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Multiple interannual records of young-of-the-year identify an important area for the protection of the Shortfin Mako, *Isurus oxyrinchus*.

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Highlights

- The Shortfin Mako is one of the most threatened pelagic sharks by fishery
- Several Young of the Year individuals occurred in the same area for two consecutive years
- The species represents common by-catch of longlines in the area
- This is the most abundant record of YOY shortfin makos in the Mediterranean

Abstract

The shortfin mako (*Isurus oxyrinchus*) is the second most fishery-exploited pelagic shark in the Mediterranean Sea, thus its conservation status is a cause for concern. Despite the species has been listed in fishery and trade regulations to hinder its population decline, the lack of knowledge on its distribution patterns and habitats essential for its persistence still hampers the implementation of sound conservation actions. Combining data from local expert knowledge, opportunistic catch records, and Baited Remote Underwater Videos, we show evidence of the interannual presence of young-of-the-year (YOY) *I. oxyrinchus* in the Pelagie Archipelago (Central Mediterranean Sea). A total of sixteen individuals ranging 71 –81 cm TL were by-caught (on average 3.4 YOY/1,000 hooks) or documented on BRUVS in July and August over two consecutive years. These data coupled with questionnaires administered to longline fishers identify one specific area used by YOY in the summer months. Our study presents the most abundant record of YOY shortfin makos in the Mediterranean Sea within such a restricted time and limited area providing important information for the protection of this threatened species.

Keywords: Pelagic Sharks, Longlines, Bycatch, Conservation, Fisheries

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34

35

1. INTRODUCTION

37 Shark and ray species are facing a global risk of extinction (Dulvy et al. 2021) and we need swift and
38 transformative approaches to their management and conservation to halt their ongoing population decline
39 (Pecoureau et al. 2023). In the Mediterranean Sea, more than 50% of shark species are threatened with
40 extinction (Dulvy et al. 2016), and many of them are still accidentally or deliberately caught and sold in the
41 markets (Dent and Clark 2015). Despite this, the implementation of targeted protection measures is still
42 inadequate (Milazzo et al. 2021), and – along with better enforcement and control at ports – would require
43 reliable data on the distribution patterns of threatened shark species and the identification of ecological
44 corridors and habitats that are essential to their population replenishments. The management and
45 conservation of threatened sharks are particularly challenging for pelagic and wide-ranging species
46 (Pacoureau et al. 2021), for which available knowledge in the Mediterranean Sea is fragmented, mostly
47 belonging to scattered fishery-dependent data and opportunistic evidence that often concern single or a few
48 records of individuals.
49 The shortfin mako *Isurus oxyrinchus* (Rafinesque, 1810) is a solitary and highly migratory epipelagic predator
50 that is targeted or bycaught by different fishing gear and is generally retained for the high-value meat and fins
51 (Campana et al. 2005; Dent and Clarke 2015). In the Mediterranean Sea, it represents the second most caught
52 pelagic shark after the blue shark *Prionace glauca* (Carpenteri et al. 2021; Megalofonou et al. 2005; Serena
53 2005). Like other sharks of the family Lamnidae, *I. oxyrinchus* shows late maturity (males and females mature
54 at 7.5 and 18-22 years, respectively; Natanson et al. 2020), and low fertility and productivity (on average 12
55 pups every three years after a gestation period of 15-18 months; Mollet et al. 2000), which make the species
56 particularly vulnerable to high fishing intensity. In this regard, there is evidence that Mediterranean
57 populations declined by more than 96% over the past few decades due to overfishing (Ferretti et al. 2008).
58 According to this, the species has been regionally assessed as 'Critically Endangered' (CR) (Walls and Soldo
59 2016) and is now included in several fisheries, conservation, and trade regulations, such as the Annex II of the
60 Barcelona Convention, the Appendices II of CITES and the Convention of Migratory Species (CMS), aimed at
61 hampering species exploitation.
62 However, the available information on the status of the Mediterranean population of shortfin makos is
63 presently very limited and mostly derives from fragmentary catch data. To partially overcome the scarcity of
64 records, recent studies used unconventional data sources (e.g. social media data) that provided insights into
65 the historical distribution of the species across the basin (Bargnesi et al. 2022; Mancusi et al. 2020). Examining

records available in the scientific literature, newborns, juveniles, and adults of *I. oxyrinchus* have been reported in different sectors of the Mediterranean Sea (Ergüden et al. 2022; Saidi et al. 2019; Panayiotou et al. 2020; Sperone et al. 2012; Udovičić et al. 2018). A considerable proportion of these catches consisted of immature individuals caught in the northeastern sector of the basin, mostly off the Turkish coast, suggesting that this area could host breeding or nursery grounds for the species (Ergüden et al. 2022). However, these findings were based on isolated occurrences of one or very few individuals scattered across different times and locations.

