

## The use of fishers' Local Ecological Knowledge to reconstruct fish behavioural traits and fishers' perception of the conservation relevance of elasmobranchs in the Mediterranean Sea

Matteo BARBATO<sup>1</sup>, Claudio BARRÍA<sup>2</sup>, Andrea BELLODI<sup>3</sup>, Sara BONANOMI<sup>4</sup>, Diego BORME<sup>5</sup>, Ilija ČETKOVIĆ<sup>6</sup>, Francesco COLLOCA<sup>7</sup>, Ana I. COLMENERO<sup>2</sup>, Fabio CROCETTA<sup>7</sup>, Francesco DE CARLO<sup>8</sup>, Egemen DEMİR<sup>9</sup>, Manfredi DI LORENZO<sup>10</sup>, Maria Cristina FOLLESA<sup>3</sup>, Fulvio GARIBALDI<sup>11</sup>, Gianni GIGLIO<sup>12</sup>, Ioannis GIOVOS<sup>13</sup>, Giulia GUERRIERO<sup>14</sup>, Olfa HENTATI<sup>15</sup>, Mohamed KSIBI<sup>15</sup>, Claudia KRUSCHEL<sup>16</sup>, Luca LANTERI<sup>11</sup>, Francesco Luigi LEONETTI<sup>12</sup>, Alessandro LIGAS<sup>17</sup>, Adriano MADONNA<sup>14</sup>, Sanja MATIĆ SKOKO<sup>18</sup>, Renata MIMICA<sup>19</sup>, Dimitrios K. MOUTOPOULOS<sup>20</sup>, Antonello MULAS<sup>3</sup>, Vedrana NERLOVIĆ<sup>21</sup>, Ana PEŠIĆ<sup>6</sup>, Cristina PORCU<sup>3</sup>, Emilio RIGINELLA<sup>7</sup>, Emilio SPERONE<sup>12</sup>, Konstantinos TSOUKNIDAS<sup>20</sup>, Sezginer TUNÇER<sup>9</sup>, Dario VRDOLJAK<sup>18</sup> and Carlotta MAZZOLDI<sup>1</sup>

<sup>1</sup> Department of Biology, University of Padova, Padova, Italy

<sup>2</sup> Institut de Ciències del Mar, CSIC, Barcelona, Spain

<sup>3</sup> Department of Life Sciences and Environmental, University of Cagliari, Cagliari, Italy

<sup>4</sup> Italian National Research Council (CNR), Institute of Marine Biological Resources and Biotechnologies (IRBIM), Ancona, Italy

<sup>5</sup> National Institute of Oceanography and Applied Geophysics - OGS, Italy

<sup>6</sup> University of Montenegro, Institute of Marine Biology, Kotor, Montenegro

<sup>7</sup> Department of Integrative Marine Ecology, Stazione Zoologica Anton Dohrn, Naples, Italy,

<sup>8</sup> CIBM/Soc. Coop. Aplysia, Livorno, Italy

<sup>9</sup> COMU, Marine Science and Technology Faculty, Çanakkale Merkez, Çanakkale, Turkey

<sup>10</sup> Italian National Research Council (CNR), Institute of Marine Biological Resources and Biotechnologies (IRBIM), Mazara del Vallo, Italy

<sup>11</sup> Dipartimento di Scienze della Terra dell'Ambiente e della Vita, University of Genova, Genova, Italy

<sup>12</sup> DiBEST, University of Calabria, Arcavacata di Rende, Italy

<sup>13</sup> iSea-2. Technological Educational Institute of Western Greece, Thessaloniki, Greece

<sup>14</sup> Department of Biology, Federico II University, Napoli, Italy

<sup>15</sup> Higher Institute of Biotechnology, University of Sfax, Sfax, Tunisia

<sup>16</sup> University of Zadar, Zadar, Croatia

<sup>17</sup> CIBM, Consorzio per il Centro Interuniversitario di Biologia Marina ed Ecologia Applicata, Livorno, Italy

<sup>18</sup> Institute of Oceanography and Fishery, Split, Croatia

<sup>19</sup> Fishery Office, Rijeka, Croatia

<sup>20</sup> Department of Animal Production, Fisheries & Aquaculture, University of Patras, Mesolongi, Greece

<sup>21</sup> University of Split, University Department of Marine Studies, Split, Croatia

Corresponding author: [matteo.barbato.1@phd.unipd.it](mailto:matteo.barbato.1@phd.unipd.it)

Contributing Editor: Fabrizio SERENA

Received: 13 November 2020; Accepted: 3 September 2021; Published online: 14 October 2021

### Abstract

The Mediterranean Sea has a long-lasting history of fishery exploitation that, together with other anthropogenic impacts, has led to declines in several marine organisms. In particular, elasmobranch populations have been severely impacted, with drastic decreases in abundance and species diversity. Based on their experience, fishers can provide information on marine species occurrence, abundance and behavioural traits on a long-term scale, therefore contributing to research on the poorly studied biological aspects of elusive or rare elasmobranch species. In this study, for the first time, the Local Ecological Knowledge (LEK) of fishers was applied to study the behavioural traits of sharks, rays and skates in 12 FAO-GFCM geographical sub-areas (GSAs) of the Mediterranean Sea. This study found both new insight and proved the reliability of LEK-based catch seasonality, reflecting seasonal movements, by comparing LEK-based findings and available literature on five elasmobranch taxa (*Mustelus* spp., *Squalus acanthias*, *Raja* spp., *Myliobatis aquila* and *Scyliorhinus stellaris*) in the Adriatic Sea and 7 taxa (*Mustelus* spp., *Raja* spp., *Prionace glauca*, *Scyliorhinus canicula*, *Torpedo* spp., *Pteroplatytrygon violacea* and *Isurus oxyrinchus*) in the remaining

Mediterranean GSAs. In addition, LEK provided new insights into a novel comprehensive representation of species aggregations (*Mustelus* spp., *S. acanthias*, *M. aquila* and *S. canicula*) in the sampled GSAs and supplied the first descriptions of the size, number of individuals and sex composition of the aggregations. When the limits and shortcomings of LEK-based research are considered, this methodology can be a complementary and cost-effective tool used to study elasmobranchs in either a data-poor scenario or a scenario in which a baseline is missing. LEK can also be useful for the evaluation and inclusion of fishers' perceptions of bottom-up management and to provide important evidence for conservation plans.

**Keywords:** Fishery; space use; aggregations; migration; management; shark; ray.

---

## Introduction

The study of different aspects of the biology of elasmobranchs, a class of cartilaginous fish including sharks, rays and skates, has always been challenging. Their generally low abundances compared to other marine taxa, such as most teleosts, and their elusive nature makes several elasmobranch species difficult to observe and study in the field (Chin & Pecl, 2019; Bargnesi *et al.*, 2020). Therefore, these difficulties have led to a paucity of published data on the behaviour and ecology of elasmobranchs, such as the use of space by the animals at different life stages or sexes as well as the movements, mating and feeding behaviours of the animals. Since these species constitute the target or accidental catch of a wide range of fisheries, such as longliners, trawlers and gillnets, landing data often constitute the most accessible source of information in developed countries (Casey & Myers, 1998; Morgan & Burges, 2005; Serena, 2021). Fishery-independent methods also represent powerful tools to study these species, including scientific surveys (see, for instance, Sguotti *et al.*, 2016), satellite tracking (Hammerschlag *et al.*, 2011), and, more recently, environmental DNA analyses (Bakker *et al.*, 2017) and the citizen science approach (Chin & Pecl, 2019; Bargnesi *et al.*, 2020).

Sharks, rays, and skates are particularly exposed to human activities such as habitat degradation, fishery exploitation and pollution (Myers & Worm, 2003; Barría *et al.*, 2015). One-quarter of chondrichthyans (including chimaeras) are estimated to be threatened by extinction at the global scale (Dulvy *et al.*, 2014). The risk of extinction increases in small ocean basins, such as the Mediterranean Sea; according to the last IUCN regional assessment, in the Mediterranean Sea, among the 73 assessed species (in a total of 88 species registered in the Mediterranean Sea; Serena *et al.*, 2020), 20 are listed as “Critically Endangered” and 11 as “Endangered” (Dulvy *et al.*, 2016). Gaps in the knowledge of some elasmobranch species have not been filled despite research advancements. There are 13 data-deficient species living in the Mediterranean Sea (Dulvy *et al.*, 2016).

The vulnerability of elasmobranchs to fisheries and other anthropogenic activities is tightly related to their life history and behavioural traits. Slow growth rates, late maturity at large sizes, long pregnancies, the deposition of eggs on the seabed and generally large body sizes are recognised as factors that make these species vulnerable and poorly resilient to overexploitation (Ricklefs, 1979; Dulvy & Reynolds, 2002; Field *et al.*, 2009). Additional-

ly, behaviours such as long migrations, sexual segregations, aggregations for reproduction and site fidelity, and the need for specific, often coastal, areas as nurseries are known to contribute to the risks associated with elasmobranch survival and reproduction and thus to their decline (Maguire *et al.*, 2006; Jacoby *et al.*, 2012; Braccini *et al.*, 2016; Byrne *et al.*, 2017; Dulvy *et al.*, 2017).

The gaps in knowledge encompass several aspects of elasmobranch biology, from their current geographical distribution to the details of their life-history traits and from their trophic ecology to their use of space and behavioural traits (Huepel *et al.*, 2019). Additionally, the incorporation of specific information on these aspects is essential for developing appropriate and effective management strategies (Jacoby *et al.*, 2012; Chapman *et al.*, 2015; Braccini *et al.*, 2016). While several studies in the Atlantic and Pacific Oceans have been performed on the social behaviours, movements and migration of elasmobranchs (see, for review, Jacoby *et al.*, 2012; Braccini *et al.*, 2016), very little information is currently available in the Mediterranean Sea (Abudaya *et al.*, 2018; Barash *et al.*, 2018; Chaikin *et al.*, 2020).

The movements, use of space, and behavioural traits such as the occurrence of sexual segregations, social interactions, and aggregations of elasmobranchs may be investigated using different tools and approaches, such as the application of satellite and radio tracking, genetic analyses, and fishery data (Hammerschlag *et al.* 2011; Chapman *et al.*, 2015). These approaches may also be combined (Kessel *et al.*, 2014).

An emerging approach to studying wildlife is represented by the collection of information from nonscientist stakeholders. In particular, so-called Local Ecological Knowledge (LEK), i.e., the knowledge that people in direct contact with wildlife may have on species/ecosystems, often as the result of extensive observation, is increasingly recognised as an important source of information (Huntington, 2000; Anadón *et al.*, 2009; Albuquerque *et al.*, 2021). In the marine environment, LEK usually involves fishers and has been demonstrated to provide relevant information, mainly on species abundances and distributions and their changes over time (e.g., Azzurro *et al.*, 2011, 2019; Maynou *et al.*, 2011; Fortibuoni *et al.*, 2016; Bastari *et al.*, 2017; Peñaherrera-Palma *et al.*, 2018; Taylor *et al.*, 2018; Colloca *et al.*, 2020), as well as on seascape management (Berkström *et al.*, 2019). For some species, LEK may also provide information on the habitat, diet, reproductive season and even behaviours, such as the occurrence of aggregations (Colin *et al.*, 2003; Moreno *et al.*, 2007; Gerhardinger *et*

*al.*, 2009; Begossi, 2008; Begossi *et al.*, 2019).

Fishing practices are often tightly linked to the knowledge of the behavioural traits of a species, and fishers may adjust fishery activities according to species migrations and uses of space (Moreno *et al.*, 2007). Moreover, fishery exploitation of spawning aggregations is a well-known phenomenon for species such as groupers (Sadovy de Mitcheson & Colin, 2011; Russel *et al.*, 2014), but shark aggregations are also known and exploited (Bada-Sánchez *et al.*, 2019). Therefore, experienced fishers may highly contribute to the knowledge of these biological aspects. The involvement of fishers in gathering information may also constitute the first step towards a comanagement approach (Begossi, 2008; Berkström *et al.*, 2019), especially if fishers perceive these species as important for ecosystems.

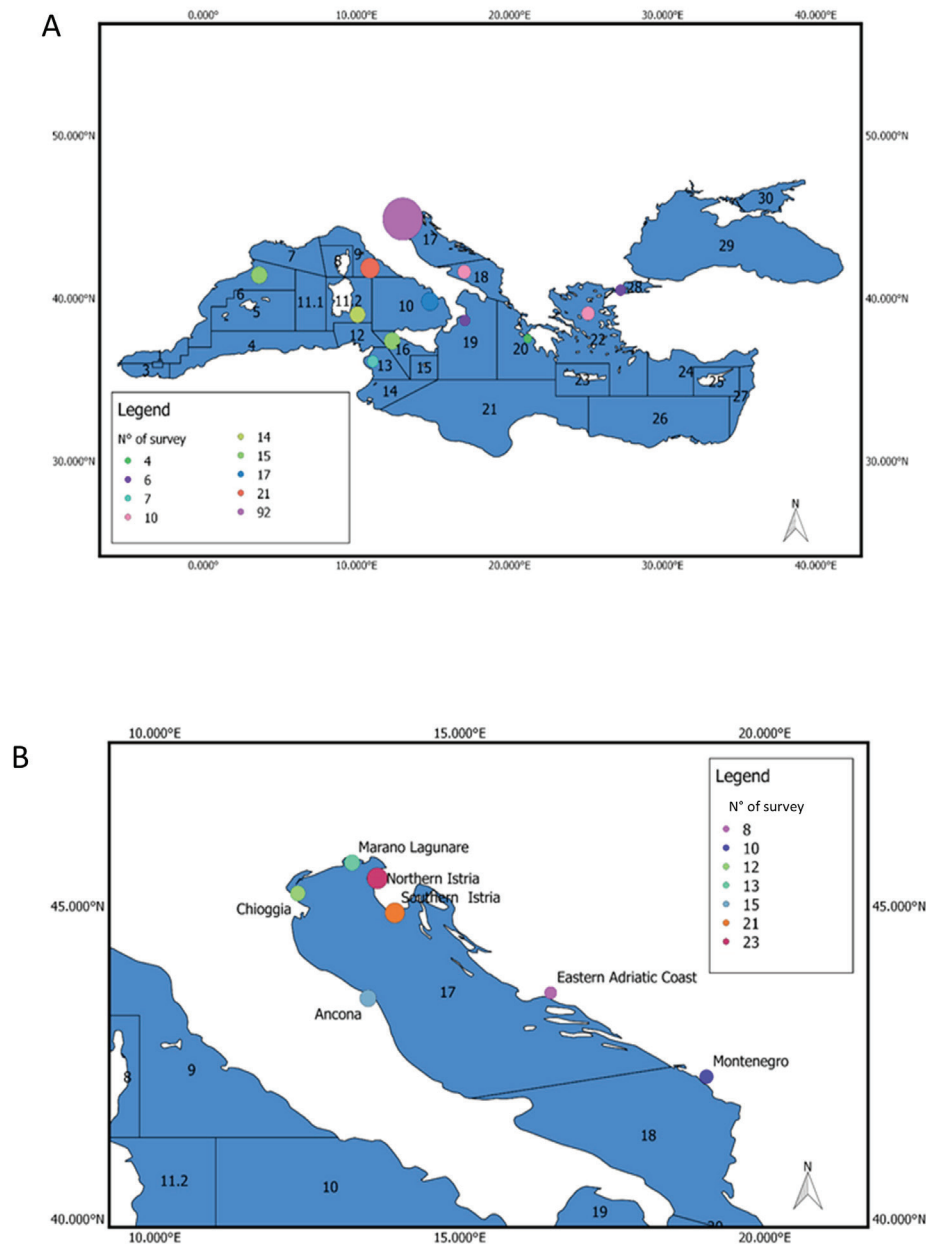
This study aims to benefit from the experience gained by fishers in the Mediterranean Sea to 1) evaluate the

potential of LEK in reconstructing the behavioural traits of elasmobranchs, in particular movements and aggregations, and 2) collect fishers' perceptions on the relevance of elasmobranch to fisheries and their conservation importance.

