Local Ecological Knowledge and fishery data provides important information on the distribution and seasonal dynamic of Critically Endangered Angel sharks in Corsica (Mediterranean Sea, France).

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Highlights

- New stronghold identified for Angelsharks (*Squatina squatina*) in Corsica
- Corsica is identified as a presence area for Sawback Angelsharks (*Squatina aculeata)*
- Angelsharks aggregate in late winter and early spring on the east coast of the island
- Three areas are described as potential nursery on the north and east coasts

Abstract

The Mediterranean Sea is experiencing an important decline in shark, ray and chimaera populations. It is home to some of the most threatened families of sharks and rays, including angel sharks. Three species are present in the basin (*Squatina squatina*, *Squatina oculata* and *Squatina aculeata*) and all of them are classified as Critically Endangered by the IUCN Red List of Threatened Species. *Squatina squatina* was commonly thought to be extinct from the Northwestern Mediterranean basin, but in Corsica Island where the individuals are still reported. To fill the knowledge gaps regarding the distribution and seasonal dynamics of angel sharks in Corsica, we carried out a local-ecological-knowledge (LEK) survey with professional fishers accidently catching angel sharks and analysed long-term series of MEDITS and small-scale-fisheries (SSF) data. The study confirmed the year-round residency of *Squatina squatina* and the occasional presence of *Squatina aculeata* in Corsica. LEK data suggests that *Squatina oculata* is also captured, but additional proof is required to certify its occurrence in Corsica. The distribution of *S. squatina* bycatch suggest that the species is present from the Désert de l'Agriate to the Bonifacio Strait Nature Reserve and is particularly abundant on the east coast of the island. SSF and LEK data indicate that nursery areas could be also present on the eastern part of the island, but a field-based study is required to confirm this information. Overall, this study identified a new stronghold for the Angelshark (*Squatina squatina*) and provides first insights of the spatio-temporal dynamics in the coastal waters of Corsica. Moreover, Corsica may also be an important hotspot for the Sawback Angelshark (*Squatina aculeata*).

Keywords: Local Ecological Knowledge; fisheries; Angel shark; Mediterranean Sea

1 Introduction

Chondrichthyan species – including sharks, rays and chimaeras – are increasingly threatened worldwide. The proportion of threatened species, according to International Union for the Conservation of Nature (IUCN) Red List criteria, has increased from one fourth to one third between 2014 and 2021, primarily due to overexploitation through targeted fisheries and bycatch (Dulvy et al., 2021, 2014). The Mediterranean Sea sits amongst the regions experiencing the highest risks of threat and serious shark and ray populations depletion, including regional extinctions (Walls and Dulvy, 2021). In this region 65% of sharks, rays and chimaeras assessed by the IUCN, are threatened with extinction (Walls and Dulvy, 2021). Among them, the family of Squatinidae is one of the two most threatened family of sharks, with the Rhinobatidae (Dulvy et al., 2016).

Angel sharks are dorso-ventrally flattened, benthic sharks that mostly inhabit sandy and muddy substrates but can also be found on seagrass and reefs (Ellis et al., 2021b; Lapinski and Giovos, 2019; Mead et al., 2023; Meyers et al., 2017). Estuaries and bays are also important habitats for the presence of Angelsharks (*Squatina squatina*) (Hiddink et al., 2019; Mead et al., 2023) and other species of Squatinidae (Molen et al., 1998; Shelmerdine and Cliff, 2006) providing a shelter for resting or nursery areas (Ellis et al., 2021b). They appear to have a long gestation period that can last from eight to ten months and a low fertility rate (between 1 to 25 individuals per litter, depending on the species; Ellis et al., 2021). The combination of slow growth and late sexual maturity – indicated by males reaching maturity at a minimum size of 99.9 centimetres and females at 102.8 centimetres (Ellis et al., 2021; Osaer et al., 2015) – extends the time required for population renewal. To date, twenty-four species make up the Squatinidae family, found worldwide, mostly on the continental shelf in warm temperate to tropical waters (Ellis et al., 2021; Gordon, 2022), but only three of them occur in the Mediterranean Sea (Gordon et al., 2017). All three species – the Angelshark (*Squatina squatina;* Linnaeus, 1758), the Sawback Angelshark (*Squatina aculeata;* Cuvier, 1829) and the Smoothback Angelshark (*Squatina oculata;* Bonaparte, 1840) – encountered in the basin are listed "Critically Endangered" by the IUCN Red List of Threatened Species (Ferretti et al., 2016; Ferretti et al., 2016; Soldo and Bariche, 2016). Past and present overexploitation from demersal fisheries, mostly from bottom-trawling, have caused a steep decline in angel shark populations and caused local extinction from their original range (Bom et al., 2020; Gordon et al., 2017; Hiddink et al., 2019; Lawson et al., 2020).

Historical and present fisheries data can provide valuable information on past and present distribution of a species as well as trends on the evolution of catch of commercially abundant species (Ramírez-Amaro et al., 2020), such as angel sharks in the 20th century . They were mostly fished for their flesh, and dedicated fishing gears were used in the Mediterranean Sea to target the species in many different areas such as Balearic islands ("Escatera"; Morey et al., 2006), Corsica ("Squadrara" and "Bistinara"; Miniconi, 2008), Croatia ("Sklatara"; Bakiu *et al.*, 2023) or Italy ("Squaenera"; Fortibuoni et al., 2016). All three angel shark species occurring in the Mediterranean are strictly prohibited to fishing in the European Union's waters since 2010 (Gordon et al., 2019). However, bycatch still occur on a regular basis – depending on the area – in demersal fisheries (Bakiu et al., 2023; Barker et al., 2022; Bonanomi et al., 2023; Giovos et al., 2019; Holcer and Lazar, 2017; Lapinski and Giovos, 2019; O'Keefe et al., 2023; Rafrafi-Nouira et al., 2023). Fishery-dependent data often lacks precision, especially when it comes to the discards of bycatch (Cashion et al., 2019) and although angel sharks are no longer targeted by fisheries in EU countries, it is possible that discards are unintentionally misreported or even unreported (Dulvy et al., 2014).