Indeed, the peculiar biological characteristics of the Shortfin Mako (e.g. late maturity, low reproductive rate, and production of few offspring), its high vulnerability to fishing operations (particularly to longline fisheries), and the limited information on its distribution, all pose a significant conservation challenge at the regional scale and further efforts should be made to make the protection of this species more effective. Identifying important areas for the species' early life cycle, and the study of the interactions of these individuals with fishing operations is crucial and represents a key information for its actual conservation. In this frame, the identification of areas that are recurrently used by newborns, young-the-year (YOY), or immature individuals cannot be validated considering isolated records of few individuals. Therefore, there is justified attention toward the detection and characterization of essential habitats showing a recurrent presence of early stages. In this study, following evidence obtained from a wider survey focused on elasmobranchs' catches by fishers in the Central Mediterranean Sea, we combined Local Expert Knowledge (LEK), Baited Underwater Video systems (BRUVs), and opportunistic catch reports (OCR) by longliners to identify important areas for early life stages of the Shortfin Mako in the Pelagie archipelago, a recognized hotspot for threatened shark species (Cattano et al., 2021; 2023) and one of the most fishery exploited areas in the Mediterranean (Jarboui et al. 2022).

2. MATERIAL AND METHODS

2.1 Study area

The Pelagie Archipelago (PA), a group of three islands (Lampedusa, Linosa, and Lampione) in southern Italy, is located in the central Mediterranean Sea just off the Tunisian coasts (Fig. 1). The PA falls within the Sicilian Channel, an Ecologically or Biologically Significant Marine Area (EBSA) and an important area for the conservation of threatened shark species in the Mediterranean Sea (Cattano et al. 2021, 2023; Di Lorenzo et al. 2018; Enajjar et al. 2022). The archipelago partially overlaps with the Pelagie Islands Marine Protected Area (Pelagie MPA) and two Natura 2000 sites. The influence of Atlantic currents makes it a high-energy area

with intense hydrodynamics caused by wave motion and deep-waters upwellings along the coast. A water mass of Modified Atlantic Mediterranean Water (MAW) comes from westward and splits into the Atlantic Ionian Stream (AIS) and the Atlantic Tunisian Current (ATC), this latter moving through the PA and contributing to enhancing water productivity of the area (Di Lorenzo et al. 2018). The sea bottom is mostly shallow and flat and is alternated by highly productive structures, such as the Lampione islet and the "Levante shoal" located 12 nm westward and eastward, respectively from Lampedusa island (Fig.1).

2.2 Data collection

We preliminary gathered information on sharks from a wider survey on elasmobranchs carried out through questionnaires administered over three years (2020-2022) to 43 fishers from the PA. Among these, 41 fishers (95% of the total) declared to accidentally catch sharks (e.g., the Blue shark *Prionace glauca*, the Shortfin Mako *Isurus oxyrhincus*, the Sandbar shark *Carcharhinus plumbeus*, the Smooth-hounds *Mustelus* spp.) in PA waters and that these catches were distributed in the following areas: northward Lampedusa (12% of the respondents), the 'channel' between Lampedusa and Linosa islands (41%), around Lampione Islet (83%), around the Levante shoal (63%), Southward Lampedusa (27%).