## Materials and Methods

### Study area

The survey was conducted opportunistically in several locations in the Mediterranean Sea, in 12 (6, 9, 10, 11, 13, 16, 17, 18, 19, 20, 22 and 28) out of the 30 Mediterranean GSAs (Resolution GFCM/33/2009/2; FAO, 1990-2021) (Fig. 1a) and in seven countries (Italy, Croatia, Montenegro, Greece, Spain, Tunisia and Turkey). The number of interviews per site depended on fishers' availability and



**Fig. 1:** Sampled GSA of the Mediterranean Sea with a focus on Adriatic sampling points. Coloured bubbles represent the number of interviews in (A) the different Mediterranean GSAs and (B) sampling sites in the Adriatic Sea.

actual opportunities to interview them. In GSA 11, fishers operate in both GSA 11.1 and 11.2, hereafter referred to as GSA 11. Within GSAs 17 and 18, seven different sites were sampled: Ancona (ANC), Chioggia (CHIO), Marano Lagunare (ML), northern Istria (NI; including Funtane, Novigrad, Poreč, Savudrija, Umag, Vabriga, and Vrsar), southern Istria (SI; including Banjole, Pula, Rovinj, and Rabac), the eastern Adriatic coast (EAC; including Crikvenica, Dubrovnik, KrK, Lošinj, Punat, Primošten, Privlaka, Split, and Zadar) and Montenegro (MON; including Bar, Budva, Herceg Novi, Tivat, and Ulcinj) (Fig. 1b).

Starting from previously available studies (see, for instance, Azzurro *et al.*, 2011, 2019; Maynou *et al.*, 2011), a semistructured questionnaire was developed and translated into different languages. The questionnaire response collection was carried out by trained marine biologists assisted with species tables to allow accurate taxonomic identification by fishers. To facilitate fisher collaboration, all interviewers were local and had previous experience working with fishers. The interviews were completed between spring 2017 and spring 2019.

Fisher interviews were structured in five sections: (i) demographics and technical information (question numbers, QNs, 1 to 3); (ii) description of catch abundance and diversity (QNs 4 to 12); (iii) knowledge about elasmobranch movement and catch seasonality (QNs 13 to 15); (iv) knowledge about elasmobranch aggregations (i.e., a conspecific and high-density aggregation during a specific time of the year; Colin, *et al.*, 2003; Sadovy de Mitcheson & Colin 2011) and their characteristics (QNs 16 to 20); and (v) fisher opinion on the elasmobranch role and value in the marine environment (QNs 21 to 23) (Supplementary data, Fig. S1).

In the first section, personal information (fisher age and years of fishing experience) and information on the fishery (gear type, number of fishing trips per year, past and present fishing areas) were included. The gear types were categorised into gillnets (GNS), longlines (LLS), bottom otter trawls (OTB), beam trawls (TBB) and others, such as purse seines (PS) and traps (FPO).

The catch data section (QNs 4 to 12) included information on four time periods of twenty years each (1940-1960, 1960-1980, 1980-2000 and 2000-present). The interviewed fishers were asked to indicate the relative abundance of sharks, skates and rays in the four time periods, naming the species in an open question and choosing among five categories (Very abundant - more than 3 times more abundant in comparison to the present; Abundant - twice more abundant than in the present; The same; Less abundant; No assessment). The fishers were then asked to indicate the main species perceived as declining or disappearing and if they witnessed any change in size. These data were collected to provide a key for the interpretation of the general framework of species presence in the different Mediterranean areas according to fisher perception and therefore to help to understand the answers of the fishers to the following questions.

Seasonality (QNs 13 to 15) was investigated by collecting responses on the main seasons of catch and the main migration drivers (e.g., reproduction, foraging or

abiotic factors).

In the fourth section, questions on elasmobranch aggregations included their occurrence (QN 16), frequency (QN 17) and features such as number, size, and sex composition over the four abovementioned periods (QN 18). Additionally, the area where and the period of the year when the aggregation takes place were assessed (QNs 19 and 20).

Finally, fishers were asked to express their opinion on the ecological value, commercial significance and conservation importance of sharks, skates, and rays, as well as what measures they would adopt to conserve the species (QNs 21, 22 and 23).

### Data processing and analyses

No-answer entries (NA) and null answers (NULL) were identified and discarded because they were too vague (e.g., use of general terms such as shark, ray, and skate instead of specifying a species name) throughout the whole questionnaire. Concerning the second section (description of catch abundance and diversity), the ranges of the frequency of NA and null answers were between 18% and 30%. The third section, regarding the catch season (movement and catch seasonality), had an overall frequency of discarded NA and null answers of 14%. To depict general patterns, a minimum response threshold was set in which only species that were indicated by at least 25% of the interviewees in each GSA were considered (Supplementary data, Tables S1 and S2). Genera were used instead of species when scientific names were not reported in the answers (e.g., *Raja* spp. and *Mustelus* spp.). The fourth section (elasmobranch aggregations and their features) had different percentages of NULL and NA answers among different periods, with valid answers collected only for the 1960-1980 period. Data on aggregation features were retrieved while considering only the last three time frames (1960-1980, 1980-2000 and 2000-present) and keeping the Adriatic and other GSA entries separate (Tables S3 and S4). The other GSA data were pooled together due to the limited sample size (Table S5). QNs 14, 15, 19 and 20, from the third and fourth sections, were excluded from further analyses because of overall inconsistent and generalist answers. Only a few fishers marked an aggregation area on the provided map; thus, this part was not included.

Data on fisher age, years of fishing activity and annual fish trips were evaluated to check similarity by the Kruskal–Wallis test in R studio (R Studio team 2020).

For the questions related to the second section (catch abundance and diversity), the interviews were analysed according to GSA (GSA 22 and 28 were grouped since fishers from GSA 28 declared to also fish in GSA 22) and period (A: 1940-1960; B: 1960-1980; C: 1980-2000; D: 2000-present). Because the different species of the genera *Mustelus* (Marino *et al.*, 2018) and *Alopias* (Serena *et al.*, 2005) present similar morphological traits, thus possibly favouring misidentification, we chose to pool together in the genus all answers related to the species belonging to these taxa.



Data on the declared most-fished species per period and GSA were first transformed into ratios relative to the total number of interviews that answered the related question. Then, the data were analysed by calculating a Bray-Curtis similarity matrix and were represented through cluster analysis (group average as cluster mode). SIMPER analysis was applied to investigate which main species were responsible for the similarity within each GSA, with a threshold of 10% relative contribution to the similarity. Multivariate analyses were performed using Primer 6 and PERMANOVA plus (Clarke & Gorley, 2006; Anderson *et al.*, 2008).

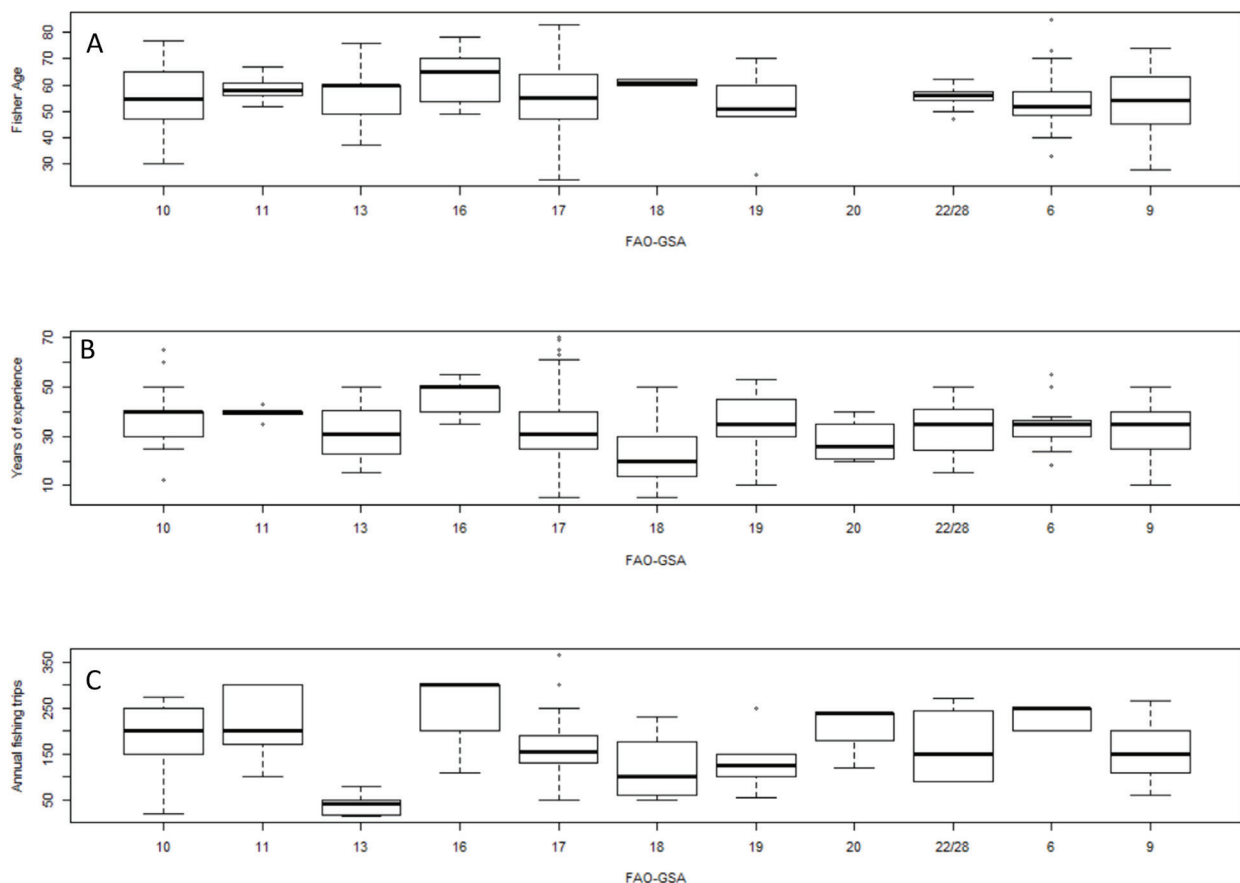
To analyse which species were declared to have declined (from the answers to questions in the catch abundance and diversity section), the data on the declined species per GSA were transformed into ratios relative to the total number of interviews that answered the related question.

Only in the Adriatic Sea seasonality data were transformed by ratios over the total number of interviews and visualised by QGIS (<https://qgis.org>) according to the geographic area or city. To investigate whether the fishers' knowledge about seasonality was related to the fishers' experience (years of fishing activity, days of fishing and change in fishing area) and whether seasonality varied according to sub-basins, we applied generalised linear modelling (GLM) (Dobson & Barnett, 2008) by using R (R studio team, 2020). The presence of seasonality was considered a binomial (yes/no) dependent variable. Three

Mediterranean areas, the Adriatic Sea (GSAs 17 and 18), Central-Western Mediterranean (GSAs 6, 9, 10, 11, 16, 13) and Eastern Mediterranean (GSAs 19, 20, 22, 28), were considered categorical dependent variables, and years of fishing experience, days of fishing and change in the fishing area (binomial, yes/no) were used as independent variables. Years of experience and fishers' age showed collinearity, so only the first was kept in the analysis. Based on the Akaike information criterion (AIC) values, the best GLM model was chosen.

## Results

In total, 218 questionnaires were collected in the 12 GSAs of the Mediterranean Sea (Fig. 1a). The Adriatic Sea (GSAs 17 and 18) was the sub-basin where the largest number of interviews was gathered ( $N = 92$ ) (Fig. 1b). In the other areas, the number of interviews varied from 4 to 21 per GSA. The age of the fishers was not different between GSA (Kruskal–Wallis chi-squared = 7.3876,  $df = 10$ ,  $p$  value = 0.6884), whereas year of fishing activity (Kruskal–Wallis chi-squared = 21.104,  $df = 11$ ,  $p$  value = 0.0323) and number of fishing trips (Kruskal–Wallis chi-squared = 65.179,  $df = 11$ ,  $p$  value =  $9.971e-10$ ) significantly differed among sampled GSA (Fig. 2a, 2b, 2c). Many interviewed fishers (65%) did not change the fishing area from the beginning of their activity compared to the current one, whereas 31% of them operated in other



**Fig. 2:** Boxplots reporting the data on interviewed fishers for each GSA. A) Fisher age. B) Years of fishing experience. C) Annual fishing trips.

areas within the same GSA, and 9% did not reply. Nearly all fishers had caught sharks in the past (96%), as in the present (90%). Likewise, rays and skates were frequent catches in the past (95%) and the present (81%). Across GSAs, the fishers' LEK was based on different fishing gear (Table S6), among which the TTB was sampled only in GSAs 13, 17 and 28 and the PTM was sampled only in GSAs 6, 17, 18 and 28. LEK based on GNT fishers was not collected in GSA 6 or GSA 28. The LLS and OTB gears were represented in every GSA.

No LEK-based information was gathered for the periods 1940-1960 and 1960-1980 for either shark or ray/skate abundance catches. Between 1980 and 2000, shark catches were higher than those at present. In detail, forty-two percent of fishers in all sampled GSAs indicated that catches were either twice (21%) or three times (21%) more abundant than in the present, while 25% perceived that catch abundance remained the same. Only 9% indicated that catches were less abundant between 1980 and 2000 than at present.

For rays and skates, fishers highlighted a sharp decline in catch abundance in the last twenty-year period; 30% of fishers expressed present catches as being less abundant, 34% described them as remaining the same, and only 16% suggested an increase in captures compared to the present. Similar to sharks, in the 1980-2000 period, ray and skate catches were shown to be greater than those in the present. Between 2000 and the present, a decline in catches was highlighted as well (Fig. 3a and 3b).

