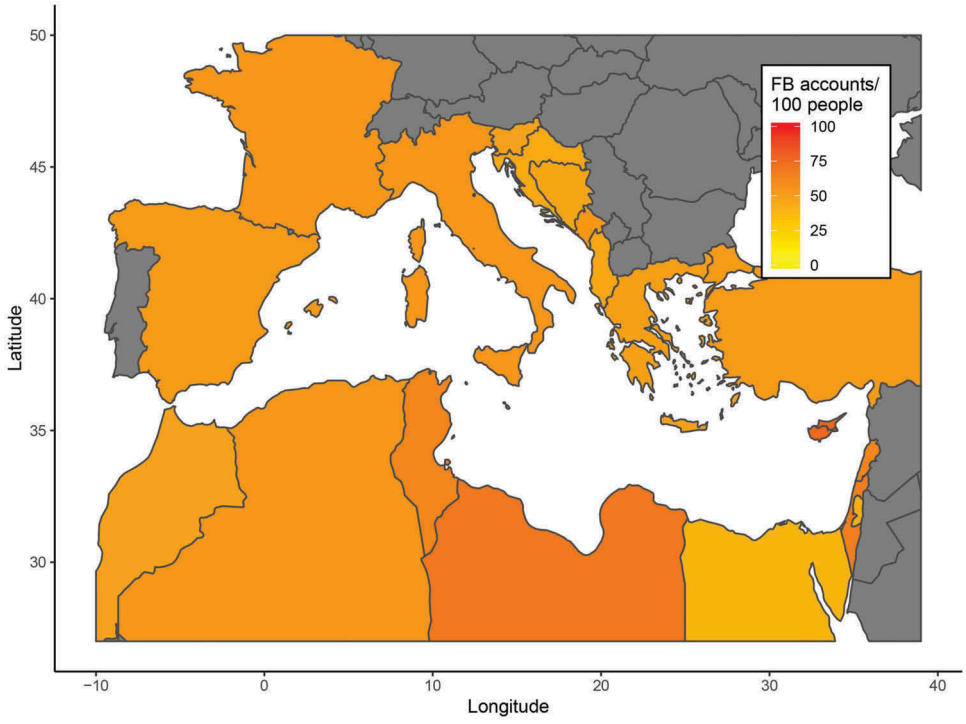

Figure 5. Pattern of Facebook accounts in the countries facing the Mediterranean Sea (source napoleoncat.com), showing that public access to new technology is uniform in the area, with good opportunities for CS to reach users.

often shared online. Hence it is extremely important that the surge of new observations becoming available through social networks and other online platforms are carefully validated by scientists before being used for research and management.

CS networks for shark research in the Mediterranean Sea can become more effective when educational efforts accompany them. Although shark-based ecotourism in the area is uncommon, marine tourism offers ample opportunities for interpretation and education on threats affecting shark populations, from overfishing to climate change and pollution. The Ocean Literacy movement, which originated in the United States, characterizes an important component of public education on the connection between humans and the ocean, including descriptions of marine food webs and predator-prey interactions (Steel et al. 2005). Similarly, institutions including museums and aquaria would represent important partners supporting CS projects as they play a critical role in public education and stimulate the public's interest in the ocean (Lucrezi et al. 2018a). Aquaria also allow the public to gain high-impact firsthand knowledge of shark biology and ecology, through the direct observation of individuals and interpretation programs run by staff and researchers (Friedrich et al. 2014; Grassmann et al. 2017; Pepin-Neff & Wynter 2018). Ultimately, museums and aquaria are capable of casting a wide promotional net for several shark CS projects. For example, iNaturalist is managed by the California Academy of Science. Similarly, the Monterey Bay Aquarium in California, USA, is collaborating in the sharkPulse initiative.

While there are cases of successful CS promotion and management by museums and aquaria, the number of institutes of this kind engaging in CS remains limited globally. Let alone in the Mediterranean Sea, the Cattolica Aquarium, in Italy, actively collaborates with sharkPulse and is currently the only Mediterranean aquarium involved in a shark CS initiative (Bargnesi et al. 2018). Europe counts a total of 107 aquaria having shark exhibitions, and 12 of them lie along the coasts of the Mediterranean Sea. These structures have been playing a crucial role in shark conservation, through the improvement of husbandries and captive management techniques, reaching the important goal of captive reproduction for several endangered species (Janse et al. 2017). A future commitment to CS by these structures would increase the opportunities of ocean education for visitors, enable visitors to participate in shark CS actively, and ultimately increase the capacity of these initiatives in thus gathering information on focal shark species.

Conclusion

The relationship between humans and sharks has been historically characterized by a mixture of mystery, fear, and respect. Especially in the last few decades, the attitude of people toward sharks changed from having a negative connotation to a strong attraction, fascination and awareness of their conservation status as probably never happened before. Sharks have become more important in management and conservation agendas, and this has produced a beneficial effect on the attitude of people toward these animals. This attraction offers an opportunity to engage citizens in shark science through CS, especially to counteract the negative effects that human activities are having on shark species and populations. Overall, shark CS has successfully gathered important data for the mapping of distributions and abundance of shark species at several locations. In the Mediterranean Sea, despite the limited capacity of shark-based ecotourism, several shark CS projects are undergoing, thanks to the coordination of associations and nongovernmental organizations, and the contributions of ocean users. These projects can potentially aggregate a large amount of data on the occurrence and distribution of endangered and extremely rare species, which require research and protection. New technologies such as mobile phone apps, together with social network initiatives, are fundamental to reach and recruit a large number of people and create a large, diverse CS community, including both regular and occasional ocean users. Although multiple CS initiatives for shark research are ongoing in the Mediterranean Sea, coordination, networking and collaboration are needed for effective data collection, and for informing spatial and temporal analysis of shark species' distribution and abundance. These elements can ensure that useful and up to date data are provided to decision-makers for developing effective conservation measures for threatened shark species. CS projects can also stimulate public awareness of marine issues and active participation in shark conservation. Several institutions can be involved in this process and, among all, aquaria are the best candidates, considering their role in connecting people and the ocean through the direct observation of species and other experiential learning programs. Networking and new technologies are key for the future of CS (Newman et al. 2012), and this is particularly true for the Mediterranean Sea, where CS efforts of scientists, institutions, communities, organizations, and volunteers, are not yet efficiently coordinated and integrated for the common goal of promoting effective shark conservation measures.

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Geolocation information

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