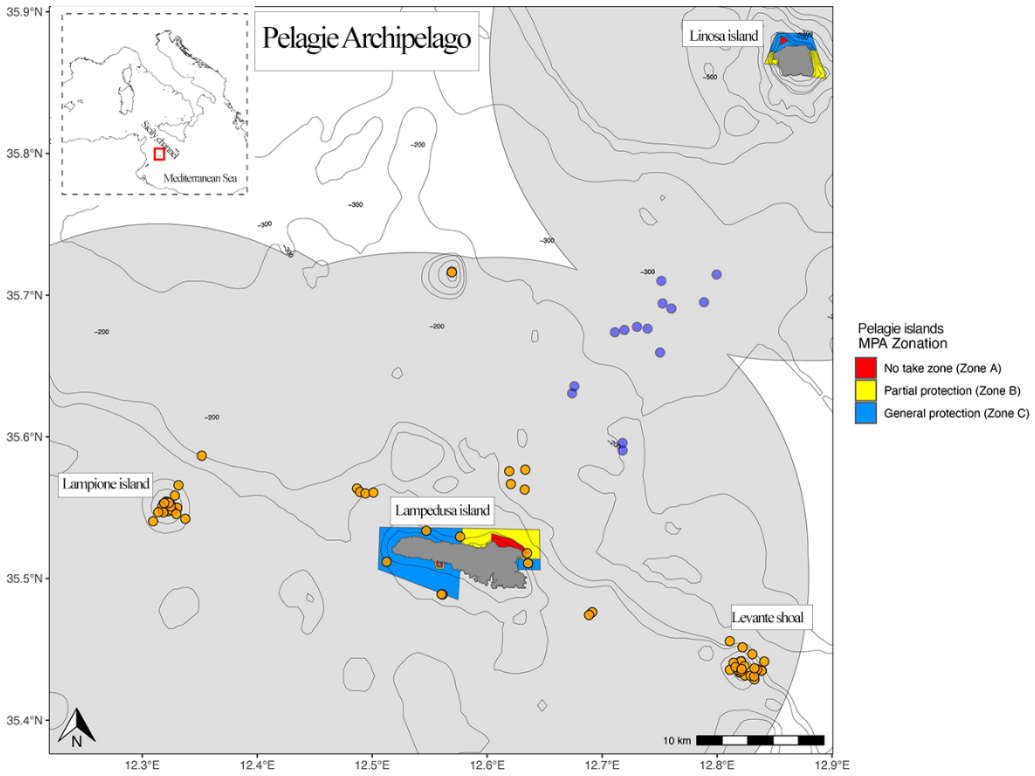
In the present study, we build on this information to carry out mid-water BRUV surveys in these sites. In addition, we combined this survey with questionnaires on YOY shortfin mako catches administered to longline fishers and with opportunistic catch records reported in the area.

In July 2021 and 2022, mid-water BRUVs (n=66) were deployed at multiple sites as part of a wider study aimed to survey the pelagic fish community in the PA (Fig. 1). BRUVs consisted of a stainless steel frame equipped with a metal cage (20Lx10Wx10H cm) containing a fixed amount of bait (500g of *Sardinella aurita*) and placed at a standardized distance of 1.2 m from one GoPro 8 camera. Each BRUV was attached to a surface buoy that was anchored to the bottom with a 6 kg weight at depths between 40 and 60 m. The BRUV was suspended at a depth of about 20m from the surface using a sub-surface buoy placed at a distance of about 5 m above the system to reduce movement due to wave action. Each replicate lasted 80 min., during which the boat moved away from the sampling site to avoid any effect of noise or shade.

We collected specific information on YOY shortfin mako catches from questionnaires administered in 2022 to 15 out of 17 longline fishing boat owners operating in the PA waters and targeting tuna and swordfish. The questions aimed to collect information on the fishing areas, the fishing period within the year, and the approximate size of individuals by-caught. Results on the location of early stage *I. oxyrhincus* by caught are reported as the frequency of occurrences (%).

Opportunistic catch records of YOY shortfin makos came from four different swordfish-targeting mid-pelagic drifting longline sets made by local fishers at the end of July and the beginning of August 2022 between Lampedusa and Linosa islands (Fig. 1). Fishers stated that each fishing operation lasted up to 10-12 hours, starting early in the morning or late in the afternoon and retrieving began after midnight or after sunset. The fishing gear consisted of a nylon monofilament (1,6 mm diameter) with monofilament branch lines of 1,2 mm diameter and about 6 m long attached every 30 m to the mainlain. At regular time intervals (1nm), floating buoys were attached to the mainline to maintain the gear between 6 meters below the sea surface and about 70m. Each set comprised an average of 1100 hooks of 6cm. Round Sardinella (*Sardinella aurita*) alternated with artificial squids (filled with round sardinella) were used as baits. Biological data for the specimens by-caught were provided by fishers and included total length (TL) in cm, and weight when possible. Data for by-caught specimens were collected onboard before release and included total length (TL) in cm, and weight when possible. Average catch per unit effort (CPUE) was calculated as the number of YOY shortfin mako individuals per 1000 hooks.