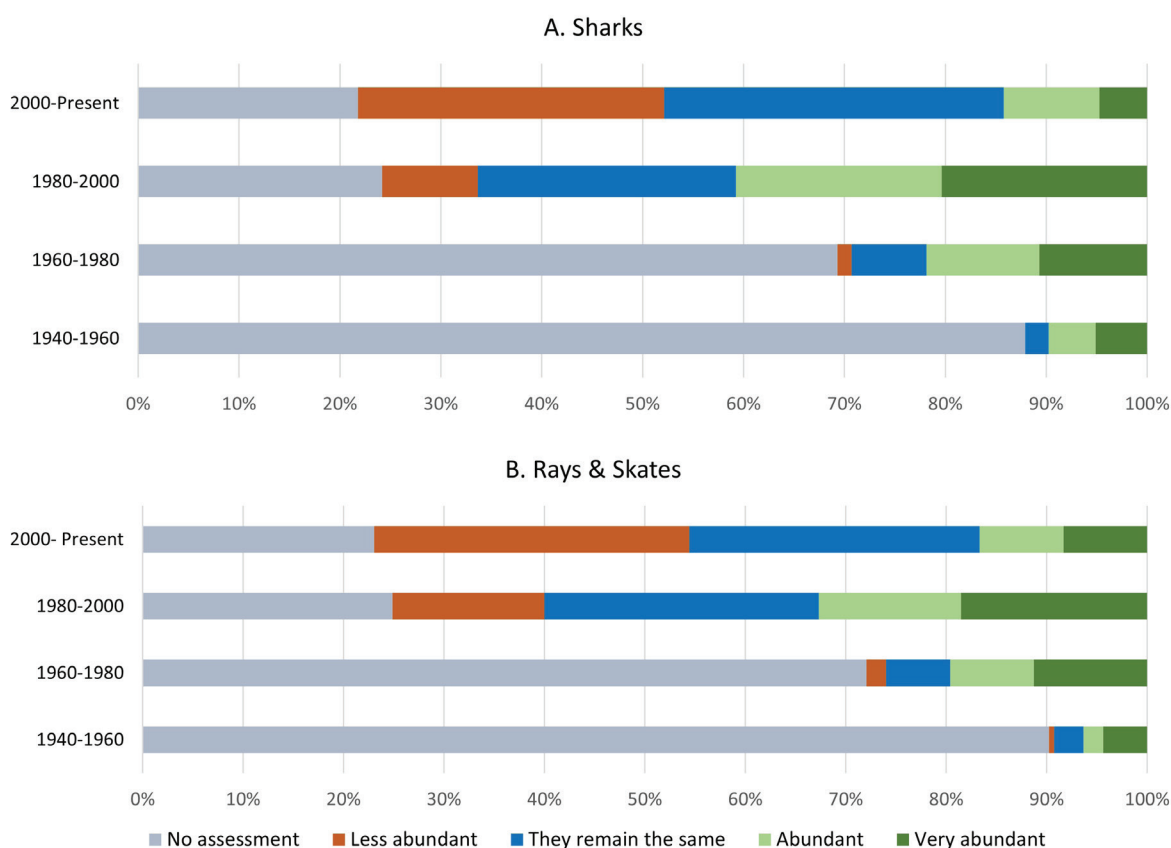
### Most-fished species

Considering the species that were declared to be the most fished reported per period and GSA, the cluster analysis grouped the samples mainly according to geographic area, regardless of the period (Fig. 4). However, clustering was not completely related to the contiguity of the GSAs; some GSAs were clustered with other distant GSAs (see, for instance, the clustering of GSA 9 with GSAs 17 and 18). Within each GSA, some temporal trends are recognisable, with sample clustering mainly by period. SIMPER analyses identified the main species responsible for the similarity within each GSA, therefore characterising the different GSAs (Table 1).

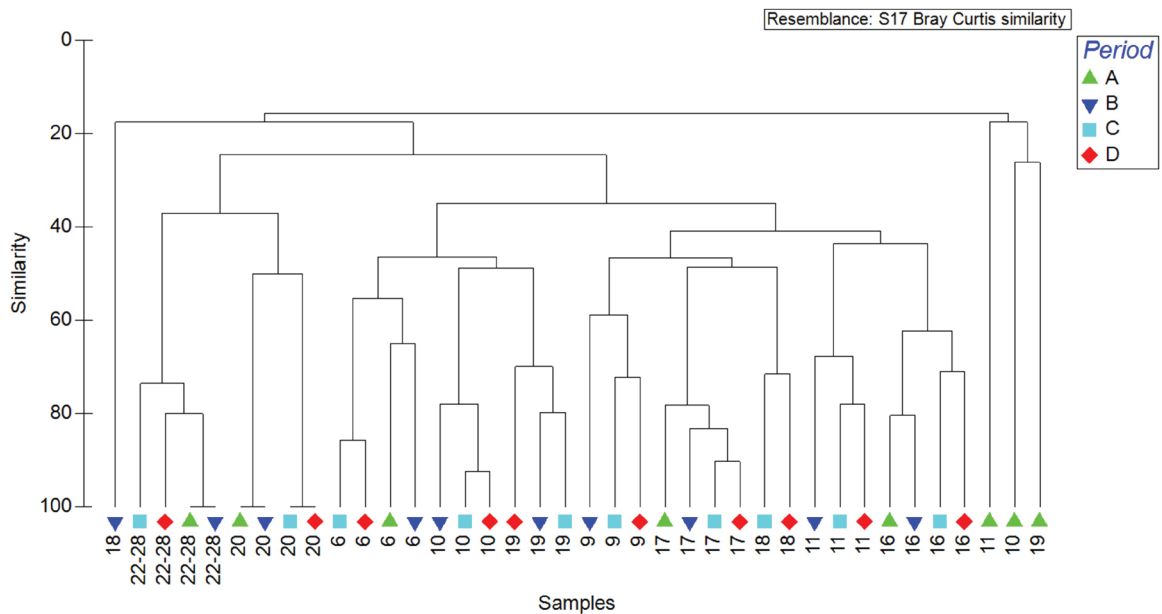
### Declined species

Fishers indicated that 40 species declined in their fishing areas. The species that were perceived as declining the most, in more than half of the analysed GSAs (11 GSAs, with GSAs 22 and 28 grouped), were *Alopias* spp. and *Mustelus* spp., with 8 GSAs reporting their decline over time, followed by *S. acanthias*, *P. glauca*, *Squatina squatina* and *Raja clavata*. GSA 17 was the one with the highest number of declining species ( $n = 27$ ), followed by GSA 11, with 17 species shown to have declined.

In general, there was no wide consensus among fishers on the declining species; indeed, the percentage of fishers who indicated that the same species had declined was



**Fig. 3:** Catches in the different time periods of Sharks (a) and Skates and Rays (b).



**Fig. 4:** Cluster analysis of elasmobranch diversity. GSAs are indicated by numbers and time periods by letters (A: 1940-1960; B: 1960-1980; C: 1980: 2000; D: 2000-present).

**Table 1.** Species responsible for GSA similarity, listed by relative contribution (SIMPER analyses).

Species	Average relative presence	Contribution (%)
GSA 6: average similarity 61.67 %		
<i>Scyliorhinus canicula</i>	0.67	18.69
<i>Galeus melastomus</i>	0.55	13.06
GSA 9: average similarity 63.26 %		
<i>Raja clavata</i>	0.43	19.29
<i>Scyliorhinus canicula</i>	0.40	15.50
<i>Raja asterias</i>	0.38	15.50
<i>Pteroplatytrygon violacea</i>	0.28	10.26
GSA 10: average similarity 59.07 %		
<i>Raja clavata</i>	0.91	19.77
<i>Prionace glauca</i>	0.65	12.29
GSA 11: average similarity 43.23 %		
<i>Scyliorhinus canicula</i>	0.60	11.73
<i>Raja polystigma</i>	0.56	11.30
<i>Prionace glauca</i>	0.48	10.39
GSA 16: average similarity 66.73 %		
<i>Mustelus</i> spp.	0.80	30.10
<i>Raja miraletus</i>	0.63	26.14
<i>Raja clavata</i>	0.67	19.54
GSA 17: average similarity 81.83 %		
<i>Mustelus</i> spp.	1.00	17.53
<i>Squalus acanthias</i>	0.74	12.64
<i>Raja clavata</i>	0.76	11.16
GSA 18: average similarity 54.04		
<i>Mustelus</i> spp.	0.80	45.73
<i>Myliobatis aquila</i>	0.65	31.50
GSA 19: average similarity 56.93 %		
<i>Prionace glauca</i>	0.60	19.73
<i>Alopias</i> spp.	0.38	12.53
<i>Isurus oxyrinchus</i>	0.43	12.53
<i>Sphyrna zigaena</i>	0.34	11.20
GSA 20: average similarity 77.78 %		
<i>Mustelus</i> spp.	0.25	29.76
<i>Squalus acanthias</i>	0.25	29.76
<i>Scyliorhinus canicula</i>	0.25	29.76
<i>Rhinobatos rhinobatos</i>	0.38	10.71
GSA 22-28: average similarity 80.07		
<i>Dasyatis pastinaca</i>	0.54	18.33
<i>Alopias</i> spp.	0.42	12.77
<i>Scyliorhinus canicula</i>	0.42	12.77
<i>Galeus melastomus</i>	0.42	12.77

generally below 20% among the GSAs (Fig. 5). There are many factors at play, such as the different distributions of elasmobranch species, different fishing pressures, and different gear types. Considering the species most reported by fishers, pelagic sharks such as *P. glauca*, *Alopias* spp. and *I. oxyrinchus* and some demersal species, such as *Mustelus* spp., *S. acanthias*, *S. stellaris* and *S. squatina*, were reported to decline in the Adriatic Sea (GSAs 17 and 18). Similarly, rays and skates such as *R. clavata*, *Raja asterias* and *Raja miraletus* have become less abundant than in the past. In the other sampled GSAs, different species were indicated as relatively abundant. The most-indicated species within GSAs were *Mustelus* spp. in GSAs 9 and 11, *S. acanthias* in GSA 9, *Squatina* spp. in GSA 11, *R. clavata* in GSA 6, *Aetomylaeus bovinus* in GSA 19, *Dipturus oxyrinchus* in GSA 6, and *Rhinobatos rhinobatos* in GSAs 16 and 20 (Table 2). The other survey questions in this section (QNs 6, 7, 10 and 11) were not included in the analyses due to the extensive lack of answers.

### Seasonality

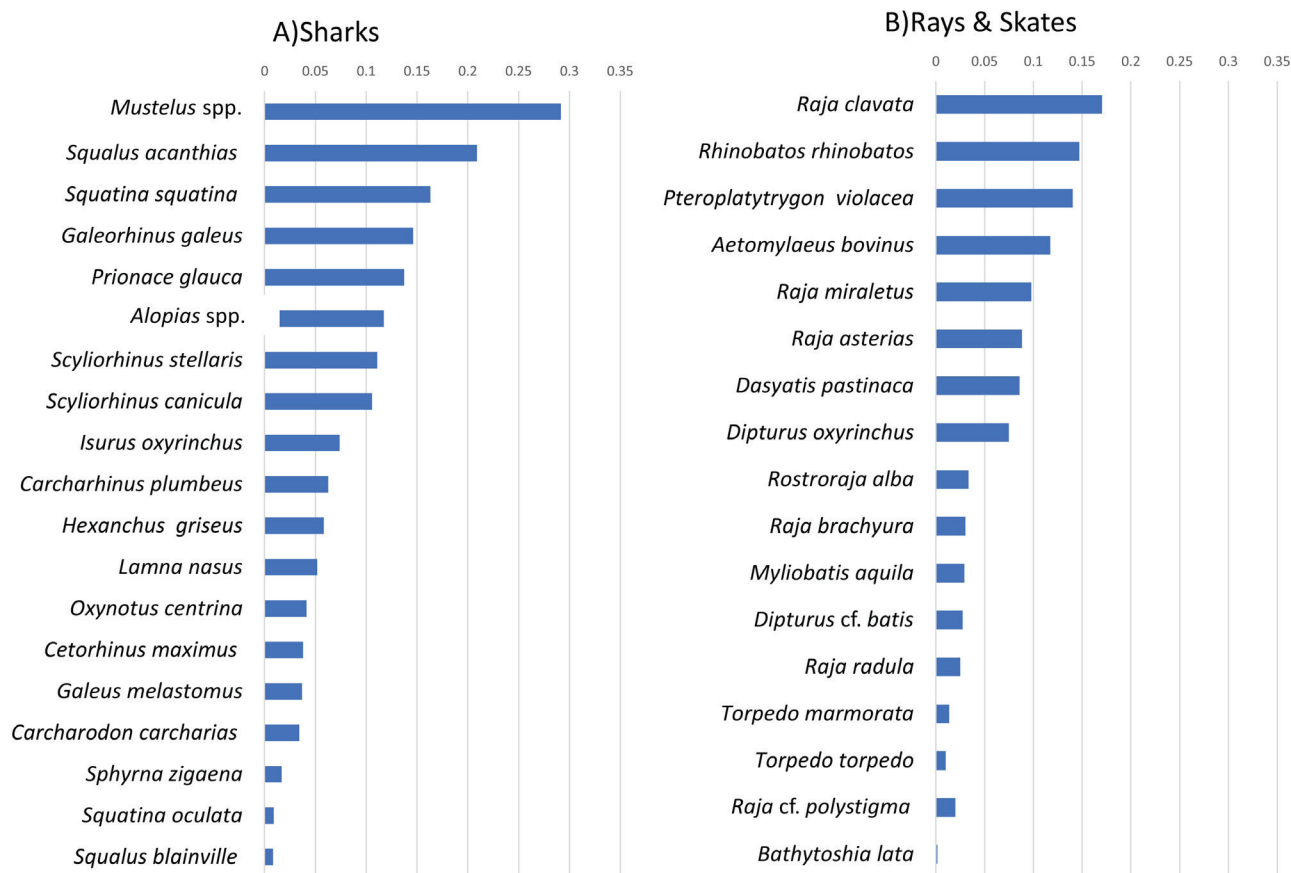
The seasonality of catches was indicated for 5 elasmobranchs (*Mustelus* spp., *S. acanthias*, *Raja* spp., *M. aquila* and *S. stellaris*) in the Adriatic Sea and 7 (*Mustelus* spp., *Raja* spp., *P. glauca*, *S. canicula*, *Torpedo* spp., *P.*

*violacea* and *I. oxyrinchus*) in the remaining Mediterranean GSAs.

According to the lowest AIC value, the best-fit model (dispersion parameter equal to 0.8) included the Mediterranean subdivisions, years of fishing experience, fishing days and fishing area as variables (Table 3). The GLM parameters showed that species seasonality was correlated with the considered subdivisions (Adriatic Sea and Central-Western Mediterranean, both  $p$  values  $< 0.001$ , and Eastern Mediterranean,  $p < 0.05$ ), whereas years of experience of the fishers, days of fishing and fishing area change were found not to be significantly correlated with the occurrence of seasonality (Table 4).

Adriatic fishers indicated a north-south (GSAs 17) and in-offshore migration (GSA 18) of *Mustelus* spp., as represented by a stronger seasonality of catches in the north (CHIO, NI and ML) in summer than in the SI site. At the central and southern sites of the Adriatic (EAC and MON), strong seasonality also emerged in summer. Winter was broadly a time period with low catches (Fig. 6a).