To address the gaps faced in declarative fisheries data, unconventional methods – such as local-ecological-knowledge (LEK), citizen science or social media – are increasingly used (Colloca et al., 2020; Giovos et al., 2019; Séguigne et al., 2023). Recognizing indigenous and local knowledge as valuable information to assess biodiversity, not only fills the gaps of academic research – especially when it comes to rare species – but it also strengthens the involvement of local populations in marine research, monitoring, spatial planning and conservation (Copete et al., 2023; Silvano et al., 2022; Thornton and Scheer, 2012).

Despite its potential attractiveness for fishers, the waters around Corsica have never experienced heavy industrial fishing pressure (Le Manach et al., 2011). Its fleet is composed of 95% of small-scale-fishers (*i.e.* boats measuring less than 12 meters and operating in coastal waters; e. A total of 164 fishers holds a professional license in 2023 and this number has been decreasing since the 1950s (Le Manach et al., 2011), making the island's waters ones of the least harvested of the Mediterranean Sea. Artisanal fisheries have been monitored for the past 30 years on the island, either focusing on species with economic interest (Marengo et al., 2016; Marin, 1987; Pere, 2012; Pere et al., 2019), on the impact of Marine Protected Areas (Albouy et al., 2010; Claudet et al., 2008; Marengo et al., 2015; Mouillot et al., 2008; Rocklin et al., 2009; Roncin et al., 2008) or on

its global exploitation characterization (Bousquet et al., 2022; Marengo et al., 2023; Vanalderweireldt et al., 2022). These numerous studies are the results of a longstanding collaboration among fishers, scientists and environmental managers, facilitating the active involvement of all stakeholders in research and management processes. This collaboration greatly simplifies the analysis of multi-sources biological data. Combining the analysis of bottom-trawling campaigns and small-scale-fisheries with LEK surveys represent a significant step forward in the improvement of scientific knowledge of rare, threatened and protected species. Moreover, recent evidence of *S. squatina* presence in Corsican waters (Faure et al., 2023; Lapinski and Giovos, 2019) have urged the need for the description of the species distribution on the island.

This study aims to investigate the present distribution of the Critically Endangered Angelshark (*Squatina squatina*), the Sawback Angelshark (*Squatina aculeata*) and the Smoothback Angelshark (*Squatina oculata*) in Corsica. To achieve this objective, we examined both fishery independent data from MEDIterranean Trawling Surveys (MEDITS) and onboard small-scale-fisheries monitoring data, and we also collected professional fishers' knowledge about the three species through face-to-face interviews.

2 Material and methods

2.1 Study site

This study was carried out in the coastal waters of Corsica, a French island located between the Gulf of Genoa, the Tuscan archipelago and the island of Sardinia (**Figure 1**). Corsica has a 1000-km-coastline, making it the fourth largest island of the Mediterranean. Its waters are characterized by a mountainous landscape shaping deep underwater canyons to the West and wide expanses of soft sandy bottoms and large continental shelf to the East (Le Manach et al., 2011; Pluquet, 2006). The east coast is of particular interest in this study as it hosts one of the widest meadows of seagrass in the Mediterranean Sea (mostly composed of *Posidonia oceanica*) (Telesca et al., 2015; Valette-Sansevin et al., 2019) and muddy and sandy bottoms – which is the preferred habitat of angel sharks (Ellis et al., 2021b; Meyers et al., 2017). The high productivity of seagrass meadows makes the area of high conservation value (Pasqualini et al., 1998; Valette-Sansevin et al., 2019; Vanalderweireldt et al., 2022). Its large continental shelf (up to 150 m depth, 11 km offshore) is connected to the four largest lagoons of Corsica and seven estuaries, providing significant amounts of sediments and nutrients to the coastal area, therefore increasing the productivity of the ecosystem. The area is a Site of Community Importance, as defined through the Natura 2000 network, is located within the Pelagos Marine Mammal Sanctuary and was recently recognized as an Important Shark and Ray Area (ISRA) (Jabado et al., 2023).

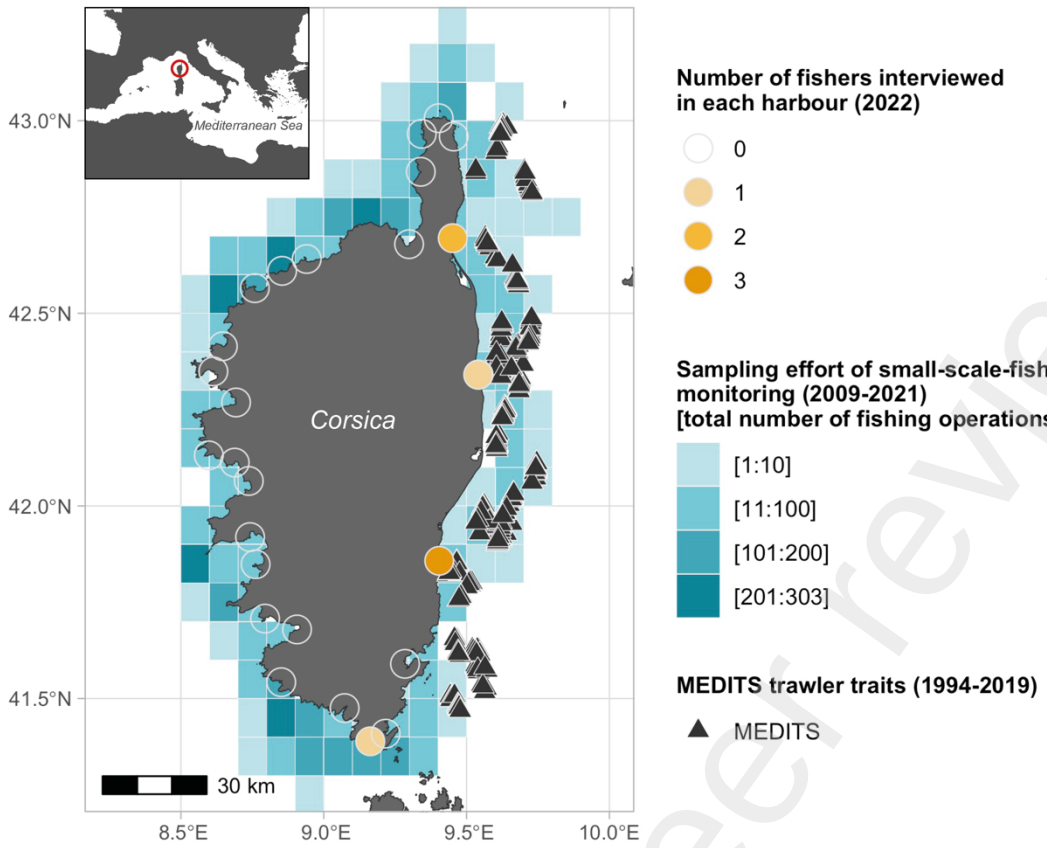

Figure 1: Study site and sampling effort of MEDIterranean Trawling Surveys (1994 – 2019), small-scale-fisheries monitoring (2009 – 2021) and local-ecological-knowledge survey (2022) in Corsica.

