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Unexpected Records of Newborn and Young Sharks in Ligurian and North Tyrrhenian Seas (North-Western Mediterranean Basin)

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Abstract: Between 2007 and 2022, 112 specimens of newborn and young pelagic sharks were recorded in the waters of Tuscany Region, in the South Ligurian–North Tyrrhenian Seas (north-western Mediterranean basin). The sharks belonged to the *Carcharhinus plumbeus* (n = 14), *Prionace glauca* (n = 66), *Isurus oxyrinchus* (n = 16), *Mobula mobular* (n = 5) *Alopias vulpinus* (n = 7) and *Hexanchus griseus* (n = 4) species. Each animal was correctly identified thanks to the photographs or videos collected. All specimens were incidentally captured with set nets in inshore shallow waters, except bluntnose six-gill sharks, which were bycatch of deep-water bottom-trawl fishery. Body mass, sex, total length and biometric measurements were recorded in 34 baby sharks following the Mediterranean Large Elasmobranches Monitoring (MEDLEM) protocol. The presence of very evident and often non-healed umbilical scar confirmed that some of the sample specimens were newborn. Further confirmation came from the comparison between the total length observed and the size at birth known for the sampled species as reported in the literature. Some baby sharks were preserved in the Museums of Natural History of Pisa and Florence University collections. The importance of the coastal area studied as a possible shark nursery is discussed.

Keywords: North Italian waters; young of the year; umbilical scar; incidental catch; MEDLEM

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1. Introduction

The Mediterranean basin displays relatively high chondrichthyan richness, with 7% of the total number of elasmobranchs being represented inside the basin [1–7]. Due to their life history traits, sharks and rays are particularly susceptible to over-exploitation, and their populations have very low resilience. Species often show restricted distributions and small population sizes, dependent on mating, spawning, nursery and breeding grounds, or on specific habitats [4,8]. Although there is no real direct fishery targeting large cartilaginous fishes in the Mediterranean, they are incidentally caught, mainly with gillnets and bottom longlines targeting European hake [9]. Surface drifting longlines, targeting tuna and swordfish, also capture some pelagic shark species as bycatches or discards [9–15].

To face the biodiversity loss and to increase the effectiveness of the conservation measures in the Mediterranean basin, it is important to establish a common procedure to collect data on shark individuals that are accidentally captured, sighted at sea or stranded. In this light, the Mediterranean Large Elasmobranchs Monitoring (MEDLEM) database aims at contributing to the improvement in knowledge on the presence, spatial distribution and bycatch of large cartilaginous fishes species present in the Mediterranean and Black Seas. Officially established in 1985 [16], it became fully operational in 2000, beginning to record data on elasmobranch catches, sightings, strandings and historical records in a single database [17,18].

More recently, in Tuscany Region (Italy, north-western Mediterranean), monitoring activities foreseen by MEDLEM were included into the former Tuscany Observatory for Cetacean in 2007, now Tuscany Observatory for Biodiversity (Osservatorio Toscano Biodiversità (OTB)) sensu art. 11 Regional Law 30/2015, together with the monitoring of strandings and incidental capture of cetaceans and sea turtles. This action taken by Tuscany Region represents a real contribution to the international effort for the conservation of the marine ecosystem and its resources. In Tuscany, the Region Administration has created a coordinated and synergic system among its technical instruments, represented by ARPAT (Environmental Protection Agency, Tuscany Region), universities, research centers, museums, aquaria, environmental associations and fishermen [19].

The main features of the MEDLEM Database Application are (i) the implementation of data collection, especially for bycatch evaluation; (ii) the standardization of data entry procedures; (iii) effective data sharing among the participating countries; and (iv) free access to the website for participants.

In the Ligurian and North Tyrrhenian Seas, pelagic sharks represent a limited part of the commercial bycatch of professional longline fishery targeting sword fish and tuna. The most frequently caught species are *Prionace glauca* (Linneo, 1758), followed by *Isurus oxyrinchus* (Rafinesque, 1810), *Lamna nasus* (Bonnaterre, 1788), *Alopias vulpinus* (Bonnaterre, 1788) and *Carcharhinus plumbeus* (Nardo, 1827) [20]. Sharks of the genus *Carcharhinus* are represented in the Mediterranean Sea by at least eight species [21,22], but there is a great lack of information about species identity, abundance and distribution, mainly due to the scarcity of catches and the difficulty in their correct identification, especially for juveniles.