*S. acanthias* did not show any clear pattern of seasonality across the Adriatic sites, except for ECA and MON, where catches reached a peak between spring and summer (Fig. 6b). *M. aquila* showed a marked peak at the northeastern sites (ML and NI) in summer. In contrast, this species presented no seasonality at the ECA site (Fig. 6c). Regarding *Raja* spp., LEK information showed that catches were equally common throughout the year,



**Fig. 5:** Declined sharks (A) and rays and skates (B) according to fishers' perception (ratio calculated over the total answers for each species).



**Table 2.** Species indicated to be declined in each GSA. The ratio consists of species frequency in the answers over the total.

GSA	Species	Ratio
GSA6	<i>Raja clavata</i>	0.57
	<i>Prionace glauca</i>	0.36
	<i>Cetorhinus maximus</i>	0.36
GSA9	<i>Mustelus</i> spp.	0.76
	<i>Squalus acanthias</i>	0.41
GSA 10	<i>Lamna nasus</i>	0.43
	<i>Pteroplatytrygon violacea</i>	0.33
	<i>Raja clavata</i>	0.33
	<i>Raja miraletus</i>	0.33
	<i>Rostroraja alba</i>	0.33
	<i>Aetomylaeus bovinus</i>	0.33
GSA 11	<i>Mustelus</i> spp.	0.58
	<i>Scyliorhinus canicula</i>	0.33
GSA 16	<i>Scyliorhinus stellaris</i>	0.36
	<i>Rhinobatos rhinobatos</i>	0.50
GSA 17	<i>Squalus acanthias</i>	0.45
	<i>Raja clavata</i>	0.42
	<i>Mustelus</i> spp.	0.33
	<i>Prionace glauca</i>	0.33
	<i>Scyliorhinus stellaris</i>	0.32
GSA 18	<i>Mustelus</i> spp.	0.50
	<i>Raja asterias</i>	0.40
	<i>Squalus acanthias</i>	0.30
	<i>Isurus oxyrinchus</i>	0.30
GSA 19	<i>Aetomylaeus bovinus</i>	0.67
	<i>Pteroplatytrygon violacea</i>	0.67
	<i>Dasyatis pastinaca</i>	0.33
	<i>Mustelus</i> spp.	0.33
	<i>Carcharhinus plumbeus</i>	0.33
GSA 20	<i>Rhinobatos rhinobatos</i>	0.75
GSA 22-28	<i>Squalus acanthias</i>	0.33
	<i>Prionace glauca</i>	0.33
	<i>Dasyatis pastinaca</i>	0.33

whereas marked seasonality was reported exclusively in EAC and MON (Fig. 6d). The lack of seasonal movements indicated for *S. stellaris* was not surprising given that this species showed no seasonality in abundance at the ML and NI sites.

Even though it was not possible to sample several sites in the other Mediterranean GSAs, LEK indicates that some species do follow a seasonal trend in catches,

**Table 3.** Formula of tested GLMs and corresponding AIC value.

Models ID	Formula	AIC value
Model 1	glm (formula = Seasonality ~ Subdivision + Years of experience + Fishing days + Fishing area, family = binomial (link = "logit"))	136
Model 2	glm (formula = Seasonality ~ Subdivision + Years of experience + Fishing days, family = binomial (link = "logit"))	147
Model 3	glm (formula = Seasonality ~ Subdivision + Years of experience, family = binomial (link = "logit"))	155

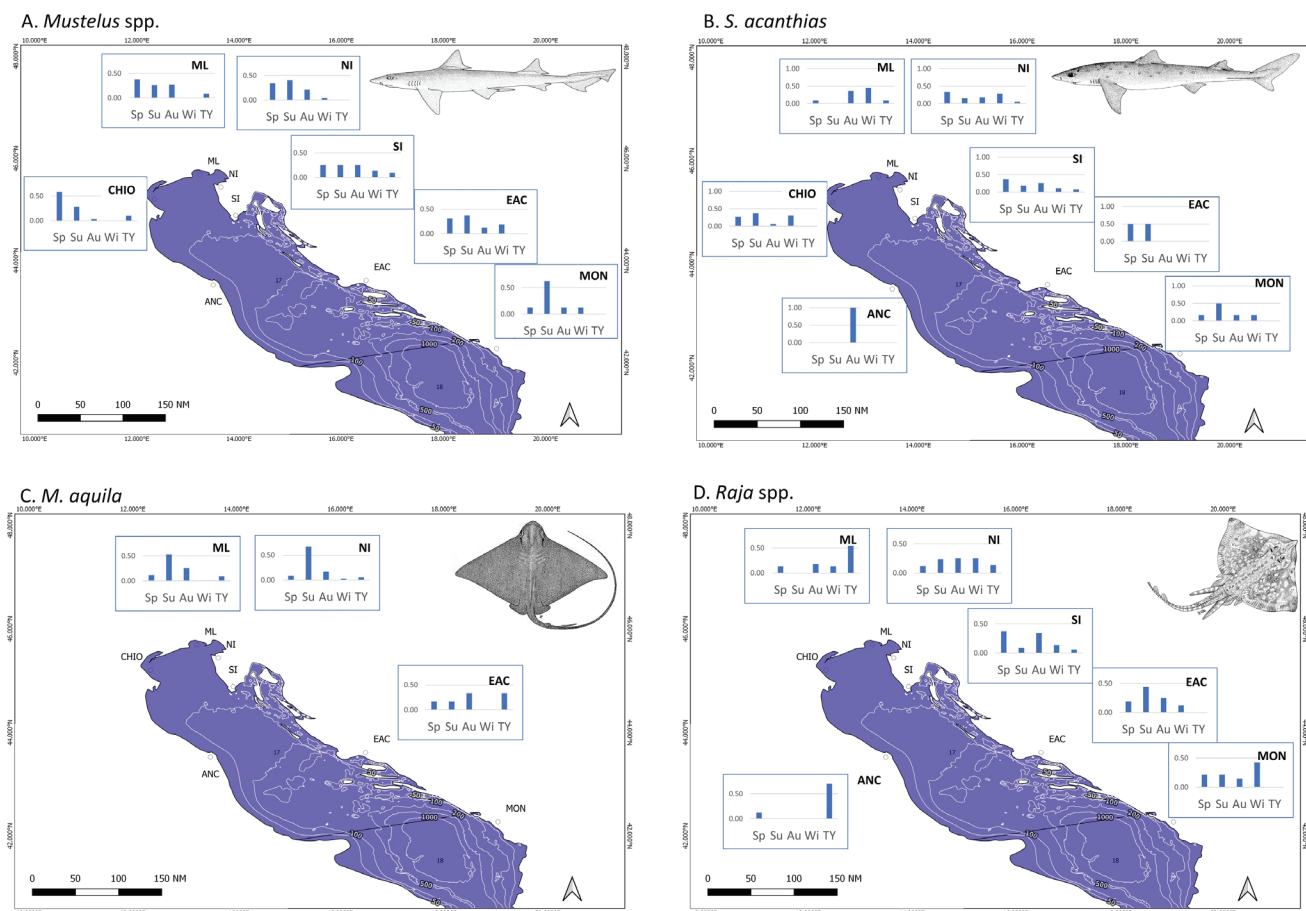
while others appear to have an unclear pattern. For instance, spring and summer seem to be the catch seasons for *Torpedo* spp. (GSAs 11 and 19), *I. oxyrinchus* (GSA 19), *S. canicula* (GSA 11) and *P. violacea* (GSA 6). Moreover, some aspects of species seasonality are consistent with the data from the Adriatic Sea; for instance, *Raja* spp. shows highly variable seasonality across GSAs 9, 11, 22/28 and is catchable year-round. In contrast, *Mustelus* spp. does not appear to have strong seasonality in GSA 16, likely since LEK-based information may suffer from seasonal shifts in the fishery distribution in that GSA. *P. glauca* catches present an equivocal pattern; no seasonal trend appears in GSAs 19 and 6, while the species is likely to occur in autumn and winter in GSA 9 (Table 5).

### Aggregations

Many fishers experienced the occurrence of elasmobranch aggregations in the Mediterranean Sea, either through catches or visual witnesses. In the Adriatic Sea, such events were experienced by 80% of the interviewed fishers, while 13% did not report having experienced them, and 7% did not answer. *Mustelus* spp. (57%), *S. acanthias* (32%), *M. aquila* (26%) and *Raja* spp. (11%) were the most frequent species caught in aggregations in both GSA 17 and 18. Other species, such as *P. glauca* and *Dasyatis pastinaca*, were indicated to be rare catches in aggregations (Fig. 7). In the other sampled GSAs, a large portion of the interviewed fishers (58%) confirmed having fished on an elasmobranch aggregation. In comparison, 31% of fishers declared to have not had this experience, and 11% did not answer. By com-

**Table 4.** Model 1: Estimated regression parameters, standard errors, z-values and P-values. Significant values in bold.

Variable	Estimate	Std. Error	z-value	p-value
Adriatic Sea	3.756273	1.012022	3.712	< <b>0.001</b>
Central-Western Mediterranean	-3.182497	0.669038	-4.757	< <b>0.001</b>
Eastern Mediterranean	-1.775696	0.896434	-1.981	< <b>0.05</b>
Years of experience	-0.004263	0.019640	-0.217	> 0.05
Fishing Days	-0.002594	0.003186	-0.814	> 0.05
Fishing Area	0.138850	0.547402	0.254	> 0.05



**Fig. 6:** Seasonality of *Mustelus* spp., *Squalus acanthias*, *Myliobatis aquila*, *Raja* spp. as perceived by fishers at the Adriatic sites: Ancona (ANC), Chioggia (CHIO), Marano Lagunare (ML), northern Istria (NI) and southern Istria (SI), the eastern Adriatic coast (EAC) and Montenegro (MON). The ratio of answers over the total in the four seasons (spring (SP), summer (SU), autumn (AU) and winter (WI) and throughout the year (TY).

**Table 5.** Seasonality in Mediterranean GSAs (Italy (ITA), Turkey (TUR), Spain (SPA)). GSAs 17 and 18 are not included. Values are reported as a ratio, meaning the frequency of each species in fisher's answers over the total. Throughout the year (TY).

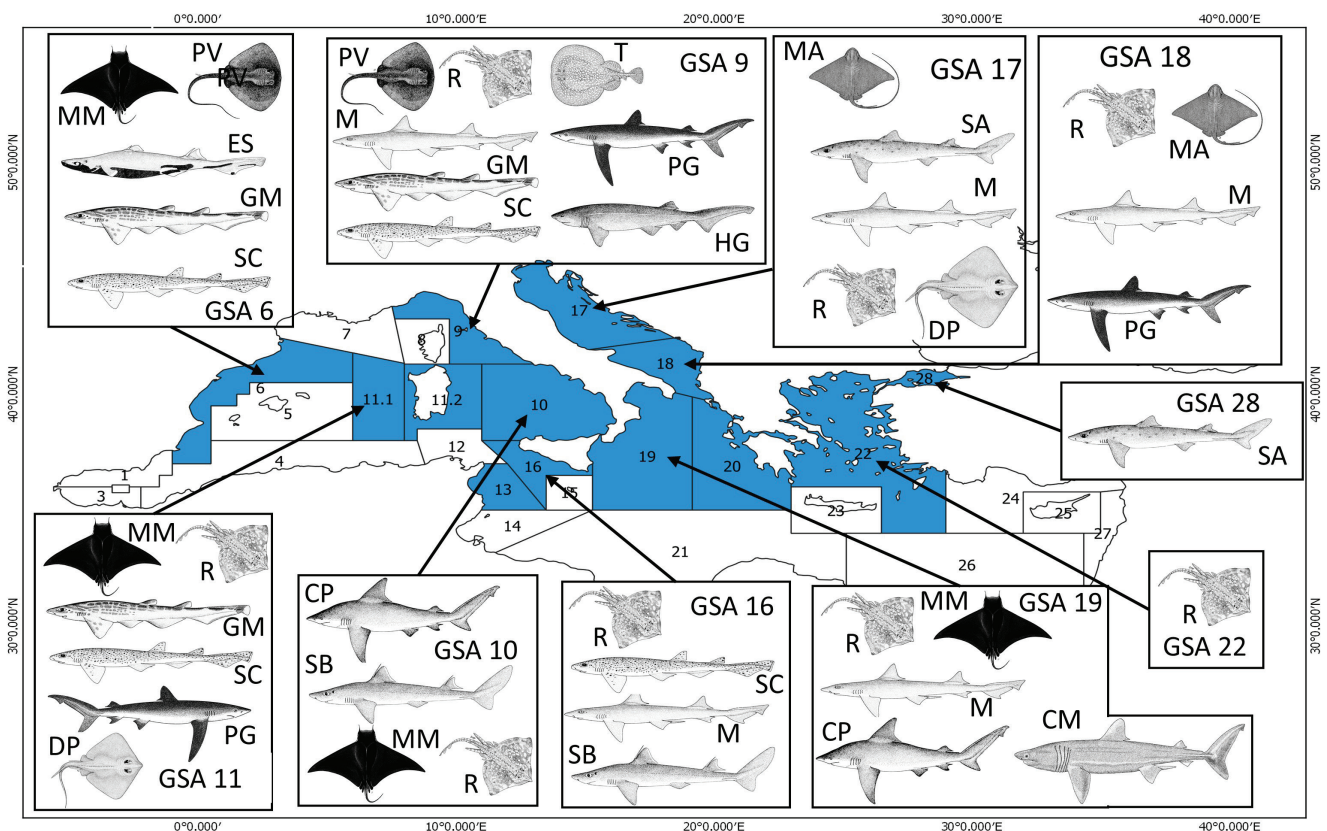
GSA	Country	Species	Spring	Summer	Autumn	Winter	TY	N
9	ITA	<i>Raja</i> spp.	0.1	0.2	0.3	0.3	0.1	21
9	ITA	<i>P. glauca</i>	0.0	0.0	0.5	0.5	0.0	21
28/29	TUR	<i>Raja</i> spp.	0.8	0.0	0.0	0.0	0.3	10
11	ITA	<i>Raja</i> spp.	0.5	0.3	0.1	0.0	0.1	14
11	ITA	<i>S. canicula</i>	0.3	0.8	0.0	0.0	0.0	14
11	ITA	<i>Torpedo</i> spp.	0.5	0.5	0.0	0.0	0.0	14
16	ITA	<i>Mustelus</i> spp.	0.1	0.1	0.3	0.2	0.3	15
6	SPA	<i>P. violacea</i>	0.1	0.5	0.0	0.2	0.2	15
6	SPA	<i>P. glauca</i>	0.0	0.5	0.0	0.3	0.3	15
10	ITA	<i>I. oxyrinchus</i>	0.0	0.5	0.5	0.0	0.0	6
19	ITA	<i>P. glauca</i>	0.3	0.2	0.2	0.0	0.3	6
19	ITA	<i>Torpedo</i> spp.	0.3	0.8	0.0	0.0	0.0	6

binning all sampled GSAs, *Raja* spp. (25%), *S. canicula* (19%) and *Mustelus* spp. (14%) appeared to be the most common species caught in aggregations. Other elasmobranchs, such as *Mobula mobular*, *P. violacea*, *Galeus melastomus*, *P. glauca*, *D. pastinaca*, *Squalus blainville*, *Cetorhinus maximus*, *Torpedo* spp., *Etmopterus spinax*, *Hexanchus griseus*, *Sphyrna zygaena*, and *S. acanthias*, were occasionally caught in aggregations. Nevertheless, such events appear to be rare (between 1% and 8% of answers) (Fig. 7). The latter species group includes less commercially relevant species, such as *P. violacea*, *D. pastinaca* and *Torpedo* spp., and rare species, according to the results of this survey regarding the most fished elasmobranchs. Overall, some species aggregations were present in more GSAs than other species. For instance, *Raja* spp. and *Mustelus* spp. aggregations appeared in the highest number of GSAs in eight and five GSAs, respectively (Fig. 7).