2.2 Sampling method

2.2.1 MEDIterranean Trawling Survey (MEDITS data)

The MEDIterranean Trawling Survey (thereafter referenced as MEDITS) occurs in every European Union's country with a Mediterranean Coast having an interest in bottom trawling fisheries. Each campaign has a standardized bottom trawl protocol, and each region is sampled every year – depending on the country – at the same time of the year (Bertrand and Spedicato, 2017).

These surveys took place every year between May and July from 1994 to 2019 (except in 2002) on the east coast of Corsica exclusively – due to the highly variable bathymetry of the island's western coast, making bottom-trawling impossible. Each year, between 12 and 25 bottom-trawler traits of 30 minutes at standard speed sampled benthic fauna at depth between 63 and 590 meters on the east coast of Corsica. All catch were identified to the species level – when possible – counted and measured.

2.2.2 Small-scale-fisheries monitoring (SSF data)

Scientists collected catch data each year from 2009 to 2021 except in 2016, first half of 2017 and first half of 2020 in Corsican coastal waters (**Figure 1**). From 2009 to 2015, data were collected by the Submarine and Oceanographic Research Station (STARESO), with 2012 to 2014 being part of the ObsMer Corse project, coordinated by the Fisheries and Aquaculture Direction. From 2017 to 2021, data were collected by the Environment Agency of Corsica as part of the DACOR project (2017-2019) and the Corsican Fishery-Data Collection Framework (2020-2021).

Every month between March and October were sampled every year – corresponding to the fishing activity period –, February, November and December were occasionally sampled, and January was never sampled given the extremely low activity of fishers during this period. For safety reasons and administrative authorizations, an average (± SD) of 20 ± 9 % of the entire SSF fleet was sampled every year, and a total of 151 fishers were sampled between 2009 and 2021. A metier-based sampling was used aiming at sampling the largest range of existing metiers on the island. A total of 17 metiers were sampled in 12 years, with fishing operations occurring between 1 and 430 meters for gillnets, entangling nets and traps and between 6 and 930 meters for hooks and lines. Bottom trawling monitoring was not part of the protocol given that it is not considered as a "small-scale coastal metier". For all fishing operations, each catch – both retained and discarded – was identified to the species level, counted and measured down to the nearest centimetre. The date, geographic position (when possible), mean depth and fishing time were recorded for each fishing operation.

2.2.3 Local Ecological Knowledge surveys (LEK data)

Local ecological data were collected by conducting face-to-face structured interviews with seven professional fishers. By working with the Regional Fisher Committee – an organization representing the professional fishers – all active fishers of the island (n = 164) received an invitation by e-mail to participate in the survey. Amongst the 164 fishers, seven (4,3%) declared they had knowledge about angel sharks and wanted to participate in the survey, four additional fishers (2,4%) declared they had no knowledge about angel sharks or did not want to participate and another three fishers (1,8%) declared they had knowledge about angel sharks but had no time to participate in the survey.

Prior to the interviews, we also used SSF data to identify the professional fishers whose participation would greatly improve the study. Amongst the 10 fishers identified through SSF data, two of them answered to the e-mail and said they had knowledge about angel sharks but had no time to participate in the survey, one did not answer the email and seven answered positively and were interviewed. The two fishers who did not have time to participate and the one identified who did not answer the e-mail were contacted again but still declined the invitation.

Data collection started in November 2021 and ended in June 2022, with seven fishers exclusively operating on the east coast of Corsica (**Figure 1**). Interviews were conducted face-to-face close to the harbours where fishers are operating (n = 5), by phone (n = 1) or by e-mail (n = 1). Three employees from the Regional Fisher Committee conducted the structured interviews. Conducting the interviews by a local organization helped maximizing the chances to obtain the most honest response from fishers. Fishers were guaranteed anonymity and had the right to omit any question they did not feel comfortable to answer.

The survey was divided into six parts: the first three were dedicated to the fishers' profile, their fishing habits, and the perception of the environment they are fishing from. The fourth and fifth parts were dedicated to the perception of the fisheries impact on angel sharks and the final part was dedicated to the knowledge of the ecology of species (Appendix 1). Photos of the three species of angel sharks were shown to the fishers to help identify the species that they catch. In the end, they were given a map to indicate areas where angel sharks were commonly caught during their fishing activity.

2.3 Data analysis

2.3.1 Spatiotemporal dynamic of Angelshark

Areas of occurrence for *Squatina squatina* were mapped using the three methodologies (*i.e.* MEDITS, SSF and LEK). For MEDITS and SSF, these areas correspond to polygons where *S. squatina* were sighted at least once over the surveys period. For LEK, fishers were asked to delineate polygons where they usually caught *S. squatina*, regardless of the season.

Depth was recorded for all MEDITS observations, all SSF bycatch and interviewed fishers provided information on the depth ranges at which they catch *S. squatina*. This information allowed for a description of depth distribution according to each method.

Regarding seasonality, for MEDITS and SSF data, we calculated the average number of Angelsharks caught for each fisher and classified it into four categories: 1 to 10 sharks / month; 11 to 50 sharks / month; 51 to 100 sharks / month; and over 100/month. For LEK data, fishers were asked to report their monthly shark bycatch according to these same categories, whenever they have a fishery activity.