Due to the low reproduction rate of elasmobranchs, newborn records are very limited in comparison to other reproductive strategies, for example, those displayed by many osteichthyes. Knowledge about the early stages of juvenile sharks is extremely poor, and newborns require particular attention. Furthermore, the need to identify grounds of possible aggregation or nursery areas is very important for eventually establishing a protection area for a local and regional management plan of the maritime space.

Data gathered in the study area, shown in this paper, can provide useful information for this purpose. Juvenile numbers and detailed morphometrics, although representing a still-too-small data set for species and sex, feature an important initial database to be improved.

2. Materials and Methods

2.1. Study Area

The study area encompassed the marine waters of Tuscany, in Italy, between the Ligurian and the North Tyrrhenian Seas, in the north-western part of the Mediterranean basin; relating to bluntnose six-gill sharks records, we also considered the northernmost part of Latium Region (Figure 1). The data analyzed in this paper were collected in Tuscany during the period of 2007–2022.

2.2. Sampling Protocols

The sampling protocol adopted is characterized by the word "large", which defines the nature of the database (Mediterranean Large Elasmobranchs Monitoring). This refers to maximum size reached by each different species; particularly, we only consider sharks

with more than 100 cm in total length (TL) and batoids with more than 150 cm in disc width (DW) as maximum sizes [23]. Applying this rule to the species in the Mediterranean and Black Seas, we restricted the MEDLEM protocol to 16 different families and 7 orders [24]. Thanks to the collaboration of several research institutes, military authorities, professional and recreational fishermen, and NGOs, a great amount of valuable information on catches, sightings and strandings of large cartilaginous fishes was archived into the regional database.

Figure 1. Map of the study area: coasts of Tuscany and northern Latium counties; Ligurian and North Tyrrhenian Seas (north-western Mediterranean basin).

When some of these stakeholders get involved in a capture event (or more rarely, in a stranding one), it is strongly recommended to immediately call the free blue number 1530, made available 24 h a day throughout the national territory by the Italian Port Authority; it is also very useful to take and send some photographs of the whole specimens or of some details (fins, teeth, ventral part, etc.), which can help correct taxonomic identification, sex attribution or size estimation. If the cartilaginous fish is still alive, it is advisable to free it at sea. On the contrary, if the specimens are dead, the Port Authority calls some reference numbers, in particular ARPAT's, as coordinator of the regional nets, which activate all the necessary procedures to recover the shark. Spatial–temporal data about catches, strandings or sightings (date, time, country, latitude, longitude, etc.) are registered; then, the species and fishing gear responsible for capture are annotated and communicated to the MEDLEM account (medlemcontact@gmail.com).

2.3. Biological and Biometrical Parameters

When possible, all biological parameters were collected. Total length was recorded to the nearest centimeter with a measurement tape; body mass, with an electronic dynamometer to the nearest gram; sex and all the other thirty-one biometrical measurements, following the MEDLEM protocol: fork length and from snout tip to pre-caudal pit, 1st dorsal origin, 2nd dorsal origin, pectoral fin origin, pelvic fin origin, anal fin origin, 1st gill opening and 5th gill opening; head (snout–eye length, snout–mouth length, snout–nostril length, 1st-5th gill opening length, horizontal diameter eye and vertical diameter eye); pectoral fin (base length, anterior margin length, posterior margin length and height); 1st dorsal fin (anterior margin length, posterior margin length, height and base length); caudal fin (dorsal lobe length, terminal margin length, sub-terminal margin length, ventral lobe length, post-ventral margin length and pre-ventral margin length); and claspers (outer length and inner length) [23].

Species identification and taxonomic nomenclature followed [22,25–27]. Some specimens were preserved in alcohol at 75% and were stored in the collections of Museum of Natural History of Pisa University and Museum of Natural History of Florence University, zoological section, La Specola. Photographs of the examined specimens were stored in the digital archives of the authors and are available for further comparisons. Genetic samples were collected from all the specimens.