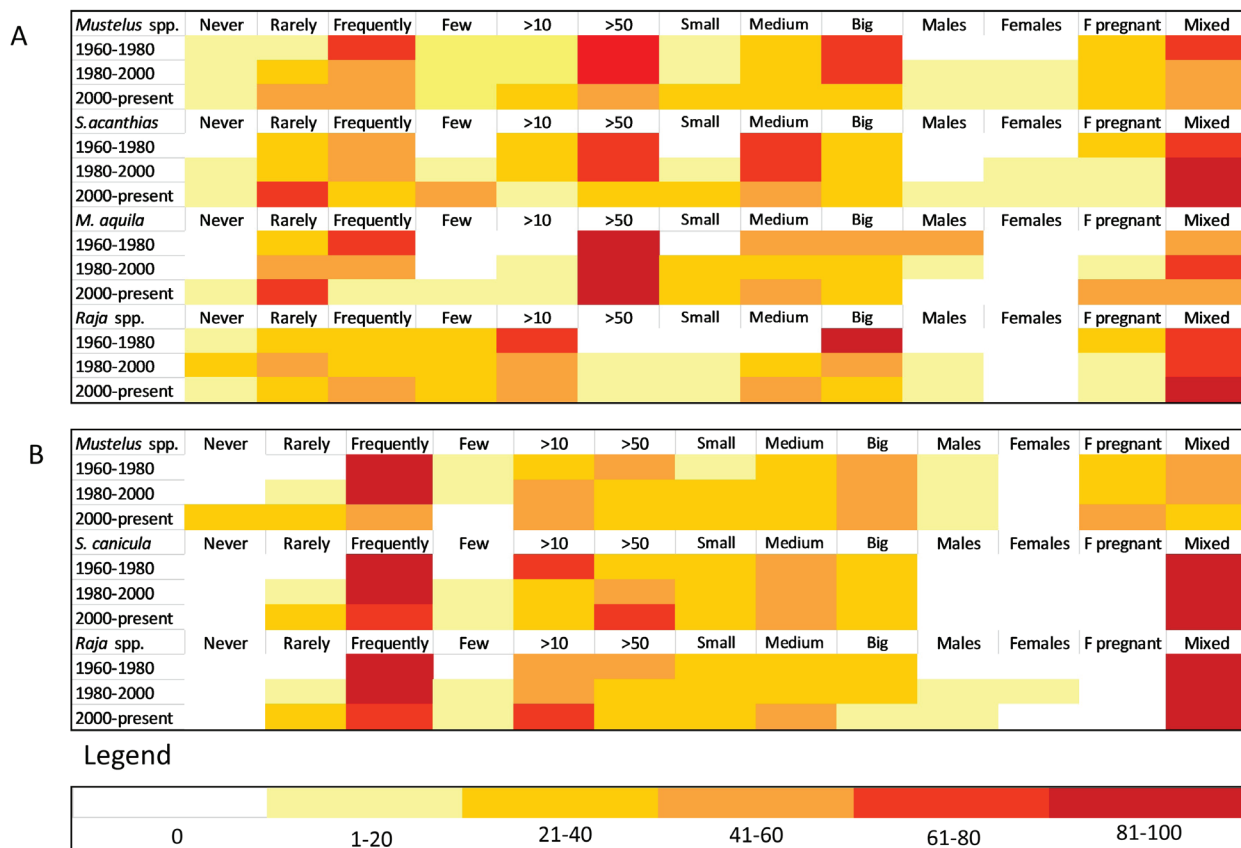
In both the Adriatic Sea and the other Mediterranean GSAs, LEK indicated declining trends in aggregation occurrence for *Mustelus* spp., *S. acanthias*, *M. aquila* and *S. canicula*. Regarding the frequency of *Raja* spp., a slight trend seems to indicate an increase only in the Adriatic Sea (Fig. 8a and 8b).

LEK information allowed the description of some aggregation features, such as individual number, size, and

sex composition (Fig. 8a and b). There is a general consistency in the results among the Mediterranean GSAs regarding the aggregation characteristics of *Mustelus* spp. Comparing the three periods represented by the fishers' answers, more than fifty individuals were usually found in the aggregations, there was a prevalent presence of mixed sexes in the aggregations, and pregnant females were commonly encountered. Adriatic LEK on *S. acanthias* showed that the individual composition of aggregations changed over time in number, decreasing from more than fifty animals to a few per aggregation. The individual size remained the same over time, as did the presence of mixed sexes. The characteristics of *M. aquila* aggregations in the Adriatic Sea were similar across periods; most of the aggregations were formed by more than fifty individuals and were composed of mixed sizes and sexes. *Raja* spp. were frequently found in aggregations that were consistently composed of more than ten individuals and mixed sexes. In all the Mediterranean GSAs, a size reduction was noted for *Raja* spp. aggregations. Only for GSAs 9, 11 and 6 information on *S. canicula* aggregations was collected. The data showed an increase in the number of individuals per aggregation and a constant presence of medium-size individuals. Mixed sexes were common across the investigated periods.



**Fig. 7:** Data on aggregating species in sampled GSAs in the Mediterranean Sea. The absence of icon means zero aggregating species (GSA 19) or no-available data for the GSA (GSA 13). Species name and used abbreviations: *Cetorhinus maximus* (CM), *Carcharhinus plumbeus* (CP), *Dasyatis pastinaca* (DP), *Etmopterus spinax* (ES), *Galeus melastomus* (GM), *Hexanchus griseus* (HG), *Myliobatis aquila* (MA), *Mobula mobular* (MM), *Mustelus* spp. (M), *Prionace glauca* (PG), *Pteroplatytrygon violacea* (PV), *Raja* spp. (R), *Squalus acanthias* (SA), *Scyliorhinus canicula* (SC), *Squalus blainville* (SB), *Sphyrna zygaena* (SZ), *Torpedo marmorata* (TM).



**Fig. 8:** Characteristics of the aggregations of the main elasmobranch species indicated by fishers in the Adriatic Sea (11a) and in other Mediterranean GSAs (11b). Legend by colours refers to answer ratio in percentage.

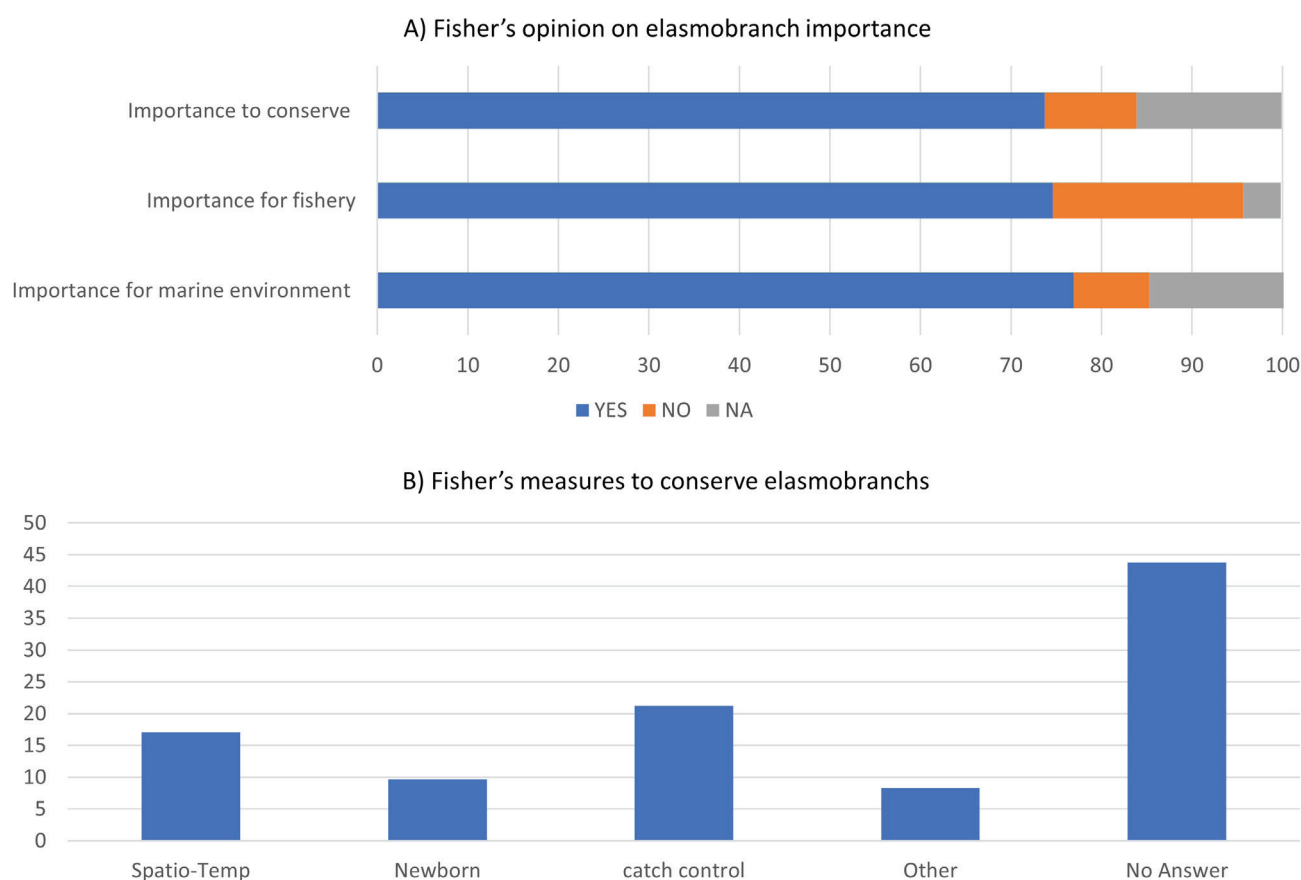
### Fishers' perceptions of elasmobranch value

Regarding the value and role of elasmobranchs in ecosystems, it was generally acknowledged by fishers that elasmobranch species are important for the marine environment (77% YES, 8% NO and 15% no answer-NA). Similarly, sharks, rays and skates were also recognised to have relevant economic value for fishery revenue (75% YES, 21% NO and 4% NA). Interestingly, 74% of the interviewed fishers answered that there is a need for conservation actions for elasmobranchs. In comparison, 10% did not agree, and the rest (16%) of the fishers did not answer the question (Fig. 9a). Fishers in favour of elasmobranch protection indicated three actions: (i) spatial-temporal closures (17%), for instance, during the reproductive season; (ii) release of captured small relative-sized individuals (e.g., newborn or juveniles) as good fishing practice (10%); and (iii) catch control, such as regulation surveillance and enforcement, to more broadly reduce illegal, unreported and unregulated fishing (21%). Other measures made up 8% of the answers, whereas 44% of interviewed fishers did not give any indication of specific measures, although they were in favour of conservation measures (Fig. 9b).

### Discussion

This study has shown that LEK can be useful for collecting behavioural and ecological information on elasmobranch populations. LEK has already proven to be important for studying abundance trends of commercially exploited elasmobranchs in GSA 16 (Colloca *et al.*, 2020) as well as several aspects of other marine species (Azzurro *et al.*, 2011, 2019; Maynou *et al.*, 2011), but this is the first time that the study of elasmobranch behaviour has been applied in Mediterranean GSAs collectively. As a general perspective on LEK-based information, the robustness of the data collected from fishers was supported by their long average fishing experience and by the fact that many fishers did not change fishing areas during their activity, and if changed, the new fishing areas were within the same GSA. As a consequence, the fishers provided long-term data referring to specific areas. Interviewed fishers used different fishing gear and were therefore able to provide information on different species. Their ability to provide a reliable picture is supported by the high correspondence of the species distribution and changes over time reconstructed by fishers' LEK with those evaluated with scientific and fishery surveys in the Mediterranean Sea (Ferretti *et al.*, 2013; Barausse *et al.*, 2014; Colloca *et al.*, 2017; Follesa *et al.*, 2020; Ramírez -Amaro *et al.*, 2020). For instance, according to LEK, *Mustelus* spp., *S. acanthias* and *S. squatina* were widely caught in several GSAs in the past. The decline of these species has already





**Fig. 9:** Elasmobranch importance in the marine environment, fishery revenue and conservation aspects according to fishers (12a). Measures for elasmobranch conservation proposed by fishers: spatial-temporal closure (Spatio-Temp), newborn release (new-born), catch control (e.g., quotas, law enforcement) and others.

been documented in the Mediterranean Sea (Ferretti *et al.*, 2013; Fortibuoni *et al.*, 2016; Colloca *et al.*, 2017; Gordon *et al.*, 2019). Similarly, pelagic species such as *Alopias* spp., *Lamna nasus*, *P. glauca* and *I. oxyrinchus* have recently experienced drastic decreases, and the LEK results indicated similar trends (Ferretti *et al.*, 2008). Conversely, other species have remained at stable levels or are less affected by fishery exploitation, as is the case for *G. melastomus*, *S. canicula* and *R. clavata* in the western Mediterranean Sea (Abella *et al.*, 2017; Ramírez -Amaro *et al.*, 2020) and in the northern Ionian Sea (Serena, 2014; Ricci *et al.*, 2021). If the correspondence between LEK and scientific data is important to evaluate LEK reliability, fishers provided new insights for other species, both commercial, such as *D. oxyrinchus* in GSA 6, and even noncommercial, such as *A. bovinus*, in GSA 19.

### Species seasonality

The present study suggests that LEK can be an important source of information about seasonal migrations of species in the Mediterranean Sea. Several species were indicated by fishers as showing seasonality in catches as the likely consequence of seasonal movements. Moreover, some differences in migratory patterns among areas emerged. It could have been expected that fishers' knowledge of fish movement could be related to their ex-

perience at sea. Our analyses did not show any influence of fishers' experience on this information, highlighting either that our sample included experienced fishers or that even fishers with a short time of activities can have a clear perception of fish movements. Before discussing the results for the different species, it is also worth noting that the distribution of fishing efforts may influence the perceptions of catch seasonality if fishing grounds change seasonally. While this point was not highlighted by fishers, it could limit the reliability of some information, especially in some areas, such as the largest Mediterranean subbasins (e.g., the central, western and eastern Mediterranean areas), and therefore the comparability between areas. However, this issue appears to be less relevant for other areas, such as the Adriatic Sea, where fishery distribution does not show a wide spatial difference across seasons (Russo *et al.*, 2020). In addition, to overcome this potential bias, the 25% answer threshold was set to establish coherence across the fishers' replies. In general, both static and active fishing gear may be used in different areas to follow fish movements; therefore, the use of different fishing gear is not expected to provide differently biased results.