2.3.2 First step into the delineation of functional areas

The occurrence of *S. squatina* was mapped according to the life-stages of the sharks using SSF and LEK data. In SSF data, the total length of the sharks was recorded for all individuals. We classified them into two different categories based on the size categories used in the Angel Shark Sighting Map: immature (35-100 centimeters) and mature (> 100 centimeters) specimens. The category "immature" includes young of the year/newborns (< 40 centimeters), juveniles (40 to 60 centimeters) and sub-adult (61 to 100 centimeters). In LEK data, fishers were asked if they regularly encountered juveniles and adults in their fishing area and when, through the year, they encountered most of them (Appendix 1). Areas where at least one individual was caught during SSF monitoring campaigns were qualified as "certain" and areas identified by fishers during LEK surveys as "potential", given the impossibility of verifying the total length categories. Seasonality was described using the number of fishers catching mature and immature Angelsharks. Depth ranges and trends in bycatch of mature and immature *S. squatina* were described using SSF data only.

3 Results

3.1 Fisheries impact on Angel sharks

The three species of angel sharks that are present in the Mediterranean Sea were reported in Corsica over the past thirty years (**Table 1**). Amongst the seven fishers interviewed, three of them indicated that they only caught the Angelshark (*Squatina squatina*), two fishers indicated that they caught both the Angelshark and the Smoothback Angelshark (*Squatina oculata*), and one fisher only caught the Smoothback Angelshark. SSF data (2009 – 2021) only allowed the identification of the Angelshark (**Figure 2A**) while MEDITS (1994 – 2019)

documented the presence of both Angelshark (*Squatina squatina*) and Sawback Angelshark (*Squatina aculeata*) (**Table 1, Figure 2**). All bycatch occurred in either gillnets / trammel nets according to the monitoring of SSF and the fishers' knowledge, or in bottom trawlers according to MEDITS.

Table 1: Angel shark species observed on the eastern coast of Corsica according to the data sources (MEDITS [1994-2019], small-scale-fisheries monitoring campaigns [2009-2021] and local-ecological-knowledge surveys [2022]).

Species	MEDITS	Small-scale-fisheries	Local Ecological Knowledge
Squatina squatina	X	X	X
Squatina oculata			X
Squatina aculeata	X		

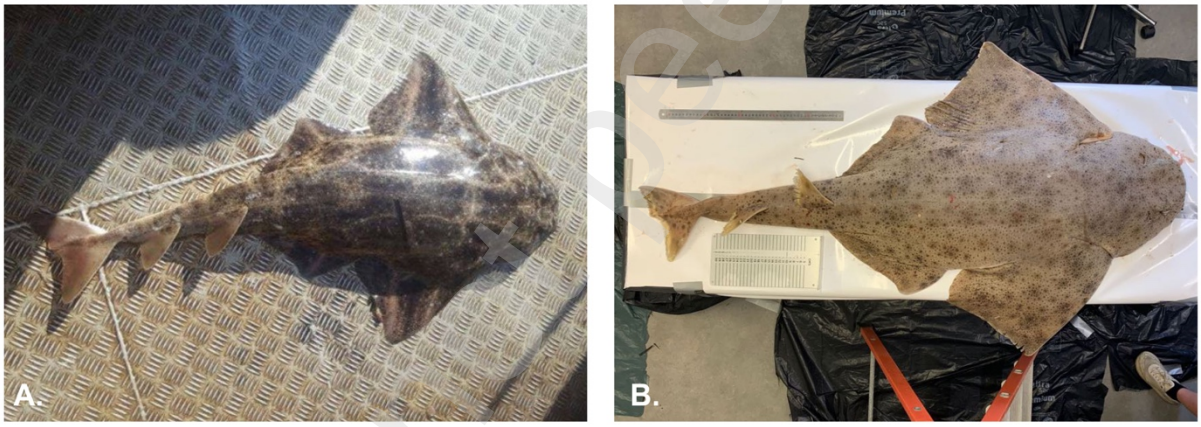

Figure 2: Observations of A. an Angelshark (*Squatina squatina*) caught in 2017 and B. a Sawback Angelshark (*Squatina aculeata*) caught in 2023 on the east coast of Corsica.

During MEDITS campaigns, six Angelsharks (*Squatina squatina*) and three Sawback Angelsharks (*Squatina aculeata*) were observed between 1994 and 2019 (**Figure 3**). This suggests that bottom-trawlers make very few bycatch when fishing between 60 and 600 meters, as most professional fishers suggest (71.4%, n=5). Indeed, one fisher reported that both bottom-trawling and SSF had high amount of angel shark bycatch, three fishers reported that only SSF had a high amount of bycatch and two fishers indicated that both types of fishing gear had low discards.

A total of two angel sharks (*Squatina* spp.) and 79 Angelsharks (*Squatina squatina*) were observed during the SSF monitoring campaigns (*i.e.* between 2009 and 2021). With the implementation of these campaigns in 2009, the number of angel shark bycatch increased, reaching a peak of 25 individuals in a single fishing operation in 2011 and then decreased between five to ten individuals occasionally caught in the following years (**Figure 3B**). Amongst the 151 fishers sampled through these years in Corsica, five of them (3.3%) caught at least one angel shark, and 73% of the bycatch was released alive. The absence of angel shark in SSF data happened twice – in 2013 and 2017 – over 12 years of monitoring. This suggests an 83% probability that an angel shark is incidentally caught in SSF monitoring within a year.

No clear trend in the number of angel shark bycatch in fishers' nets was observed, but the number began to rise with the start of SSF monitoring (**Figure 3B**). Three fishers believe the abundance of angel sharks caught in the nets remains stable over time, one states that they increase, and one states that they decrease (**Figure 3C**).