For this paper's purpose, individuals were divided into four size groups based on the observed length and related information in the available literature: newborn, young of the year, juveniles and adults. Newborn (NB) size corresponded to the size at birth; young of the year (YOY) were considered those individuals of age 0; the separation between juveniles (JUV) and adults (ADL) was determined according to the total length (LT) at which 50% of the population reached sexual maturity (LT50). According to the literature, the four groups were established for six species of interest (Table 1).

Table 1. The four size groups established in the present paper according to the bibliography. NB = newborn; YOY = young of the year; JUV = juveniles; ADL = adult; TL = total length; DW = disc width.

Species	NB (cm)	YOY (cm)	JUV (cm)	ADL (cm)	References
I. oxyrinchus	$60 < TL \leq 70$	$70 < TL \leq 100$	$100 < TL \leq 200$	$TL > 200$	[28,29]
P. glauca	$35 < TL \leq 45$	$45 < TL \leq 80$	$81 < TL \leq 180$	$TL > 180$	[28,29]
C. plumbeus	$56 < TL \leq 75$	$75 < TL \leq 100$	$100 < TL \leq 140$	$TL > 140$	[29–31]
A. vulpinus	$114 < TL \leq 160$	$160 < TL \leq 170$	$170 < TL \leq 300$	$TL > 300$	[29,32,33]
H. griseus	$65 < TL \leq 74$	$74 < TL \leq 100$	$100 < TL \leq 300$	$TL > 300$	[29,34,35]
M. mobular	$160 < DW \leq 180$			$DW > 300$	[4,8,36]

We focused on newborn or young of the year specimens of six species: *P. glauca*, *I. oxyrinchus*, *A. vulpinus*, *C. plumbeus*, *H. griseus* and *M. mobular*.

2.4. Biometrical and Statistical Analyses

We show the average $\pm$ 1 SD, and minimum and maximum values of each measure for each species. In the case of a single specimen, we present one value. In the case of samples with size ≥ 3 and at least 3 records/sex, we tested if sexual differences in body morphometrics were present within each species (*P. glauca* and *C. plumbeus*) with Student's *t*-test and Levene's test for variance homogeneity. In addition, to detect if occurrence of sex was a stochastic or an actual pattern, we applied the χ^2 test with Yates's correction for <5 expected frequencies. We performed all analyses with IBM SPSS, 20.0 release.

3. Results

From 2007 to 2022, in the study area, 222 large elasmobranch records belonging to 10 different species were registered as bycatch, sightings or, rarely, stranding events; all the data of the findings are reported in Table S1 (Supplementary Materials). The most frequent species was the blue shark *P. glauca* (40 %) (Table 2; Figure 2).

Table 2. Elasmobranchs registered in South Ligurian–North Tyrrhenian Seas between 2007 and 2022; * = disc width.

Species	Total	Range (TL, cm)	Number of Measured Individuals
Prionace glauca	89	45–300	62
Mobula mobular	39	96–370 *	8
Hexanchus griseus	27	80–420	22
Alopias vulpinus	22	120–432	14
Isurus oxyrinchus	21	70–200	13
Carcharhinus plumbeus	15	54–211	11
Cetorhinus maximus	6	295–800	6
Alopias superciliosus	1		
Carcharodon carcharias	1	350	1
Aetomylaeus bovinus	1	80 *	1
Total	**222**		**138**

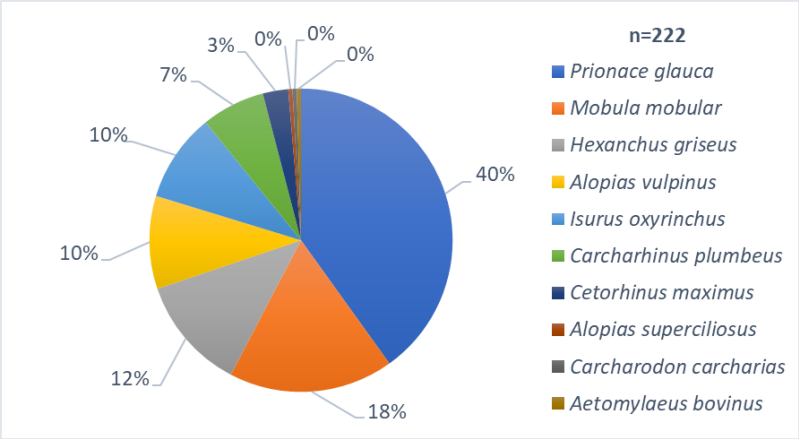


Figure 2. Percentage of species registered in the period 2007–2022 in the study area; 0% = 0.0045% (n = 1).