### Species seasonality of demersal species

Migration patterns in the Adriatic Sea have already been suggested for some demersal species (Fortuna *et al.*, 2010; Bonanomi *et al.*, 2018). The application of seasonality in catches as an indicator of seasonal migrations has been proposed for *Mustelus* spp., *S. acanthias* and *M. aquila* (Bonanomi *et al.*, 2018). In the present study, fishers indicated similar seasonality patterns for these species as well.

The LEK from the two sides of the Adriatic Sea provided a more comprehensive picture of the movements of *Mustelus* spp. and *M. aquila* with respect to the available data. For these species, indeed, in the Adriatic Sea, two patterns emerged from LEK: a north-south pattern in the northern Adriatic, as suggested by Bonanomi *et al.* (2018), and an off-inshore pattern in the southern Adriatic. Interestingly, *Mustelus* spp. seasonality at the Montenegro site may indicate a different migration pattern compared to those indicated at the northern Adriatic sites, similar to what was found for other species whose movement is influenced by the abiotic characteristics of the Adriatic Sea (Papetti *et al.*, 2013). The greater depth of the southern Adriatic, in comparison to the northern-central Adriatic, may favour winter migration into deep waters with mild temperatures, which are more favourable for shark physiological needs such as metabolism and somatic growth (Schlaff *et al.*, 2014). Moreover, for *Mustelus* spp. no clear evidence of seasonality emerged in GSA 16. Differences in movement behaviours among areas are not unexpected, considering that the common drivers of such migrations, such as environmental factors, may indeed vary in their seasonality among areas. For instance, compared to the Adriatic Sea, the Strait of Sicily does not have a strong seasonal variation in sea water temperature (Bethoux, 2003).

A comparison of the results between the two coastal areas of the Adriatic Sea showed seasonality but did not reveal any clear pattern (i.e., north-south or west-east movement) in the migrations of *S. acanthias*. In the Atlantic Ocean, this species can have different movement ranges in different study areas (Carlson *et al.*, 2014), and the distribution of *S. acanthias* has been found to be affected by bottom temperatures and prey availability (Sagarese *et al.*, 2014).

In addition to providing new information on species known to perform migrations, LEK also provided new insights for some less-studied species in the Adriatic Sea and the Mediterranean Sea. The interview results suggested that *Raja* spp., *S. stellaris* and *S. canicula* may not undertake migrations in Mediterranean GSAs, while the seasonality that emerged for *P. violacea* is consistent with its migratory behaviours reported in the Atlantic Ocean (Weidner *et al.*, 2014). For what concerns *Torpedo* spp., little is known about its movement, and more research is therefore required.

### Species seasonality of pelagic species

This study suggests the existence of seasonality in several GSAs (6, 9, 10, 19) for some pelagic species, such as *P. glauca* and *I. oxyrinchus*. The movement of *P. glauca* has been largely studied in the Atlantic and Pacific oceans (Kohler *et al.*, 1998; 2002; Mucientes *et al.*, 2009; Stevens *et al.*, 2010; Vandeperre *et al.*, 2014). Long-term migrations of *P. glauca* have been documented by tagging studies, with some individuals moving from the Atlantic Ocean to the Mediterranean Sea and within the Mediterranean (Kohler *et al.*, 1998; 2002). In particular, in the Mediterranean Sea, where mainly immature individuals were tagged, only short movements were observed for the two species (Kohler *et al.*, 2002), supporting the observation that juveniles display residency for at least two years after birth within the same area (Vandeperre *et al.*, 2014). Similarly, *I. oxyrinchus* showed seasonal movements in the Atlantic Ocean (Rogers *et al.*, 2015), while no data on this species are available for the Mediterranean Sea. Considering the migratory behaviour of these two species, it is conceivable that the seasonality found in this study may be due to migrations. Considering the lack of information on this issue, the results of this study encourage future studies on these two species in the Mediterranean Sea to reconstruct their movements as an accessory approach to a monitoring scheme focused on large elasmobranchs (Mancusi *et al.*, 2020).

### Aggregation

This study allowed the investigation of elasmobranch aggregations (i.e., conspecific and high-density aggregation during a specific time of the year) in the Mediterranean Sea. In addition to sporadic and opportunistic events published in the literature, the occurrence, frequency, and species-specific characteristics of aggregations have often been overlooked for many elasmobranch species. In this study, LEK provided information on species known to perform aggregations but also some initial insights into the aggregation occurrence of six species (*P. violacea*, *M. aquila*, *G. melastomus*, *S. blainville*, *T. marmorata*, *E. spinax*) and one genus (*Raja* spp.) for which, to our knowledge, no previous data are available.

### Aggregation - Demersal species

The occurrence of aggregations of *Mustelus* spp. and *S. acanthias* are known in the Atlantic Ocean (Smale & Compagno, 1997; da Silva *et al.*, 2013; Carlson *et al.*, 2014) and hypothesised also in the Adriatic Sea (GSA 17) (Bonanomi *et al.*, 2018) and the Strait of Sicily (GSA 16) (Colloca *et al.*, 2017). LEK confirmed the occurrence of aggregations in those GSAs and indicated new aggregation areas for *Mustelus* spp. in other GSAs (9 and 19). For *S. acanthias*, the aggregation areas (GSAs 17 and 28) indicated by LEK correspond to the areas where the species is mostly found (Serena *et al.*, 2009; Follesa *et al.*,

2020). However, to our knowledge, this is the first report of aggregation of *S. acanthias* in the Mediterranean Sea. *S. canicula* aggregations have not been reported in Mediterranean sites (Wearmouth *et al.*, 2012). Nonetheless, LEK suggests the occurrence of such aggregations in 4 GSAs (6, 9, 11, 16), in close correspondence with the main Mediterranean distribution of the species (Follesa *et al.*, 2020). Among Mediterranean batoids, aggregation records have been published only for *D. pastinaca* in the Levantine Sea (GSA 27) (Chaikin *et al.*, 2020), but this species occurrence has been documented in other coastal areas of the central Mediterranean Sea (GSA 16, Tiralongo *et al.*, 2020). This study highlighted two more GSAs (11 and 17) where *D. pastinaca* aggregations occur according to LEK.

For the first time, specific descriptions and temporal occurrences of aggregations were recovered for four species in the Mediterranean Sea. In the Adriatic Sea, considering LEK in only three time frames (1960-1980, 1980-2000 and 2000-present), the catch and sight frequencies of aggregations decreased for *Mustelus* spp. and *S. acanthias*, likely due to fishery-driven decline. The general decline of these species was highlighted by fishers in the interviews and is consistent with the findings of Barausse *et al.* (2014). The opposite trend noted for *Raja* spp. may reflect an increase in abundance observed in landings (Clodia database, 2020) after a period of documented decline (Jukić-Peladić *et al.*, 2001), but more studies are necessary to confirm this increase. In other GSAs, *Mustelus* spp. aggregation occurrence and the number of individuals decreased over time, as expected due to recent exploitation-driven decline (Ligas *et al.*, 2013; Colloca *et al.*, 2017). In contrast, *Raja* spp. and *S. canicula* did not show substantial changes in aggregation occurrence; this was expected since no decreasing trend in abundance was observed over time in the western Mediterranean (Ramírez-Amaro *et al.*, 2020; Follesa *et al.*, 2020).

Based on LEK interviews, the reported size and sex composition of individuals in aggregations (large individuals, pregnant females) may support the role of aggregations in reproductive scope (*Mustelus* spp., *S. acanthias* and *Raja* spp.). In these species in other geographic areas, aggregations have been previously reported to be composed of adults of both sexes (Jacoby *et al.*, 2012). On the other hand, in *M. aquila* and *S. canicula*, the reported occurrence of aggregating individuals of different sizes may support the role of aggregations as a defence against predators (Sadovy de Mitcheson & Colin, 2011).

In commercially exploited species, such as *Mustelus* spp. and *Raja* spp., LEK has shown how well fishers know this behavioural-reproductive driven phenomenon. Therefore, fishers can effectively exploit such aggregations, further impacting species abundance and leading to their decline, as supported by the decline in the aggregating species *Mustelus* spp. (Ligas *et al.*, 2013; Colloca *et al.*, 2017). On the other hand, if fishers report the frequent occurrence of large aggregations for a species, this may indeed be an indicator of a good conservation status, as suggested for *S. canicula* in non-Adriatic GSAs (6, 9, 11, 16) (Abella *et al.*, 2017; Ramírez-Amaro *et al.*, 2020).

## Aggregation - Pelagic species

Among pelagic sharks, *P. glauca* has been observed to aggregate in other oceans, such as the aggregation of adult individuals around seamounts (Litvinov, 2007) and of juveniles in coastal areas (Litvinov, 2006; Serena & Silvestri, 2018). In the Adriatic (GSAs 17 and 18) and Ionian Seas (GSA 19), aggregations of *P. glauca* have already been observed (Clò & Bianchi, 1997; Pomi *et al.*, 1997). The present study provides, for the time, indications of *P. glauca* aggregations in GSAs 11 and 9.

*Carcharhinus plumbeus* has been seen aggregating in Boncuk Cove (Turkey) (Filiz *et al.*, 2019) and forming seasonal aggregations in Israel (Barash *et al.*, 2018) and Lampione Island (Sicily) (Cattano *et al.*, 2021). In addition, GSAs 10 and 19 were recognised as previously unreported aggregating areas of *C. plumbeus* by LEK in the present study.

Aggregating areas of *C. maximus* have been proposed in the Ligurian Sea (Northern Tyrrhenian) and the Balearic region (Mancusi *et al.*, 2005). GSA 19 was indicated as an additional aggregating area where the presence of this species has been indeed reported (Carlucci *et al.*, 2014).

In GSA 19, *S. zygaena* aggregation was indicated by fishers, as already documented (Sperone *et al.*, 2012). In addition, aggregation of this species was reported in the central Mediterranean (Lampedusa Island) (Bigelow & Schroeder, 1948).

Among *Mobula* species, the aggregation phenomenon is well known (Ward-Paige *et al.*, 2013). In the Mediterranean Sea, studies on the abundance and habitat associations of *M. mobular* have already suggested the occurrence of aggregations (Notarbartolo di Sciara *et al.*, 2015). Winter aggregations have also been observed in the Levantine Sea (Gaza strip) for mating (Couturier *et al.*, 2013; Abudaya *et al.*, 2018). Overall, these published studies confirmed the LEK findings for this species.

## Use of LEK in elasmobranch behavioural research

The use of LEK for the study of the behavioural traits of elasmobranchs has some shortcomings and limitations. First, LEK might tend to suffer cognitive biases, such as judgement deviation, shifting baseline syndrome (Pauly, 1995), changes in fishing effort over time, or difficulties in reconstructing past scenarios, as some elasmobranch species are not the target but accidental catch for fisheries. Second, fishers' attention may be more focused on more commercially relevant species, and biological traits may not be easily observed. For instance, for several species, sex composition information based on LEK may suffer from erroneous attribution of sex. However, in elasmobranchs, sex is easily determined based on external prominent copulatory organs called as claspers, which are extensions of the posterior bases of the pelvic fins (Musick & Ellis, 2005), and indeed, interviewed fishers provided information on sex in aggregations. Among the species reported by fishers, clasper presence may go unnoticed in *S. canicula*, since they are enwrapped in pelvic



fins (ICES, 2013). Therefore, sex misidentification for this species may indeed occur and explain a possible inconsistency between the indication of mixed-sex aggregations by LEK and the well-known sexual segregation of this species (Wearmouth *et al.*, 2013; Finotto *et al.*, 2015). Third, after the progress in elasmobranch taxonomy by new genetic tools (see, for instance, Cariani *et al.*, 2017; Marino *et al.*, 2018), interviewers and fishers, depending on the geographical area, might have different taxonomy expertise about the studied species. Fourth, the quality of the LEK results may strongly depend on the level of established trust between the interviewers and fishers. All these factors should be carefully considered when using LEK (Begossi *et al.*, 2019). To minimise these limits and collect more reliable data, in our study, we chose to perform some analyses only above a certain minimum sample size. In addition, we used available scientific data to corroborate the fishers' information, as shown above. Moreover, the interviewers were scientists working on fishery and/or elasmobranch species. Finally, the structure of a questionnaire survey should always be examined with regard to target questions and sampling locations. The trade-off between the usage of open and specific questions may dramatically affect the objectives of a study in terms of the degree of freedom as well as the quality of the results (Azzurro *et al.*, 2019). In this questionnaire survey, some questions were discarded due to the inconsistency and discontinuity of the replies.

### *Fishers' perceptions of elasmobranch value*

Halting or reversing the dramatic situation of the decline in fishery resources requires a comanagement plan based on a bottom-up approach to provide practical and feasible measures (Moller *et al.*, 2004).

This study, in collecting fishers' opinions on shark importance, value, conservation and management, provides key information for understanding the feasibility of fishers' involvement in the management process. The ecological importance of sharks and their relevance for fisheries was highlighted by fishers' answers. In fact, shark and ray meat consumption is still an important category of sea-origin food in Mediterranean countries (FAO, 2020), so the demand is still high enough to make this resource commercially valuable. Not only were more than half of the interviewed fishers in favour of conservation measures, but most of them had a pro-active and collaborative attitude to propose their own ideas on shark and ray management plans that go beyond the existing national and international protection and management regulations. Interestingly, in addition to general catch control, fishers indicated some more specific management strategies, such as the temporal closure of specific areas hosting vulnerable stages (e.g., reproductive areas) and the release of newborns. These answers confirm the knowledge of fishers about the biology of these species. Moreover, some fishers voluntarily and regularly release newborns, at least in some areas, such as the northern Adriatic Sea (Barbato & Mazzoldi, personal observation). The protection of ar-

eas used during vulnerable stages of elasmobranch life is recognised to be an effective tool by the scientific world (e.g., Martins *et al.*, 2018). On the other hand, the conservation efficacy of newborn release should be evaluated considering the population dynamics of the species and explored along with other management strategies (Prince, 2002). Although the efficacy of the management actions proposed by fishers might not be optimal, these strategies should be considered and carefully evaluated.

These results highlight that it may be possible to recognise priority measures in collaboration with fishers, both for commercial elasmobranch species, which are more sensitive to exploitation, and for nontarget and commercially less important species.

### Acknowledgements

This work was supported by funding of *Ministero dell'Istruzione, dell'Università e della Ricerca* (MIUR) to CM. We wish to thank all fishers who collaborated in the data collection and three anonymous reviewers and the editor for improving the manuscript. Thanks to the Food and Agriculture Organization of the United Nations for the Original Scientific Illustrations from the FAO Archive. Reproduced with permission.