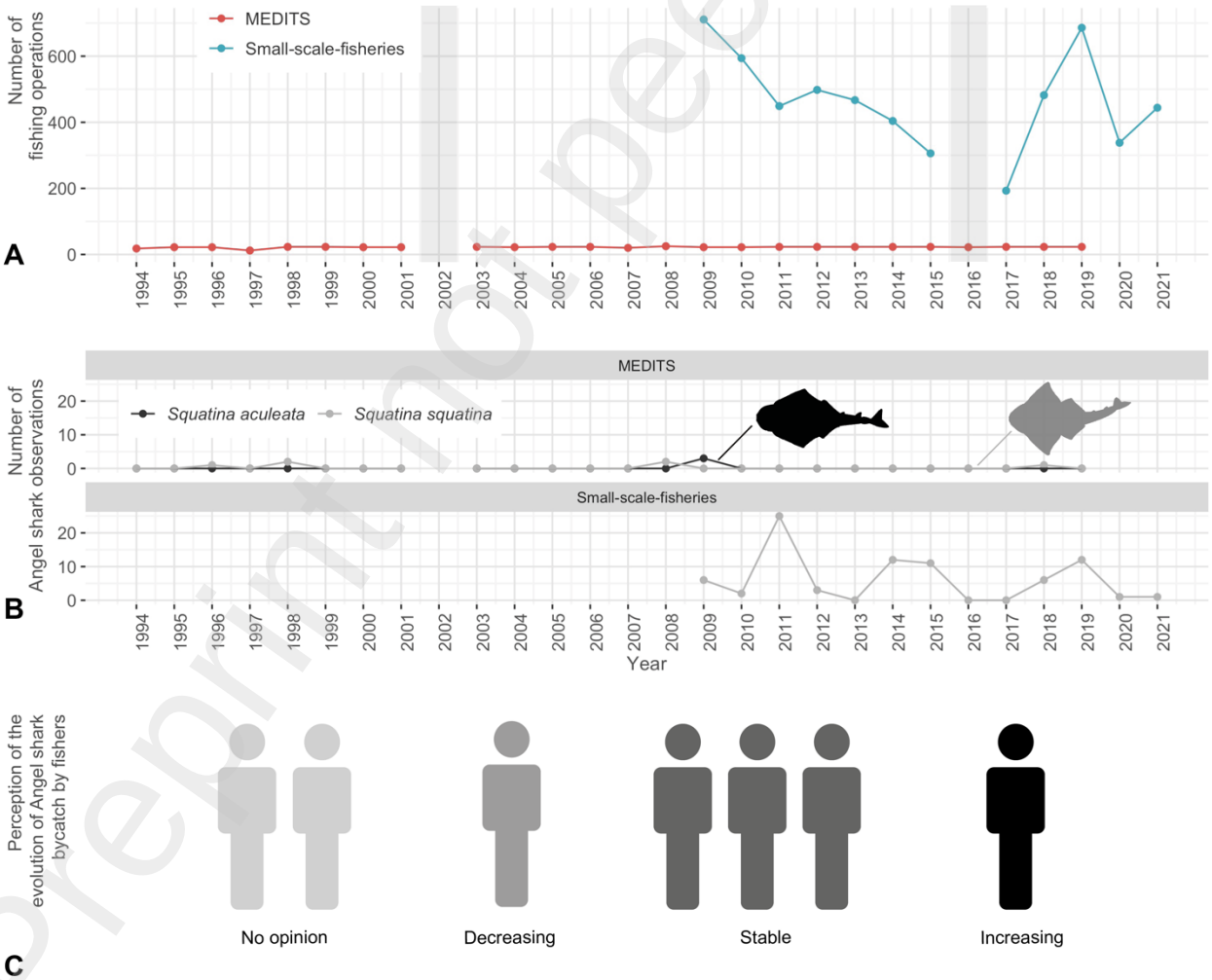

Figure 3: A. Evolution of sampling effort of MEDIT Surveys (1994 – 2019) (in total number of traits / year) and small-scale-fisheries monitoring (2009 – 2021) (in total number of fishing operations / year). Gray rectangle represents the cessation of MEDITS sampling in 2002 and small-scale-fisheries monitoring in 2016; **B.** Trends in Angelshark (*Squatina squatina*) and Sawback Angelshark (*Squatina aculeata*) observations during MEDITS and small-scale-fisheries monitoring; **C.** Perception of the evolution of angel shark bycatch according to the interviewed fishers (n = 7).

Spatio-temporal dynamics of the Angelshark (*Squatina squatina*)

Very few sharks were observed in MEDITS scientific bottom-trawl survey (**Figure 3B**). Therefore, information on the species' distribution and seasonality is very scarce when considering only MEDITS data (**Figure 4A**). However, one shark was observed at a depth of 270 meters during this campaign and the five others were caught at 70 meters (**Figure 4A**).

SSF data highlighted the rare occurrence of the species on the North coast, with only seven sharks accidentally caught (one in 2010, four in 2014 and two in 2015) (**Figure 4B**). These seven bycatch all occurred in the Cap Corse and Agriates Natural Marine Park. The other 72 sharks were yearly observed on the east coast at depths between 20 and 110 meters, with the most bycatch occurring from 30 to 45 meters (**Figure 4B**). SSF data provided an overview of occasional catch by five different fishers but did not reveal any seasonality, with low and constant numbers of individuals caught between March and September (**Figure 4B**). LEK data provided new information on the distribution on the species, with a new area being identified in the Natural Reserve of Bonifacio Strait, located in the extreme South of the island (**Figure 4C**). Depth range aligns with the one identified by SSF data, as most fishers (71,4%, n=5) declared that bycatch occurred between 25 and 60 meters (**Figure 4C**). Finally, information gathered from LEK regarding the seasonality of Angelshark bycatch highlighted large quantities spanning from February to April and July to August. Three different fishers indicated catching more than 100 sharks per month every year during these seasons (**Figure 4C**).

Angelsharks were therefore identified along the northern, eastern and southern coasts of the island, at depth ranging from 30 to 270 meters and in great numbers in late winter, early spring and summer (**Figure 4D**).