In total, 51% (n = 112) of the total elasmobranchs registered in the study area were "juveniles" (YUV + YOY + NB) and were exclusive to six species: *P. glauca, I. oxyrinchus, A. vulpinus, C. plumbeus, H. griseus* and *M. mobular*. A total of 78% of the data refer to bycatch events; 18%, to sightings; and only 4%, to strandings. Details of the fishing gear responsible for capture are shown in Figure 3.

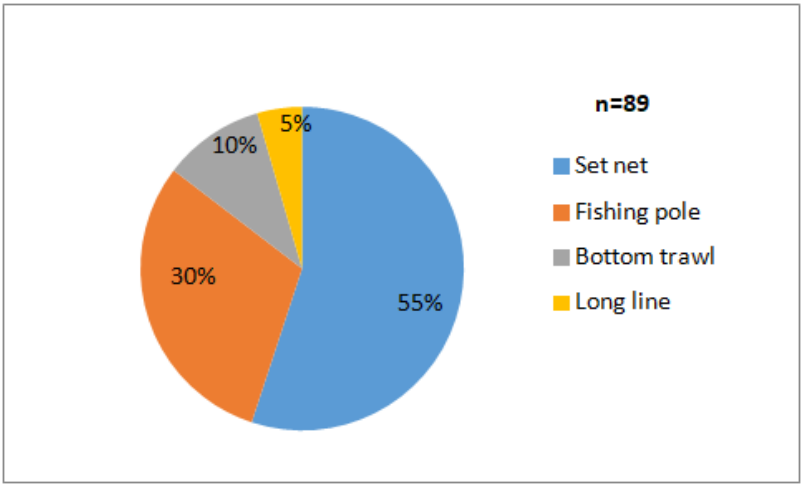


Figure 3. Types of fishing gear causing bycatch of young individuals in South Ligurian–North Tyrrhenian Seas.

Especially for three species, a predominance of juveniles or newborns with respect to adult specimens was highlighted as follows: *C. plumbeus* (93%), *I. oxyrinchus* (76%) and *P. glauca* (73%). When examined, some of these individuals showed an almost-healed umbilical scar visible on the ventral side, in the midpoint of the line joining the origin of the pectoral fins, to confirm their "newborn" condition; in particular, in seven sandbar sharks, the umbilical mark was still an open hole (on the left in Figure 4) [31].

For some species, mainly the three most abundant ones, juveniles and newborn individuals were concentrated in very restricted areas.

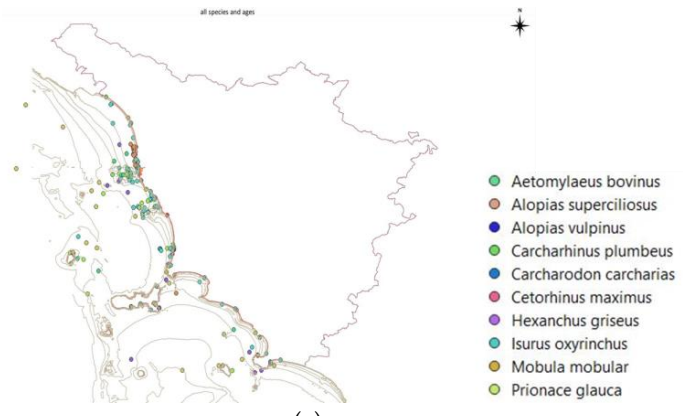
Detailed measurements of the 35 examined young individuals are reported in Table S2.