The seawater temperature at the surface, at 20 m and at 40 m depth was obtained from the EU Copernicus Marine Information Service (https://marine.copernicus.eu/) to represent the thermal environments in the days and of the areas where occurrences were recorded.



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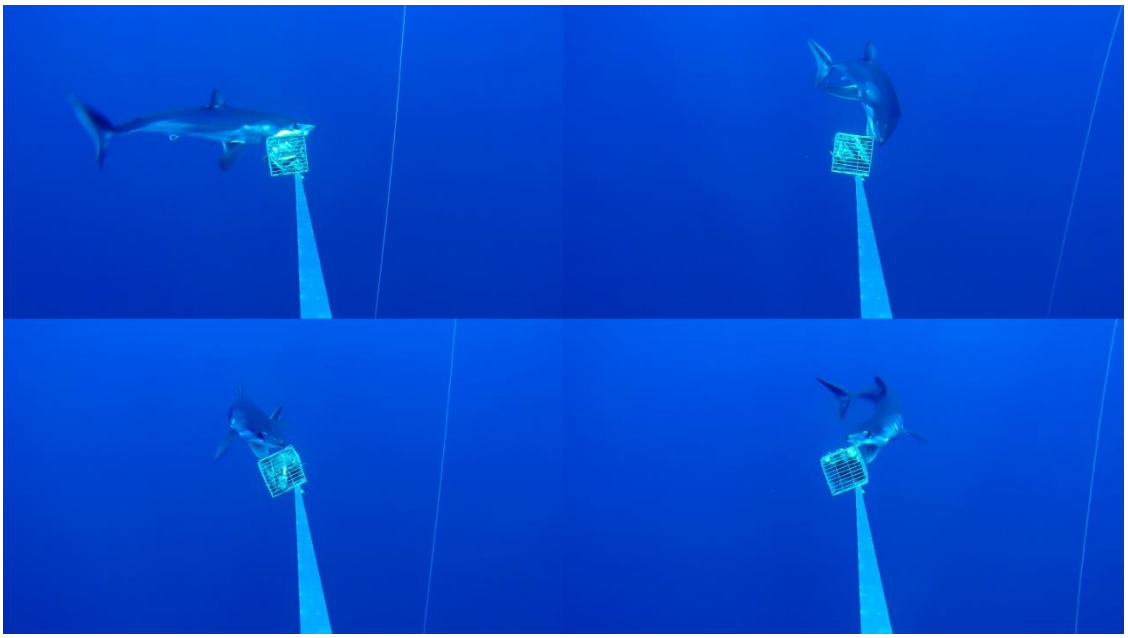
144 *Figure 1 – Map of the Pelagie Archipelago showing the distribution of mid-water BRUV deployments (orange dots) and the points*
145 *where opportunistic catch records of YOY Shortfin Makos were reported (blue dots). The borders of Italian territorial waters (grey*
146 *area) and Pelagie Island MPA are indicated. Lampione Island belongs to the general protection zone.*

147

148 3. Results

149 Mid-waters BRUVs deployed in different fishing zones of the PA recorded the occurrence of one young *I.*
150 *oxyrinchus*, in the water column at about 20m depth around the Levante shoal (Fig. 2). The YOY shortfin mako
151 was recorded at 4 p.m. and appeared in the field of view of the camera for a total of 90 sec. during which it
152 displayed five distinct bait approaches events (Fig. 2). The estimated size of the individual was ca. 80 cm (TL)
153 and was obtained using the bait cage as a reference (Table 1).



154

155 *Figure 2 – Bait approaches displayed by a YOY shortfin mako recorded on July 2021 in the Levante shoal through BRUV*

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Figure 3 -. Two pictures of opportunistic records of Young of the Year I. oxyrinchus by-caught in the Pelagie Archipelago in the Summer of 2022.

Fifteen YOY *I. oxyrinchus* individuals were also opportunistically obtained from local fishermen's incidental catches during pelagic longline sets done between late July and early August 2022 (n=4; 100% of shortfin mako occurrence). Catches Per Unit Effort (CPUE) was 3.4 individuals/1000 hooks and the daily catch composition is reported in Table 1. Three individuals were caught on the 21st of July, six individuals on the 24th of July, four individuals on the 25th of July, and two individuals on the 1st of August. Size and weight estimates were possible only for nine and six individuals, respectively (Fig. 3; Tab.1). The mean size and weight were 75.7 (±3.6 SD) cm, and 4272 (±1119 SD) g, respectively. All the captures occurred at depths between 50 and 250 meters.