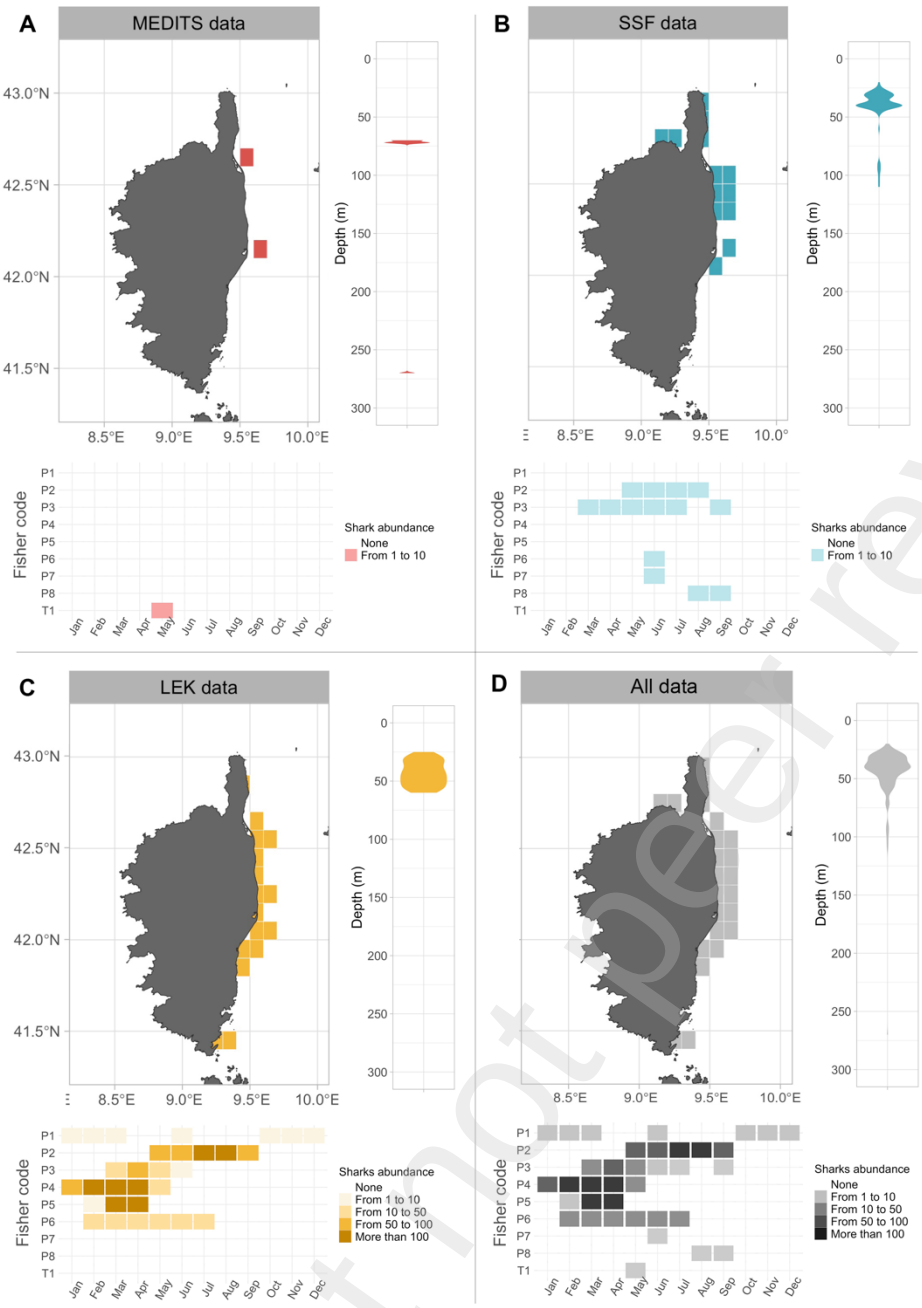

Figure 4: Horizontal, vertical and seasonal distributions of Angelsharks (*Squatina squatina*) in Corsica according to **A.** MEDITS data, **B.** Small-scale-fisheries monitoring data, **C.** Local Ecological Knowledge data and **D.** all data combined.

3.2 First insights into functional areas

Among all *Squatina squatina* bycatch observed during SSF monitoring campaigns, 30% were considered mature specimen (*i.e.* > 100 centimeters in Total Length) (n=24), and 70% were juveniles/immatures (*i.e.* from 35 to 100 centimeters TL) (n=55). All matures individuals were observed on the east coast, where three areas of