### References

- Abella, A., Mancusi, C., Mannini, A., Serena F., 2017a. *Galeus melastomus*. In: *Sintesi delle conoscenze di biologia, ecologia e pesca delle specie ittiche dei mari italiani / Synthesis of the knowledge on biology, ecology and fishery of the halieutic resources of the Italian seas*. Sartor, P., Mannini, A., Carlucci, R., Massaro, E., Queirolo, S., Sabatini, A., Scarcella, G., Simoni, R. (Eds), *Biologia Marina Mediterranea*, 24 (Suppl. 1), 136-143.
- Abella, A., Mancusi, C., Serena, F., 2017b. *Scyliorhinus canicula*. In: *Sintesi delle conoscenze di biologia, ecologia e pesca delle specie ittiche dei mari italiani / Synthesis of the knowledge on biology, ecology and fishery of the halieutic resources of the Italian seas*. Sartor, P., Mannini, A., Carlucci, R., Massaro, E., Queirolo, S., Sabatini, A., Scarcella, G., Simoni, R. (Eds), *Biologia Marina Mediterranea*, 24 (Suppl. 1), 157-164.
- Abudaya, M., Ulman, A., Salah, J., Fernando, D., Wor, C. *et al.*, 2018. Speak of the devil ray (*Mobula mobular*) fishery in Gaza. *Review in Fish Biology and Fishery*, 28, 229-239.
- Albuquerque, U.P., Ludwig, D., Feitosa, I.S., de Moura, J.M.B., Gonçalves, P.H.S. *et al.*, 2021. Integrating traditional ecological knowledge into academic research at local and global scales. *Regional Environmental Change*, 21 (2), 1-11.
- Anadón, J.D., Giménez, A., Ballestar, R., Pérez, I., 2009. Evaluation of local ecological knowledge as a method for collecting extensive data on animal abundance. *Conservation Biology*, 23 (3), 617-625.
- Anderson, M.J., Gorley, R.N., Clarke, K.R., 2008. *PERMANOVA+ for PRIMER: Guide to software and statistical methods*. PRIMER-E, Plymouth, 214 pp.



- Azzurro, E., Moschella, P., Maynou, F., 2011. Tracking signals of change in Mediterranean fish diversity based on local ecological knowledge. *PLoS One*, 6 (9), e24885.
- Azzurro, E., Sbragaglia, V., Cerri, J., Bariche, M., Bolognini, L. *et al.*, 2019. The shifting distribution of Mediterranean fishes: a spatio-temporal assessment based on Local Ecological Knowledge. *Global Change Biology*, 25, 2779-2792.
- Bada-Sánchez, E., Pérez-Jiménez, C., Martínez-Cruz, L.E., Méndez-Loeza, I., Sosa-Cordero, E., 2019. Fishery indicators during a predictable aggregation of Atlantic sharpnose sharks *Rhizoprionodon terraenovae* in the southern Gulf of Mexico: An alternative to assess a heterogeneous data-poor fishery. *Fisheries Management and Ecology*, 26, 354-364.
- Bakker, J., Wangensteen, O.S., Chapman, D.D., Boussarie, G., Buddo, D. *et al.*, 2017. Environmental DNA reveals tropical shark diversity in contrasting levels of anthropogenic impact. *Scientific Reports*, 7 (1), 1-11.
- Barash, A., Pickholtz, R., Pickholtz, E., Blaustein, L., Rilov, G., 2018. Seasonal aggregations of sharks near coastal power plants in Israel: an emerging phenomenon. *Marine Ecology Progress Series*, 590, 145-154.
- Barausse, A., Correale, V., Curković, A., Finotto, L., Riginella, E. *et al.*, 2014. The role of fisheries and the environment in driving the decline of elasmobranchs in the northern Adriatic Sea. *ICES Journal of Marine Science*, 71 (7), 1593-1603.
- Bargnesi, F., Lucrezi, S., Ferretti, F., 2020. Opportunities from citizen science for shark conservation, with a focus on the Mediterranean Sea. *The European Zoological Journal*, 87 (1), 20-34.
- Barría, C., Coll, M., Navarro, J., 2015. Unravelling the ecological role and trophic relationships of uncommon and threatened elasmobranchs in the western Mediterranean Sea. *Marine Ecology Progress Series*, 539, 225-240.
- Bastari, A., Beccacece, J., Ferretti, F., Micheli, F., Cerrano, C., 2017. Local ecological knowledge indicates temporal trends of benthic invertebrates species of the Adriatic Sea. *Frontiers in Marine Science*, 4, 157.
- Begossi, A., 2008. Local knowledge and training towards management. *Environment, Development and Sustainability*, 10 (5), 591.
- Begossi, A., Salyvonchik, S., Glamuzina, B., de Souza, S.P., Lopes, P.F. *et al.* 2019. Fishers and groupers (*Epinephelus marginatus* and *E. morio*) in the coast of Brazil: integrating information for conservation. *Journal of Ethnobiology and Ethnomedicine*, 15 (1), 53.
- Berkström, C., Papadopoulos, M., Jiddawi, N.S., Nordlund, L.M., 2019. Fishers' Local Ecological Knowledge (LEK) on Connectivity and Seascape Management. *Frontiers in Marine Science*, 6, 130.
- Bethoux, J.P., 2003. Long Term Data Series on Mediterranean Sea Temperature, Nutrients and Hydrology Changes. p. 301-306. In: *Mediterranean climate. Variability and trends*. Bolle, H.-J. (Ed). Springer, Berlin, Heidelberg, 372 pp.
- Bigelow, H.B., Schroeder, W.C., 1948. Fishes of the western north Atlantic. Lancelets, cyclostomes and sharks. Memoir. *Sears Foundation for Marine Research*, 1 (1), 1-576.
- Bonanomi, S., Pulcinella, J., Fortuna, M.C., Moro, F., Sala, A., 2018. Elasmobranch bycatch in the Italian Adriatic pelagic trawl fishery. *PLoS ONE*, 1381, E0191647.
- Braccini, M., Aires-da-Silva, A., Taylor, I., 2016. Incorporating movement in the modelling of shark and ray population dynamics: approaches and management implications. *Reviews in Fish Biology and Fisheries*, 26 (1), 13-24.
- Byrne, M.E., Cortés, E., Vaudo, J.J., Harvey, G.C.M.N. *et al.*, 2017. Satellite telemetry reveals higher fishing mortality rates than previously estimated, suggesting overfishing of an apex marine predator. *Proceedings of the Royal Society B*, 284, 20170658.
- Cariani, A., Messinetti, S., Ferrari, A., Arculeo, M., Bonello, J.J. *et al.*, 2017. Improving the Conservation of Mediterranean Chondrichthyans: The ELASMOMED DNA Barcode Reference Library. *PLoS One*, 12 (1), e0170244.
- Carlson, A.E., Hoffmayer, E.R., Tribuzio, C.A., Sulikowski, J.A., 2014. The use of satellite tags to redefine movement patterns of spiny dogfish (*Squalus acanthias*) along the US east coast: implications for fisheries management. *PLoS One*, 9 (7), e103384.
- Carlucci, R., Battista, D., Capezzuto, F., Serena, F., Sion, L., 2014. Occurrence of the basking shark *Cetorhinus maximus* (Gunnerus, 1765) (Lamniformes: Cetorhinidae) in the central-eastern Mediterranean Sea. *Italian Journal of Zoology*, 81 (2), 280-286.
- Casey, J.M., Myers, R.A., 1998. Near extinction of a large, widely distributed fish. *Science*, 281, 690-692.
- Cattano, C., Turco, G., Di Lorenzo, M., Gristina, M., Visconti, G. *et al.*, 2021. Sandbar shark aggregation in the central Mediterranean Sea and potential effects of tourism. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 31 (6), 1420-1428.
- Chaikin, S., Belmaker, J., Barash, A., 2020. Coastal breeding aggregations of threatened stingrays and guitarfish in the Levant. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 30 (6), 1160-1171.
- Chapman, D.D., Feldheim, K.A., Papastamatiou, Y.P., Hueter, R.E., 2015. There and back again: a review of residency and return migrations in sharks, with implications for population structure and management. *Annual Review of Marine Science*, 7, 547-570.
- Chin, A., Pecl, G., 2019. Citizen science in shark and ray research and conservation. Strengths, opportunities, considerations, and pitfalls. p. 299-317. In: *Shark research. Emerging technologies and applications for the field and laboratory*. Carrier, J. C., Heithaus, M. R., Simpfendorfer, C. A. (Eds). CRC Press, Boca Raton, FL.
- Clarke, K.R., Gorley, R.N., 2006. *PRIMER v6: User Manual/ Tutorial*. PRIMER-E, Plymouth, 192 pp.
- Clò, S., Bianchi, I., 1997. Osservazioni sul comportamento alimentare della verdesca, *Prionace glauca* (Linnaeus, 1758) (Chondrichthyes: Carcharhinidae). *Quaderni della Civica Stazione Idrobiologica di Milano*, 22, 79-93.
- Clodia database, 2020. Database of Fishery Data from Chioggia, Northern Adriatic Sea. <http://chioggia.biologia.unipd.it/banche-dati/>.
- Colin, P.L., Sadovy, Y.J., Domeier, M.L., 2003. Manual for the Study and Conservation of Reef Fish Spawning Aggregations. Society for the Conservation of Reef Fish Aggregations Special Publication No. 1 (Version 1.0), 1-98+iii pp.
- Colloca, F., Enea, M., Ragonese, S., Di Lorenzo, M., 2017. A century of fishery data documenting the collapse of smooth-

- hounds (*Mustelus* spp.) in the Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 27 (6), 1145-1155.
- Colloca, F., Carrozzi, V., Simonetti, A., Di Lorenzo, M., 2020. Using local ecological knowledge of fishers to reconstruct abundance trends of elasmobranch populations in the Strait of Sicily. *Frontiers in Marine Science*, 7, 508.
- Couturier, L.I., Bennett, M.B., Richardson, A.J., 2013. Mystery of giant rays off the Gaza strip solved. *Oryx*, 47 (4), 480-480.
- Dobson, A.J., Barnett, A.G., 2008. *An Introduction to Generalized Linear Models*. CRC Press, London, 301 pp.
- Dulvy, N.K., Reynolds, J.D., 2002. Predicting extinction vulnerability in skates. *Conservation Biology*, 16, 440-450.
- Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., Kyne, P.M. *et al.*, 2014. Extinction risk and conservation of the world's sharks and rays. *eLife*, 3, e00590.
- Dulvy, N.K., Allen, D.J., Ralph, G. M., Walls, R.H.L., 2016. The conservation status of Sharks, Rays and Chimaeras in the Mediterranean Sea [Brochure]. IUCN, Malaga, Spain, 14 pp.
- Dulvy, N.K., Simpfendorfer, C.A., Davidson, L.N., Fordham, S.V., Bräutigam, A. *et al.*, 2017. Challenges and priorities in shark and ray conservation. *Current Biology*, 27 (11), R565-R572.
- FAO 1990-2021. FAO Major Fishing Areas. MEDITERRANEAN AND BLACK SEA (Major Fishing Area 37). CWP Data Collection. In: FAO Fisheries Division [online]. Rome. Updated. [Cited 22 July 2021].
- FAO, 2018. *The State of World Fisheries and Aquaculture 2020*. FAO, Rome, 206 pp.
- Ferretti, F., Myers, R.A., Serena, F., Lotze, H.K., 2008. Loss of large predatory sharks from the Mediterranean Sea. *Conservation Biology*, 22 (4), 952-964.
- Ferretti, F., Osio, G.C., Jenkins, C. J., Rosenberg, A.A., Lotze, H.K., 2013. Long-term change in a meso-predator community in response to prolonged and heterogeneous human impact. *Scientific Reports*, 3, 1057.
- Field, I.C., Meekan, M.G., Buckworth, R.C., Bradshaw, C.J.A., 2009. Susceptibility of sharks, rays and chimaeras to global extinction. *Advances in Marine Biology*, 56, 275-363.
- Finotto, L., Gristina, M., Garofalo, G., Riginella, E., Mazzoldi C., 2015. Contrasting life history and reproductive traits in two populations of *Scyliorhinus canicula*. *Marine Biology*, 162, 1175-1186.
- Filiz, H., 2019. Year-round aggregation of sandbar shark, *Carcharhinus plumbeus* (Nardo, 1827), in Boncuk Cove in the southern Aegean Sea, Turkey (Carcharhiniformes: Carcharhinidae). *Zoology in the Middle East*, 65 (1), 35-39.
- Follesa, M.C., Marongiu, M.F., Zupa, W., Bellodi, A., Cau, A. *et al.*, 2020. Spatial variability of Chondrichthyes in the northern Mediterranean. *Scientia Marina*, 83 (S1), 81-100.
- Fortibuoni T., Borme D., Franceschini G., Giovanardi O., Raicevich S., 2016. Common, rare or extirpated? Shifting baselines for common angelshark, *Squatina squatina* (Elasmobranchii: Squatinidae), in the Northern Adriatic Sea (Mediterranean Sea). *Hydrobiologia*, 772, 247-259.
- Fortuna, C.M., Vallini, C., De Carlo, F., Filidei, E. Jr, Lucchetti, A. *et al.*, 2010. Relazione finale del progetto "Valutazione delle catture accidentali di specie protette nel traino pelagico (BYCATCH III)." *ISPRA*, Roma, 137 pp.
- Gallagher, A.J., Kyne, P. M., Hammerschlag, N., 2012. Ecological risk assessment and its application to elasmobranch conservation and management. *Journal of Fish Biology*, 80 (5), 1727-1748.
- Gerhardinger, L.C., Hostim-Silva, M., Medeiros, R.P., Matarezi, J., Bertoncini, Á.A. *et al.*, 2009. Fishers' resource mapping and goliath grouper *Epinephelus itajara* (Serranidae) conservation in Brazil. *Neotropical Ichthyology*, 7 (1), 93-102.
- Gordon, C.A., Hood, A.R., Al Mabruk, S.A.A., Barker, J., Bartoli, A. *et al.*, 2019. *Mediterranean Angel Sharks: Regional Action Plan*. The Shark Trust, United Kingdom. 36 pp.
- Hammerschlag, N., Gallagher, A.J., Lazarre, D.M., 2011. A review of shark satellite tagging studies. *Journal of Experimental Marine Biology and Ecology*, 398 (1-2), 1-8.
- Heupel, M.R., Papastamatiou, Y.P., Espinoza, M., Green, M. E., Simpfendorfer, C.A., 2019. Reef shark science - Key questions and future directions. *Frontiers in Marine Science*, 6, 12.
- Huntington, H.P., 2000. Using traditional ecological knowledge in science: methods and applications. *Ecological applications*, 10 (5), 1270-1274.
- ICES 2013. Report of the Workshop on Sexual Maturity Staging of Elasmobranchs (WKMSSEL2) ICES CM 2012/ACOM:59. 11-14 December 2012, Lisbon, Portugal. 113 pp.
- Jacoby, D.M.P., Croft, D.P., Sims, D.W., 2012. Social behaviour in sharks and rays: analysis, patterns and implications for conservation. *Fish and Fisheries* 13, 399-417.
- Jukić-Peladić, S., Vrgoc, N., Krstulovic-Sifner, S., Piccinetti, C., Piccinetti-Manfrin, G. *et al.*, 2001. Long-term changes in demersal resources of the Adriatic Sea: comparison between trawl surveys carried out in 1948 and 1998. *Fisheries research*, 53 (1), 95-104.
- Kessel, S.T., Chapman, D.D., Franks, B.R., Gedamke, T., Gruber, S.H. *et al.*, 2014. Predictable temperature-regulated residency, movement and migration in a large, highly mobile marine predator (*Negaprion brevirostris*). *Marine Ecology Progress Series*, 514, 175-190.
- Kohler, N.E., 1998. NMFS cooperative shark tagging program, 1962-93: An atlas of shark tag and recapture data. *Marine Fisheries Review*, 60 (2), 1-87.
- Kohler, N. E., Turner, P. A., Hoey, J. J., Natanson, L. J., Briggs, R., 2002. Tag and recapture data for three pelagic shark species: blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), and porbeagle (*Lamna nasus*) in the North Atlantic Ocean. *ICCAT Collective Volume of Scientific Papers*, 54 (4), 1231-1260.
- Ligas, A., Osio, G.C., Sartor, P., Sbrana, M., De Ranieri, S., 2013. Long-term trajectory of some elasmobranch species off the Tuscany coasts (NW Mediterranean) from 50 years of catch data. *Scientia Marina*, 77, 119-127.
- Litvinov, F.F., 2006. On the role of dense aggregations of males and juveniles in the functional structure of the range of the blue shark *Prionace glauca*. *Journal of Ichthyology*, 46 (8), 613-624.
- Litvinov, F.F., 2007. Fish visitors to seamounts: aggregations of large pelagic sharks above seamounts. *Seamounts: Ecology, Fisheries and Conservation*. *Fisheries and Aquatic Re-*