Table 1 –Size and weight estimates of the sixteen Young of the Year *I. oxyrinchus* records obtained by BRUVs and incidental longline catches in the Pelagie Archipelago in 2021 and 2022.

Date	Temperature °C (surface)	Temperature °C (20m)	Temperature °C (40m)	# individuals recorded	Size estimate (TL, cm)	Weight estimate (g)
23/07/2021	26.6	25.7	19.9	1	80.0*	NA
21/07/2022	28.7	23.7	18.4	3	75.5	3540*
					73.0	3290*
					73.5	3340*
24/07/2022	28.9	24.7	18.7	6	NA**	NA**
					72.0	3150

25/07/2022	28.5	24.7	18.7	4	76.0	3600
					79.0	4750
					71.0	3130
01/08/2022	28.3	24.4	18.7	2	81.0	5500
					80.0	5500
	* estimated value ** fishers reported that the by-caught shortfin makos in this set were the same size as the other individuals					

All the longline fishing boat owners interviewed stated that incidental catches of newborn/YOY Shortfin Makos occur outside the MPA borders every year from July to September in specific areas of the PA by angling (29%) or using bottom (14%) and surface (57%) longlines. Half of the interviewed fishers declared that the species is occasionally by-caught (representing 10-20% of the catches), whilst the other half equally reported that the catches occur rarely (less than 10% of total catches) or frequently (up to >20% of total catches). All fishers also stated that the channel between Lampedusa and Linosa (75% of the respondents), and around Levante shoal (50% of the respondents) are the only areas where bycatches of YOY shortfin makos recurrently occur, and that no such by-catch occurred in other fishing grounds of the Archipelago.

4. Discussion

This study shows multi-source compelling evidence that young-of-the-year of the critically endangered shortfin mako utilize a specific unprotected and unmanaged area during summer months within the Pelagie Archipelago, a heavily fishery-exploited area and an elasmobranch diversity hotspot in the Central Mediterranean Sea. Several individuals were filmed or opportunistically sampled over a few days for two consecutive years in the same area, which is also recognized by local fishers as an area where the species is recurrently by-caught. To the best of our knowledge, our data represent the most abundant record of young-of-the-year shortfin makos in the Mediterranean Sea within such a restricted period and spatially limited area.

Our findings suggest that all the records pertain to YOY individuals. The parturition period of this species in the Mediterranean region has been reported to occur from late winter to mid-spring (Mollet et al. 2000), with the size of newborns ranging from 60 to 70 cm (Erdugen et al., 2022). Since the yearly growth rates of the species are between 16 cm (Cerna and Licandeo, 2009) and 50 cm (Natanson et al., 2006) during the first year, we can infer that the sampled individuals were only a few months old.

The significant frequency and recurrence of YOY records reported in this study – confirmed by the combination of different techniques – suggests that the considered area could host an important spot for the

early life stages of the shortfin mako. At present, our findings meet two out of three criteria proposed by Heupel et al. (2007) for identifying shark nurseries: (1) YOY individuals were encountered more frequently in a specific area compared to other locations, and (2) the area was repeatedly utilized by the species across multiple years. Future investigations should focus on whether YOY individuals tend to stay or return to the area for extended periods, which would address the third nursery criterion proposed by Heupel et al. (2007). In this regard, we highlight a critical next step toward incorporating movement ecology (i.e. satellite tracking) and habitat use studies for the shortfin mako, and above all for its early life stages. In fact, the Mediterranean region is currently flacking such information compared to other marine regions (Andrezcjackzek et al., 2021).

To date, information on the distribution of early life stages of the shortfin makos and critical areas for their survival in the Mediterranean Sea has been limited to sporadic and isolated sightings and catch records from various sectors of the basin. Previous studies reported some records of single YOY or immature individuals on the northern coasts of the Levantine basin and the Adriatic Sea, speculating that these regions can host potential nursery areas for the species (Ergüden et al. 2022; Udovičić et al. 2018). In addition to this, Saidi et al. (2019) reported different catches of immature individuals in experimental longline settings in the Gulf of Gabés waters (SE Tunisia), a recognized nursery area for many elasmobranch species in the Mediterranean Sea (Enajjar et al. 2015). Very recently, other approaches integrating conventional and unconventional data sources (e.g., social media and data mining from websites) provided a more comprehensive picture of shortfin mako distribution in the Mediterranean basin with potential evidence of the increased frequency of occurrence in the last decade (Bargnesi et al. 2022; Mancusi et al. 2020). However, in most cases, the available data have been limited in scope and failed in the recurrent records of individuals over time, in the accurate identification of critical habitats, such as mating and nursery grounds, as well as of corridors between sites and migration routes. Our findings add significant information that can help to identify a specific area crucial for the conservation of this critically endangered species.