277 occurrence were confirmed at depth ranging from 28 to 40 meters (**Figure 5A**). The presence of mature
278 individuals ranged from January to August, with a peak from March to June (**Figure 5B**). Bycatch of mature
279 sharks was recorded in only four distinct years throughout the study period (**Figure 5C**).
280 Immatures were observed on a wider area compared to mature sharks. Confirmed areas of occurrence included
281 the 'Désert de l'Agriate' and the 'Cap Corse' region, located in the Cap Corse and Agriate Marine Natural Park
282 on the northern coast, as well as the eastern coast (**Figure 5A**). The depth range for this life stage extended from
283 20 to 110 meters, with most specimens (74.5%, n=41) being caught between 30 and 45 meters (Figure 5A). The
284 two smallest specimens (*i.e.* 35 centimeters each) were captured at depths of 27 and 31 meters. Fishers
285 confirmed these areas of occurrence and also mentioned the southern coast, in the Bonifacio Strait Nature
286 Reserve. The seasonality of the occurrence of immature sharks in fisher nets spanned from January to
287 September, peaking in June and July during the summer (**Figure 5B**). Immatures bycatch was also more regular
288 than mature individuals over the years, with only three gaps occurring during the study period – in 2013, 2017
289 and 2020 (**Figure 5C**).
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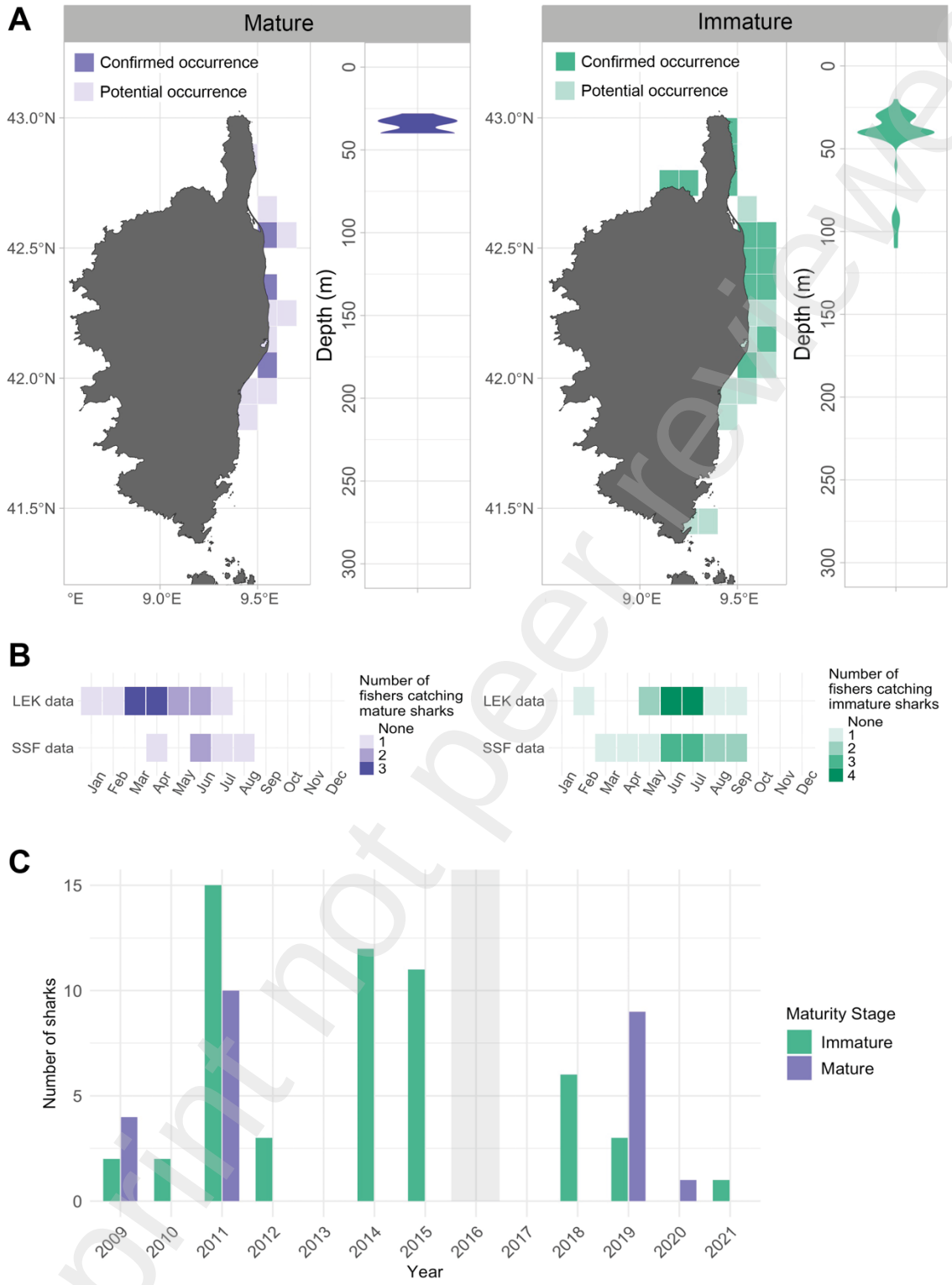

Figure 5: **A.** Confirmed and potential areas of occurrence and depth distribution; **B.** Seasonality in bycatch and **C.** Trend in the number of bycatch from 2009 to 2021 (grey rectangle represents the cessation of SSF monitoring in 2016) according to Angelsharks (*Squatina squatina*) maturity stage in Corsica.

4 Discussion

According to the IUCN, the Angelshark (*Squatina squatina*) is the only species of the Squatinidae family that is known to be resident in Corsica (Morey et al., 2019). The presence of the Smoothback Angelshark (*Squatina oculata*) is uncertain (Morey et al., 2017b), and the Sawback Angelshark (*Squatina aculeata*) is supposedly absent from the island (Morey et al., 2017a). However, MEDITS data attests the presence of three specimens of Sawback Angelshark in 2009 and local fishers indicate the presence of the Smoothback Angelshark in the coastal waters of Corsica in the survey developed in the present study. The differentiation between the latest two species is not straightforward and requires an identification expertise that is not possessed by all fishers. Although species identification in the MEDIT Surveys can be considered more robust than fishers, it is possible that *Squatina oculata* is still present in the island's waters since it was historically reported by a fish inventory (Miniconi, 1994). Pictures of fishers were not collected during this study to validate the identification of *S. oculata,* but could be in the next steps of the study to certify – or not – the presence of the species. On the other hand, the three specimens of *Squatina aculeata* identified by MEDITS scientists in 2009 are supported by one bycatch of a fisher in 2016, and two others in 2023 and 2024 (Bousquet unpublished data), and these sightings can be considered as evidence of presence of the species in the coastal waters of the island.

The annual occurrence of the Angelshark (*Squatina squatina*), which has a peak during specific times of the year, was demonstrated by consolidating data from the MEDIT surveys, SSF monitoring campaigns, and LEK surveys. Two fishers identified aggregations of adults in early spring, suggesting that their presence was potentially due to reproduction and/or to a feeding activity on *Spicara maena.* Another fisher explained the aggregations of adult Angelsharks in summer for reproduction purposes. Four fishers agreed on the peak of observations of immature individuals in June, which could align with the results obtained in the Canary Islands (Meyers et al., 2017). Indeed, the pupping season is supposedly happening between May and July, with a high proportion of neonates and gravid females in the shallow waters of the archipelago (Jiménez-Alvarado et al., 2020; Meyers et al., 2017). New insights on the species' vertical distribution were also uncovered through the analysis of MEDITS data. While *S. squatina* is commonly known to occur at depths ranging from 0 to 150 meters (Mead et al., 2023; Morey et al., 2019), the capture of one specimen at a depth of 270 meters in 1996 implies its potential presence beyond the continental shelf, extending into the continental slope. However, no