3.1. Prionace Glauca

Blue shark was the most abundant species, with 66 immature individuals: 26 JUV (90 < TL < 160 cm), 38 YOY (49,5 < TL < 81 cm) and 1 NB (TL = 45 cm). They were mainly captured with set nets or fishing poles, at depths between 3 and 75 m (exceptionally, one

little blue shark was captured at 200 m with a bottom trawl), in two restricted areas close to the Meloria (Marine Protected Area) and Vada shoals (approximately 42.405–43.980° N) (Figure 5d); for the most part, sharks were captured or sighted in the spring–summer period (May to August) and were often captured alive and released at sea. Sixteen individuals were examined (Table S2).

Figure 4. Some examples of the ventral side of the examined individuals where the almost-healed umbilical scar is more evident (red circle); PGL = blue shark *P. glauca*, CPL = sandbar shark *C. plumbeus* and IOX = mako shark *I. oxyrinchus*. Note the seven sandbar sharks (on the left) with the umbilical mark still open.



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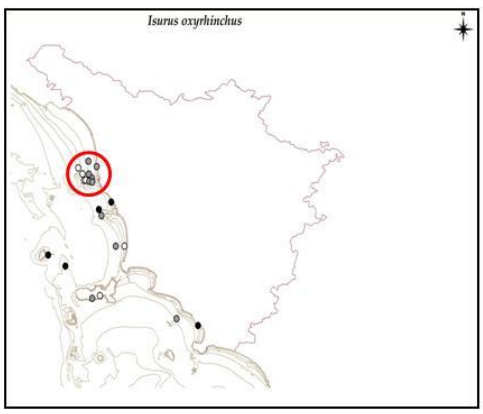

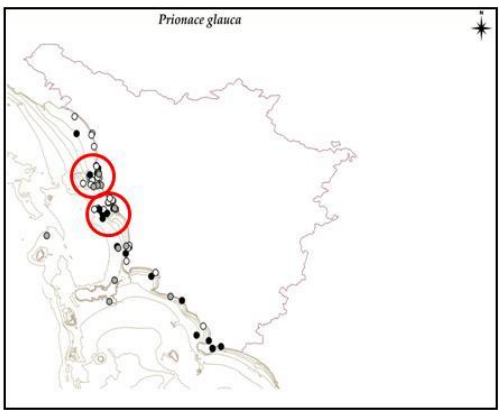

(**b**) (**c**)