- source Series, Blackwell Scientific, 202-206.
- Maguire, J.-J., Sissenwine, M., Csirke, J., Grainger, R., 2006. The state of the world highly migratory, straddling and other high seas fish stocks, and associated species. FAO Fisheries Technical Paper, No. 495. Rome: FAO. 2006. 77 pp.
- Mancusi, C., Clò, S., Affronte, M., Bradaï, M.N., Hemida, F. *et al.*, 2005. On the presence of basking shark (*Cetorhinus maximus*) in the Mediterranean Sea. *Cybiurn*, 29 (4), 399-405.
- Mancusi, C., Bairo, R., Fortuna, C., De Sola, L.G., Morey, G. *et al.*, 2020. MEDLEM database, a data collection on large Elasmobranchs in the Mediterranean and Black seas. *Mediterranean Marine Science*, 21 (2), 276-288.
- Marino, I.A.M., Finotto, L., Colloca, F., Di Lorenzo, M., Gristina, M. *et al.*, 2018. Resolving the ambiguities in the identification of two smooth-hound sharks (*Mustelus mustelus* and *Mustelus punctulatus*) using genetics and morphology. *Marine Biodiversity*, 48 (3), 1551-1562.
- Martins, A.P.B., Heupel, M.R., Chin, A., Simpfendorfer, C.A., 2018. Batoid nurseries: definition, use and importance. *Marine Ecology - Progress Series*, 595, 253-267.
- Maynou, F., Sbrana, M., Sartor, P., Maravelias, C., Kavadas S. *et al.*, 2011. Estimating trends of population decline in long-lived marine species in the Mediterranean Sea based on fishers' perceptions. *PLoS One*, 6 (7), e21818.
- Moller, H., Berkes, F., Lyver, P., Kislalioglu, M., 2004. Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society*, 9, 2.
- Moreno, G., Dagorn, L., Sancho, G., Itano D., 2007. Fish behaviour from fishers' knowledge: the case study of tropical tuna around drifting fish aggregating devices (DFADs). *Canadian Journal of Fishery and Aquatic Science*, 64, 1517-1528.
- Morgan, A.C., Burgess, G.H., 2005. Fishery-dependent sampling: total catch, effort and catch composition. In Management Techniques for Elasmobranch Fisheries, p. 182-200. In: *Fisheries Technical Paper 474*. Musick J. A., Bonfil R. (Eds). Food and Agriculture Organization, Rome.
- Mucientes, G.R., Queiroz, N., Sousa, L.L., Tarroso, P., Sims, D. W., 2009. Sexual segregation of pelagic sharks and the potential threat from fisheries. *Biology Letters*, 5 (2), 156-159.
- Musick, J.A., Ellis, J.K., 2005. Reproductive evolution of Chondrichthyans, 45-79. In: *Reproductive biology and phylogeny of Chondrichthyes. Sharks, Batoids and Chimaeras*. Hamlett W. C. (Ed). Science Publishers, INC., Enfield, New Hampshire, 562 pp.
- Myers, R.A., Worm, B., 2003. Rapid worldwide depletion of predatory fish communities. *Nature*, 423, 280-283.
- Notarbartolo di Sciara, G., Lauriano, G., Pierantonio, N., Cañadas, A., Donovan, G. *et al.*, 2015. The devil we don't know: investigating habitat and abundance of endangered giant devil rays in the North-Western Mediterranean Sea. *PloS One*, 10 (11), e0141189.
- Papetti, C., Di Franco, A., Zane, L., Guidetti, P., De Simone, V. *et al.*, 2013. Single population and common natal origin for Adriatic *Scomber scombrus* stocks: evidence from an integrated approach. *ICES Journal of Marine Science*, 70 (2), 387-398.
- Pauly, D., 1995. Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution*, 10(10), 430.
- Peñaherrera-Palma, C., van Putten, I., Karpievitch, Y. V., Frusher, S., Llerena-Martillo, Y. *et al.*, 2018. Evaluating abundance trends of iconic species using local ecological knowledge. *Biological Conservation*, 225, 197-207.
- Pomi C., 1997. Morphometric study of *Prionace glauca* (Linnaeus, 1758) in the Central and Northern Adriatic Sea. *Quaderni della Civica Stazione Idrobiologica di Milano*, 22, 159-161.
- Prince, J. D., 2002. Gauntlet fisheries for elasmobranchs-the secret of sustainable shark fisheries. *Journal of Northwest Atlantic Fishery Science*, 35, 407-416
- R Studio Team, 2020. R Studio: integrated development for R. R Studio, PBC, Boston, MA URL <https://www.Rstudio.com/>.
- Ramírez-Amaro, S., Ordines, F., Esteban, A., García, C., Gujjarro, B. *et al.*, 2020. The diversity of recent trends for chondrichthyans in the Mediterranean reflects fishing exploitation and a potential evolutionary pressure towards early maturation. *Scientific Reports*, 10 (1), 1-18.
- Ricci, P., Sion, L., Capezzuto, F., Cipriano, G., D'Onghia, G. *et al.*, 2021. Modelling the trophic roles of the demersal Chondrichthyes in the Northern Ionian Sea (Central Mediterranean Sea). *Ecological Modelling*, 444, 109468.
- Ricklefs, R.E., 1979. *Ecology* (2nd ed.). Chiron Press, New York, 966 pp.
- Rogers, P.J., Huveneers, C., Page, B., Goldsworthy, S.D., Coyne, M. *et al.*, 2015. Living on the continental shelf edge: habitat use of juvenile shortfin makos *Isurus oxyrinchus* in the Great Australian Bight, southern Australia. *Fisheries Oceanography*, 24 (3), 205-218.
- Russell, M.W., Sadovy de Mitcheson, Y., Erisman, B.E., Hamilton, R.J., Luckhurst, B.E. *et al.*, 2014. Status Report-World's Fish Aggregations 2014. Science and Conservation of Fish Aggregations, California, USA. International Coral Reef Initiative, 12 pp.
- Russo, E., Monti, M.A., Mangano, M.C., Raffaetà, A., Sarà, G. *et al.*, 2020. Temporal and spatial patterns of trawl fishing activities in the Adriatic Sea (Central Mediterranean Sea, GSA17). *Ocean & Coastal Management*, 192, 105231.
- Sadovy de Mitcheson, Y., Colin, P. L. (Eds.), (2011). *Reef fish spawning aggregations: biology, research and management*. Fish and Fisheries Series, Vol. 35. Springer Science & Business Media, 621 pp.
- Sagarese, S.R., Frisk, M.G., Cerrato, R.M., Sosebee, K.A., Musick, J.A. *et al.*, 2014. Application of generalized additive models to examine ontogenetic and seasonal distributions of spiny dogfish (*Squalus acanthias*) in the Northeast (US) shelf large marine ecosystem. *Canadian Journal of Fisheries and Aquatic Sciences*, 71 (6), 847-877.
- Schlaff, A.M., Heupel, M.R., Simpfendorfer, C.A., 2014. Influence of environmental factors on shark and ray movement, behaviour and habitat use: a review. *Reviews in Fish Biology and Fisheries*, 24 (4), 1089-1103.
- Serena F., 2005. *Field identification guide to the sharks and rays of the Mediterranean and Black Sea*. FAO Species Identification Guide for Fisheries Purposes. Rome, 97 p. 11 colour plates + egg cases.
- Serena F., 2014. *Lo status degli elasmobranchi dei mari italiani (Elasmostat)*. I Programma Nazionale triennale della pesca



- e dell'acquacoltura 2007-2009 (prorogato a tutto il 2012). Progetto di ricerca: "7 – Tematica A3". Rapporto finale, 28 febbraio 2014. 321 pp.
- Serena F. 2021. Elasmobranchs, 111-197. In: *Incidental catch of vulnerable species in Mediterranean and Black Sea fisheries - A review*. Carpentieri, P., Nastasi, A., Sessa, M., Srouf, A. (Eds) General Fisheries Commission for the Mediterranean. Studies and Reviews. No. 101. Rome, FAO, 320 pp.
- Serena, F., Papaconstantinou, C., Relini, G., De Sola, L.G., Bertrand, J.A. *et al.*, 2009. Distribution and abundance of spiny dogfish in the Mediterranean Sea based on the Mediterranean International Trawl Survey Program. p. 139-149. In: *Biology and Management of Dogfish Sharks*. Gallucci, V. F., McFarlane, G. A., Bargmann, G. (Eds). American Fisheries Society, Bethesda, Maryland, USA, 435 pp.
- Serena, F., Silvestri, R., 2018. Preliminary observations on juvenile shark catches as by-catch of the Italian fisheries with particular attention to the Tuscany coasts. *Proceedings of XX Congress of Codice Armonico*, 18b / Scientific Sez. Rossignano Marittimo (Li), 158-169.
- Serena, F., Abella, A.J., Bargnesi, F., Barone, M., Colloca F. *et al.*, 2020. Species diversity, taxonomy and distribution of Chondrichthyes in the Mediterranean and Black Sea, *The European Zoological Journal*, 87 (1), 497-536.
- Sguotti, C., Lynam, C.P., García-Carreras, B., Ellis, J.R., Engelhard G. H., 2016. Distribution of skates and sharks in the North Sea: 112 years of change. *Global Change Biology*, 22 (8), 2729-2743.
- da Silva, C., Kerwath, S.E., Attwood, C.G., Thorstad, E.B., Cowley, P.D. *et al.*, 2013. Quantifying the degree of protection afforded by a no-take marine reserve on an exploited shark. *African Journal of Marine Science*, 35 (1), 57-66.
- Smale, M.J., Compagno, L.J.V., 1997. Life history and diet of two southern African smoothhound sharks, *Mustelus mustelus* (Linnaeus, 1758) and *Mustelus palumbes* Smith, 1957 (Pisces: Triakidae). *South African Journal of Marine Science*, 18 (1), 229-248.
- Sperone E., Parise G., Leone A., Milazzo C., Santoro G. *et al.*, 2012. Spatiotemporal patterns of distribution of large predatory sharks in Calabria (Central Mediterranean, Southern Italy). *Acta Adriatica*, 53 (1), 13-24.
- Stevens, J.D., Bradford, R.W., West, G.J., 2010. Satellite tagging of blue sharks (*Prionace glauca*) and other pelagic sharks off eastern Australia: depth behaviour, temperature experience and movements. *Marine Biology*, 157 (3), 575-591.
- Taylor, S.M., Braccini, J.M., Bruce, B.D., McAuley, R.B., 2018. Reconstructing Western Australian white shark (*Carcharodon carcharias*) catches based on interviews with fishers. *Marine and Freshwater Research*, 69 (3), 366-375.
- Tiralongo, F., Messina, G., Lombardo, B.M., 2020. Biologic aspects of juveniles of the common stingray, *Dasyatis pastinaca* (Linnaeus, 1758) (Elasmobranchii, Dasyatidae), from the Central Mediterranean Sea. *Journal of Marine Science and Engineering*, 8 (4), 269.
- Vandeperre, F., Aires-da-Silva, A., Fontes, J., Santos, M., Santos, R.S. *et al.*, 2014. Movements of blue sharks (*Prionace glauca*) across their life history. *PLoS One*, 9 (8), e103538.
- Ward-Paige, C.A., Davis, B., Worm, B., 2013. Global population trends and human use patterns of *Manta* and *Mobula* rays. *PloS One*, 8 (9), e74835.
- Wearmouth, V.J., Southall, E.J., Morritt, D., Sims, D.W., 2013. Identifying reproductive events using archival tags: egg-laying behaviour of the small spotted catshark *Scyliorhinus canicula*. *Journal of Fish Biology*, 82 (1), 96-110.
- Weidner, T.A., Cotton, C., Kerstetter, D.W., 2014. Habitat utilization and vertical movements of the pelagic stingray *Pteroplatytrygon violacea* (Bonaparte, 1832) in the Western North Atlantic Ocean using short-duration pop-up archival satellite tags" Marine & Environmental Sciences Faculty Proceedings, Presentations, Speeches, Lectures. 227

## Supplementary data

The following supplementary information is available online for the article:

**Fig. S1:** Questionnaire template.

**Table S1.** Percentage of interviewed fishers answering about the seasonality of each species for the different sampling points (Ancona (ANC), Chioggia (CHIO), Marano Lagunare (ML), Northern Istria (NI), Southern Istria (SI), Eastern Adriatic coast (EAC) and Montenegro (MON) in the Adriatic Sea, above the 25% threshold.

**Table S2.** Percentage of interviewed fishers answering about the seasonality question of each species for the different sampling areas in other GSAs [Italy (ITA), Turkey (TUR), Spain (SPA)], above the 25% threshold.

**Table S3.** Percentage of interviewed fishers answering to each question (QN: question number) for each species indicating aggregation features in the Adriatic Sea during different time periods: B) 1960-1980; C) 1980-2000; D) 2000-Present.

**Table S4.** Percentage of interviewed fishers answering to each question (QN: question number) for each species indicating aggregation features in other Mediterranean GSAs during different time periods: B) 1960-1980; C) 1980-2000; D) 2000-Present.

**Table S5.** Percentage of interviewed fishers answering to the questions related to aggregations (QN 17 and QN 18) in each GSA.

**Table S6.** Percentage of fishing gears used by interviewed fishers in the different sampling areas.