Our questionnaire surveys administered to longline fishers also revealed that most of the respondents declared to accidentally catch YOY shortfin makos in the Pelagie Archipelago waters during the summer months in an area that overlaps with that identified as significant for early life stages by this study. Catches of both immature and adult shortfin makos are also common in the near Tunisian waters (Enajjar et al. 2022) and previous experimental longline surveys reported that the species is the second most caught shark in the Gulf of Gabes (Saidi et al. 2019), where on average 0.48 shortfin mako catches every 1000 hooks were recorded. Very likely, these values were lower than those reported in this study because the fishing effort was spread over different seasons. Indeed, seasonal differences in shortfin mako records have been highlighted in the basin, with seawater temperature probably playing an important role (Bargnesi et al.

2022). There is evidence that physical and environmental factors (e.g. sea surface temperature, dissolved oxygen content, depth of the mixed layer) influence the presence and distribution patterns of sharks in essential habitats (Ward-Paige et al. 2015). However, further investigations are needed since seasonal changes in observation efforts (i.e. spatio-temporal patterns of tourism and fishing efforts) may also play a role in the frequency of occurrences.

To better characterize the ecology and distribution patterns of the species there is a need to promote a systematic monitoring scheme with standardized observation efforts not limited to fishery-dependent data. The use of non-extractive sampling methods, such as Baited Remote Underwater Video or eDNA surveys (e.g. Aglieri et al. 2021, 2023; Cattano et al. 2021), should be promoted especially in studies focusing on species at risk of extinction, such as many pelagic shark species. This aspect is of particular importance since the shortfin mako is included in different international conventions and recommendations implemented by the General Fishery Commission for the Mediterranean (GFCM) and European Union (EU) that include a ban on targeted fishing and landings.

Despite improving and promoting handling and release practices among fishers are essential for limiting fishery-induced mortality in sharks, reducing capture and post-release mortalities remains the priority to ensure species persistence (Sims et al. 2021). A recent study reported that more than half of mortality in immature shortfin makos in the North Atlantic is due to fishing (Mucientes et al. 2023) and there is evidence that juveniles survival rather than fecundity contributes to population growth rates, especially for longer-lived sharks with late maturity (Cortés 2002). Although no-retention policy recommendations remain essential to increase the chance of shark survival, parallel efforts should aim to avoid shark catches and minimize fishing impacts on populations, especially on immature individuals. In this context, the use of bycatch mitigation devices such as deterrents mounted in fishing gear, gear modifications, and changes in soak times could contribute to reducing the interactions of sharks with baits and therefore catch rates. The efficacy of these devices in reducing the by-catch of elasmobranchs has been reported as highly variable being context-dependent, and varying with species, fishery, and environmental characteristics (Lucas and Berggren 2022). However, very recent experiments successfully tested catch deterrents in commercial longline fishery targeting bluefin tuna, showing by-catch reduction of pelagic elasmobranchs (Doherty et al. 2022; Raoult et al. 2023). Moreover, there is a need to develop strategies aimed to avoid overlaps between shark space-use hotspots and longline fishing efforts, such as permanent or dynamic closures of offshore areas to reduce the interactions of fisheries with YOY and immature shortfin mako sharks.

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Conclusions

Identifying and mapping essential habitats, such as breeding, nursery, and aggregation areas, are essential steps to recovering shark populations in the Mediterranean Sea. Our findings underscore the need for more intense and systematic monitoring efforts, involving the use of tagging and non-extractive sampling techniques in potential diversity hotspots and critical habitats. Addressing this issue is essential to improve the efficacy of focused conservation measures. At the same time, additional strategies for the management of these areas should be proposed and implemented, including promoting bycatch mitigation measures and/or temporal fishing regulations to reduce the interactions with threatened pelagic sharks.

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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Data availability

Data will be made available on request.

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