Figure 5. *Cont.*

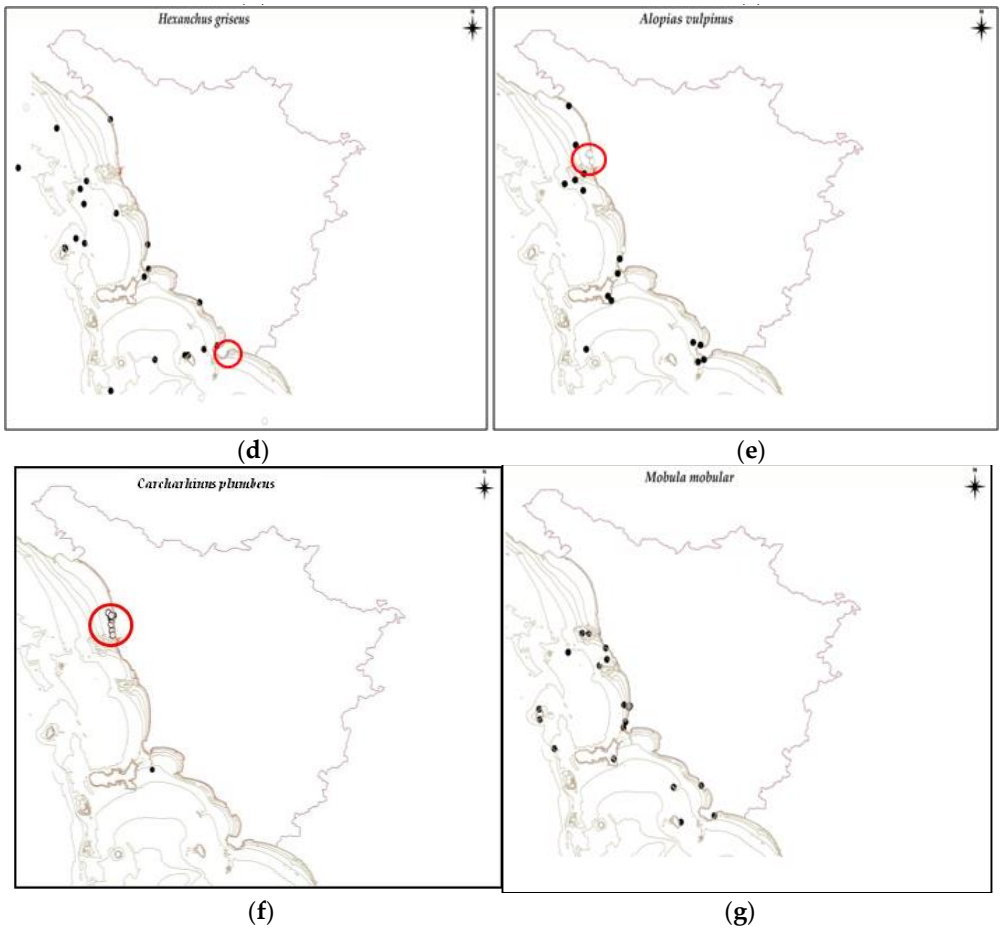

Figure 5. Geographical distribution of the findings, South Ligurian–North Tyrrhenian Seas (2007–2022). (**a**) All the species (222 individuals); (**b**) *I. oxyrinchus*; (**c**) *P. glauca;* (**d**) *H. griseus*; (**e**) *A. vulpinus*; (**f**) *C. plumbeus*; (**g**) *M. mobular*. Black symbols = adult individuals; white or gray symbols = juveniles (NB + YOY + JUV); red circles = coastal concentration of "juveniles".

3.2. Carcharhinus Plumbeus

A total of 14 newborn sharks were accidentally caught with set nets in recent years: 2018 (n = 1), 2019 (n = 1), 2020 (n = 2), 2021 (n = 9) and 2022 (n = 1). All the captures were registered in September and October and in a restricted area between Tirrenia and Gombo (Pisa) at the mouth of the Arno River and "Fiume Morto Nuovo" in very shallow waters (7–15 m depth) between 43.607° N and 43.736° N (Figure 5b). Total length ranged between 54 and 90 cm (n = 10); weight, between 0.9 and 4 kg (n = 9), in 2 females and 7 males. Four baby sharks were still alive and were released at sea. Seven dead sharks were examined; they had a still-open birth mark (Table S2, Figure 4).

3.3. Isurus Oxyrinchus

In the period 2016–2022, ten juveniles shortfin mako sharks were registered (106 cm < TL < 135 cm), together with five young of the year (80 < TL < 88.5 cm) and only one newborn of 70 cm in total length, released alive. These 16 "small" sharks were mainly captured between May and July with set nets and fishing poles in a restricted area between Livorno (Vada and Meloria shoals) and the mouth of the Arno River (Pisa), at approximately 42.601–43.678° N (Figure 5c) at depths of about 10 to 70 m. Six dead fish were examined; see Table S2 for details.

3.4. Hexanchus Griseus

Only four young individuals of this species were captured, two of them with bottom trawls at depths of 301–366 m and two in more shallow waters; two were considered juveniles, and two, young of the year. The YOY specimens were captured slightly to the south of the study area, in the northern part of Latium Region (North Tyrrhenian Sea) (Figure 5e); they were 80 and 87.5 cm long, a male and a female, respectively. Three dead fish were examined (Table S2).

3.5. Alopias Vulpinus

Seven individuals all classified as newborn were registered in 2017 (n = 2) and 2020 (n = 5). The total length ranged between 120 and 147 cm (n = 3); the weight, between 3.5 and 7 kg (n = 7). All the sharks except one were incidentally captured with set nets at depths between 7 and 15 m close to the Arno River (Pisa) at 43.628–43.677° N (Figure 5f). Two dead individuals were examined (Table S2).

3.6. Mobula Mobular

Five individuals were captured or sighted between 2008 and 2019 in coastal waters at a depth of about 20 m. Their disc width ranged between 96 and 180 cm. Only one ray was dead and was examined (Table S2bis).