observation was recorded at shallow depths (*i.e.* less than 10 meters) due to a very low sampling and fishing effort in these waters, despite previous sightings of *S. squatina* in these areas (Lapinski and Giovos, 2019). These waters could represent sheltered locations for females during gestation period, or nursery areas for juveniles . This is why it is important to consider other data sources such as citizen science or social media to capture information in areas where fishing activities are less likely to occur. The combination of MEDITS, SSF and LEK data drew a more complete picture on the distribution of the *Squatina squatina* around the island. If the present study confirmed the presence of Angelsharks along the east coast as previously shown by eDNA surveys (Faure et al., 2023), our combination of approaches extended the known spatial distribution of the species in Corsican waters as well as further information of their seasonal dynamics. Scientific bottom-trawl surveys sampled depths (*i.e.* 63 to 590 meters) at which fishers rarely operate with gillnet or trammel nets enabling the identification of rare or even unique events that fishers may not mention in interviews when asked general questions about the depths or areas frequented by a species. Therefore, MEDITS data appears to be more efficient in capturing the extreme depth values for the distribution of *S. squatina*. Moreover, LEK data brings valuable information about the seasonal presence of the species, which could not be determined through any of the other datasets used in this study. Bycatch of Angelsharks occur during very short windows and according to fishers, up to 100 sharks can be caught in a single piece of net. These events happen in a one-month-window for each fisher, at the very beginning of the fishing season (*i.e.* march), when scientists are not boarding fisher vessels very often, due to low fishing effort (Bousquet et al., 2022).The lack of information regarding seasonality in SSF data could therefore by explained by this low sampling effort during a season where *S. squatina* bycatch are numerous. Moreover, the mortality rate was estimated at 27%, based on the ratio between number of dead and live specimens observed during SSF monitoring campaign. Therefore, strengthening boarding effort during the beginning of the fishing season is a lead to explore to: (1) reduce the mortality rate and collect data by adding an on-board observer and (2) re-evaluate the mortality rate when the peak of catch is occurring.

Presence areas for immature and mature specimens were delineated according to SSF monitoring data and the fishers' knowledge, which gives a first general idea of where immature and mature sharks are encountered along the Corsican coast. This study identified 3 large areas where immature (*i.e.* < 100 centimeters) are regularly

encountered every year: in the Désert de l'Agriate, the Cap Corse and the east coast. A potential area of occurrence for immature was also delineated in the Bonifacio Strait Natural Reserve, on the South of the island. To understand if these areas are used as nursery, and meet the criteria defined in Heupel et al. (2007), long-term studies should focus on more robust identification of life-stages of the sharks encountered. Indeed, using LEK to identify functional areas requires the use of clear definitions and scientifically valid information regarding life-stages, so that the fisher can be as precise as possible when delineating functional areas in space and time. Fishers have been provided the required equipment to measure sharks and collect biological information to further identify nursery areas in the upcoming years. Considering only neonates and young-of-the-year (*i.e.* < 40 centimeters) or applying the same methodology as in the Canary Islands (Jiménez-Alvarado et al., 2020) could also provide more robust information for the recognition of Corsica as a nursery for *S. squatina* in the following steps of the project (Hyde et al., 2022). Two young-of-the-year (*i.e.*, < 40 centimeters) were observed in 2012 and 2018 during SSF monitoring campaigns. These life-stages were also observed through citizen science at shallow depths, thanks to fishers and divers posting pictures on social media (Bisch et al., 2024), which support the lead to explore regarding potential nursery areas. Areas used by mature sharks were confirmed using SSF data, although adults are not regularly observed throughout the years. However, it is a common fact among interviewed fishers that *S. squatina* gather annually in large aggregations of mature individuals – which include aborting females induced by the capture (Adams et al., 2018). These aggregations could correspond to the definition of a mating area but could also represent feeding areas or migratory pathways (Hyde et al., 2022). Further research is required to identify the biological processes that lie under these aggregations.

This study initiated the identification of Critical Angel Shark Areas (CASAs), which correspond to specific geographic area that contains essential features for the conservation of angel shark (Gordon et al., 2019). As a next step, further efforts could focus on narrowing down the areas where angel sharks are present to precisely identify CASAs in space and time – such as nursery, mating or feeding areas.

Corsica is progressively involved in research regarding angel sharks and was identified as an Important Shark and Ray Area (ISRA) for being a place where undefined aggregations of Angelsharks occur (Jabado et al., 2023). The low fishing effort around the island – and even lower on the east coast – forecasts great opportunity to work with the few fishers (~10) that still encounter these Critically Endangered species. Moreover, local

stakeholders work together to maintain a collaboration between fishers, scientists and environmental managers that started in the early 2000s (Bousquet et al., 2022). Developing these already-effective collaborations between stakeholders with the few fishers who still encounter the species, offers hope for advancing the knowledge and improving the conservation of these species. Thanks to the information provided by fishers regarding the locations and seasonal occurrence of Angelsharks, research teams and environmental managers need to develop field-based action to improve understanding about functional areas and develop conservation strategies with local fishers and local government representatives. These collaborative actions could align with the recent implementation of the Single Species Action Plan for the Angelshark in the Mediterranean Sea Region (SSAP Angelshark Med), which requires all range state to coordinate their efforts in Angelshark conservation. It is however important to keep in mind that field work requires significant financial and human effort, which is not always feasible to sustain consistently throughout the year, let alone over multiple years. This is why alternative approaches such as citizen science and social media should be used as complementary sources of information, especially to collect sightings of rare and endangered species (Giovos et al., 2019).

5 Conclusion

This study concludes on the residency of Angelshark (*Squatina squatina*) and the ponctual presence of Sawback Angelsharks (*Squatina aculeata*) in Corsica. The presence of the Smoothback Angelshark (*Squatina oculata*) is suspected but needs more tangible proof – such as photo of specimen – to validate its presence around the island. By integrating data from MEDITS and small-scale-fisheries monitoring campaigns with local-ecological-knowledge, we provided a first insight into the spatio-temporal distribution of the Angelshark (*Squatina squatina*) around the island. Further research is now required to identify and confirm functional areas such as nursery and mating areas by bringing robust scientific evidence, as well as investigate population size and movements of these endangered sharks, crucial information for proposing effective management options.

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7 Contributors

Caroline Bousquet : Conceptualization, Methodology, Formal analysis, Writing - original draft, Visualization, Project administration, Funding acquisition; **Jessica Dijoux :** Conceptualization, Methodology, Investigation, Writing - review and editing, Project administration, Funding acquisition, Supervision; **Eric D. H. Durieux :** Conceptualization, Writing - review and editing, Visualization, Supervision, Project administration, Funding acquisition; **Ioannis Giovos :** Writing - review and editing, Visualization, ; **Eva K. Meyers :** Writing - review and editing, Visualization, Supervision, Project administration, Funding acquisition; **Johann Mourier :** Conceptualization, Methodology, Writing - review and editing, Visualization, Supervision, Funding acquisition.

8 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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