The average ± 1 SD, and minimum and maximum values of each measure for each species are reported in Table S3. For the two most numerous species (see Biometrical and Statistical Analyses), we obtained the following data: For *P. glauca*, the average values of almost all body morphometrics were similar between males and females (all not significant, with p ranging from 0.65 to 0.866). It is worth noticing that two body measures slightly differed between sexes. In particular, the pectoral fin height resulted a little larger in females than in juvenile males ($p < 0.065$), as did the caudal fin sub-terminal margin length ($p < 0.096$). In *C. plumbeus*, the average values were identical or much similar between sexes (p ranging from 0.164 to 0.969), except the caudal fin ventral lobe length, which was lightly larger in females than males ($p < 0.03$). Detailed results (homogeneity tests, degrees of freedom and significance) of the comparison of body morphometrics between sexes for the two considered species are shown in Table S4.

The occurrence of sexes in our sample did not deviate significantly (χ^2 with Yate's correction = 0.518, 1 d.f., $p = 0.657$).

4. Discussion

Prionace glauca is a widespread species in the Mediterranean, and it often represents the most important bycatch fraction of tuna and swordfish longline fishery, especially in Italy, Malta, Morocco and Tunisia [9]. This species is also incidentally captured in recreational fishing in Tuscany. It is listed in Annex 3 of the Berna and Barcelona Conventions and as Vulnerable in the IUCN Red List for the Mediterranean basin. Adults reach 380 cm in total length (TL), generally between 180 and 300 cm; the total length of newborns, usually 15–30 in number, is 35–45 cm [23,37,38]. The observation of newborns in the period of May–September is compatible with the fact that complete embryos have been observed by other authors in May–July [37,39,40].

Isurus oxyrinchus is occasionally caught with swordfish longlines. Its very low reproductive capacity may cause a rapid decline also in the Mediterranean basin and Italian seas [41]. For this reason, shortfin mako shark is listed in Annex A3 of the Berna Convention and Annex A2 of the Bonn and Berna Conventions; moreover, it is listed as Critically Endangered in the IUCN Red List. Adults reach 400 cm in total length (TL), generally 150–200 cm in TL, while newborns, usually 4–25 in number, are 60–70 cm in TL [23,36].

The cosmopolitan species, i.e., present in all the Mediterranean basin, *A. vulpinus* is often bycatch in professional fishery. Listed in Annex 3 of the Barcelona Convention and as Vulnerable in the IUCN Red List, adults reach 600 cm. At birth, young specimens are more than 100 cm long, up to 120 cm in TL [29,32,33].

Carcharhinus plumbeus is an endangered shark species in the Mediterranean Sea [42] considered a protected species in the inventory of Turkish Fisheries Act Marine Protected Species [43]. It is listed in Annex 3 of the Barcelona Convention and as Endangered in the IUCN Red List. Adults can reach 240–300 cm in total length (TL), generally 220 cm in TL, while newborns are 45–75 cm in TL, usually 5–12 in number [23,36]. In the Mediterranean Sea, the size at birth of *C. plumbeus* ranges from 45 cm [44,45] to 65 cm [44–46]. The species grows larger in western Atlantic waters compared with Mediterranean waters, as the maximum size at birth recorded was 72 cm [30], and it was 75 cm for the overall northern Atlantic [47]. Our sample ranged between 54 and 90 cm in TL, which is a relatively larger length interval than the data cited above. According to Capapé [46], in the waters of Gulf Gabès, the highest number of sandbar shark juveniles was observed in the summer months. According to Carlsson [30], neonate sandbar sharks (<age 1) usually reside in primary nursery areas, where they are born in the first period of summer. Therefore, it can be assumed that the specimens described in the present paper either (1) were born and resided off the Tirrenia–Gombo coast (Pisa) or (2) were born elsewhere and migrated from another area. At present, the available data do not allow us to give a definitive answer to these questions. As a matter of fact, the occurrence of several specimens (n = 7) with a partially healed umbilical scar (a still-"open" mark) could indicate that the coast of Pisa can serve as a probable nursery ground for *C. plumbeus*. This is a promising possibility for the survival of such an endangered shark species in the Mediterranean Sea. Similar considerations can also be valid for other species, such as *I. oxyrinchus* and *P. glauca*.

Recently, in the current year (21 May 2023), all *Carcharinidi* spp. entered Appendix II of Cites (https://cites.org/eng/app/appendices.php (accessed on 21 May 2023)).

On one hand, the ecological characteristics of the coastal waters of northern Tuscany can indicate a potential favorable habitat for YOY individuals of different large elasmobranch species, according to the conventional shark nursery area theory (e.g., having high productivity and low exposure to potential predators; and adults and juveniles in open and coastal waters, respectively) [48].

On the other hand, the high abundance of both YOY and juvenile sharks alone does not warrant a definitive classification of the study area as a nursery. According to Heupel et al. [49], three testable criteria should be examined for an area to be considered a shark nursery: (1) higher-than-average density of YOY sharks in the area, (2) tendency for YOY sharks to remain or return to the area for extended periods and (3) the area being used repeatedly over the years. Further effort will be spent to verify these criteria; particularly, there is a need for accurate collection of fishery data and the implementation of tagging studies in the study area, as well as the monitoring of environmental conditions, especially related to water temperature, which appears to play an important role in defining the putative nursery habitat of YOY blue and shortfin mako sharks [28].

Regarding body size analysis, the investigated sample is undoubtedly too small to appropriately represent the morphological variability of each species. However, some weak differences that we detected in three body morphometrics suggest that sexual size dimorphism could be exhibited even in the newborn or juvenile stage in the investigated species. Forthcoming studies on larger samples per species and per sex will be necessary to address the presence or absence of early sexual dimorphism in body measures.

The apparent growing trend of reports of large cartilaginous fishes in our region, especially of "juveniles" (Figure 6), does not correspond to a real numerical increase in these species but rather to ever-increasing attention paid to and sensitivity towards the problems related to the exploitation and conservation of this group of fishes. From the foregoing, it emerges that our region is confirmed as an area of high interest from the marine biodiversity point of view, where it is necessary to perform monitoring activity with ever-increasing commitment.

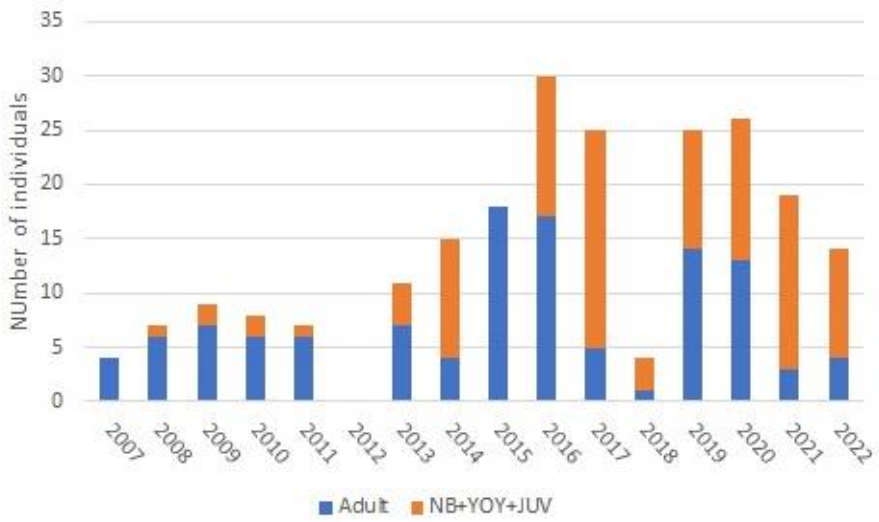

Figure 6. Trend of the individuals (adult + "juveniles") recorded over the years in the study area.

For some species, the phenomenon we are observing suggests a probable recovery in terms of abundance. In particular, in Italian waters, in the last decade, we observed a positive trend referred, above all, to the presence of young specimens of blue shark and shortfin mako in the bycatch of small-scale fishery [50].

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d15070806/s1, Table S1: All the detailed information about the findings; LAT = latitude, LONG = longitude, ADL = adult, JUV = juvenile, NB = newborn, Table S2: Detailed measurements of 35 examined young individuals, Table S2bis: Detailed measurements of young *M. mobular* examined, Table S3: Descriptive statistics (average ± 1 SD, and minimum and maximum values) of each measure for each species, Table S4: Detailed results (homogeneity tests, degrees of freedom and significance) of the comparison of body morphometrics between sexes of the two considered species, *C. plumbeus* and *P. glauca*.

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