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Using historical and citizen science data to improve knowledge about the occurrence of the elusive sandbar shark *Carcharhinus plumbeus* (Chondrichthyes – Carcharhinidae) in the Adriatic Sea

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Abstract

The Mediterranean Sea is an extinction hotspot for sharks, skates, and rays, with at least half of all species being threatened. The sandbar shark *Carcharhinus plumbeus* is among the most threatened species and is declared endangered (EN) in the Mediterranean according to the IUCN Red List of Threatened Species. The Adriatic Sea was previously proposed to be an important nursery area for this species based on sporadic sightings of neonates and juveniles. However, this species is generally considered to be rare in this region, and reports of its presence are scarce. Here, we present new records for the sandbar shark in the Adriatic Sea and review spatial and temporal data accumulated from literature, museum specimens, and citizen science initiatives in an attempt to assess the distribution and seasonality of this species. The majority of the records were from neonate and juvenile sandbar sharks, and three hotspots for their occurrence could be identified: (1) the Emilia-Romagna region, (2) the Veneto region, and (3) the Gulf of Trieste. Our data indicate a high concentration of sandbar sharks around the delta of the Po river, emphasising the need for scientific surveys in this confined area in order to confirm a possible nursery ground. Data collected by citizen science initiatives reveal that this species is still present in the Adriatic Sea and might be more abundant than previously thought, underlining the potential of citizen science as a valuable tool to monitor the distribution of rare and endangered species.

Keywords: Elasmobranchii; Estuaries; Mediterranean Sea; Migration; Neonates; Parturition.

Introduction

The Mediterranean Sea has been exploited by intensive coastal fishing for millennia (Lotze *et al.*, 2006) and is regarded as a key hotspot of extinction risk for sharks, skates, and rays (Dulvy *et al.*, 2014). Many large shark species have been severely depleted, with reported declines of between 96 and 99.99% (Ferretti *et al.*, 2008), and half of the chondrichthyan species in the Mediterranean Sea are threatened by extinction (Abdulla, 2004; Dulvy *et al.*, 2016). Large-bodied species are at the greatest risk, especially those living in shallow waters, which makes them more exposed to fisheries and habitat degradation (Ferretti *et al.*, 2008; Dulvy *et al.*, 2014). The utilisation of inshore coastal areas as nursery grounds has become a particular liability for sharks, skates, and rays, as direct and indirect fishing pressures have intensified and coastal habitat loss and degradation have accelerated in the Mediterranean (Abdulla, 2004).

The sandbar shark *Carcharhinus plumbeus* (Nardo, 1827) is a large, bottom-dwelling, shallow coastal water species that is distributed worldwide in temperate and tropical seas. Sandbar sharks can grow to a length of 240 cm and possibly up to 300 cm (Soufi-Kechaou *et al.*, 2018), with males and females reaching sexual maturity at 130–180 cm and 145–185 cm (Ebert *et al.*, 2013) and at the age of 8 and 10 years, respectively (Romine *et al.*, 2006). This coastal species' slow growth, late maturation, and low fecundity of 1–14 (mean 6.5) pups every second year make it highly vulnerable to overfishing (Saïdi *et al.*, 2005; McAuley *et al.*, 2007; Ebert *et al.*, 2013).

The sandbar shark used to be a common shark in the Mediterranean Sea, but it is currently regarded as being severely overfished (Dulvy *et al.*, 2016) and has become locally extinct along the French coast (Capapé *et al.*, 2000) and the Sea of Marmara (Kabasakal, 2015; 2019). Besides overfishing, habitat degradation of this species' coastal nursery areas through coastal development and pollution poses a significant threat for sandbar sharks in the Mediterranean Sea. According to the IUCN Red List of Threatened Species, the sandbar shark is declared globally vulnerable (VU) and endangered (EN) in the

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Mediterranean Sea (Dulvy *et al.*, 2016).

The Adriatic Sea is a highly productive area, but it is also strongly influenced by anthropogenic pressures, such as fisheries, nutrient inputs, and coastal development (Barausse *et al.*, 2009; 2011). Excessive long-term exploitation and overfishing in this area led to a steady decline and, ultimately, the collapse of elasmobranch catches in the 1980s and 1990s. However, large-sized apex and mesopredatory sharks were already depleted before 1945 (Barausse *et al.*, 2014). The sandbar shark was originally described from the Adriatic Sea as *Squalus plumbeus* (Nardo, 1827), but its presence in this region is solely documented by opportunistic reports, and it is therefore regarded to be a rare species (Kirinčić & Lepetić, 1955; Travaglini, 1982; Costantini & Affronte, 2003; Lipej *et al.*, 2000; 2008; Dragičević *et al.*, 2010; Fortuna *et al.*, 2010; Ćetković, 2018). Captured neonate sandbar sharks with unhealed umbilical scars indicate that the Adriatic Sea, especially the northern basin, might serve as a nursery area (Costantini & Affronte, 2003; Dragičević *et al.*, 2010). However, due to the scarcity of published records, little is known about the distribution, seasonality, and abundance of sandbar sharks in the Adriatic Sea, making effective conservation management for this species even more challenging in this highly productive but also heavily exploited Mediterranean sub-basin.

In the light of the data deficiency for rare and elusive species, several authors have proposed the use of alternative sources of information, such as local ecological knowledge (Stephenson *et al*., 2016) or citizen science (Giovos *et al.*, 2019a). Citizen science –an approach where the general public participates in scientific data collection– has been proven to be a valuable tool for gathering information about rare and endangered species, e.g., abundance (Becerril-García *et al*., 2020), distribution (Araujo *et al.*, 2020; McDavitt & Kyne, 2020), migration routes (Armstrong *et al.*, 2019; 2020), behavioural patterns (Chin, 2014; Jambura *et al.*, 2020), and critical habitats (Norton *et al.*, 2012; Jiménez-Alvarado *et al.*, 2020).

This study reviews the occurrence of the sandbar shark *C. plumbeus* in the Adriatic Sea and provides additional records, including the first reported occurrences off the Albanian coast. We are combining published, historical, and citizen science data to (1) evaluate the species' distribution and (2) seasonal patterns of occurrences and (3) to find further evidence of possible nursery areas in the Adriatic Sea. Furthermore, we briefly discuss the role, weaknesses, and strengths of citizen science data in an increasingly digital and data-driven world.

Materials and Methods

The Adriatic Sea is an elongated basin located in the Central Mediterranean Sea between the Italian peninsula and the Balkans. The six countries bordering the Adriatic Sea in clockwise order are Italy, Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, and Albania. The Adriatic Sea can be divided into three areas: the North Adriatic, the Central Adriatic, and the South Adriatic. The North Adriatic is the largest shelf area in the Mediterranean, with an average bottom depth of 35 m, rarely exceeding a depth of 100 m. This part is characterised by the largest riverine contributions into the basin, which induce intense phytoplankton development in autumn and winter (Cushman-Roisin *et al*., 2001; Kraus & Supić, 2011). The Central Adriatic has an average depth of 140 m and includes the Middle Adriatic Pit, which has a mean depth of 260 m. The South Adriatic is connected to the Ionian Sea by the Strait of Otranto and is characterised by a depression more than 1200 m deep, the deepest area in the Adriatic (Artegiani *et al.*, 1997; Cushman-Roisin *et al.*, 2001).

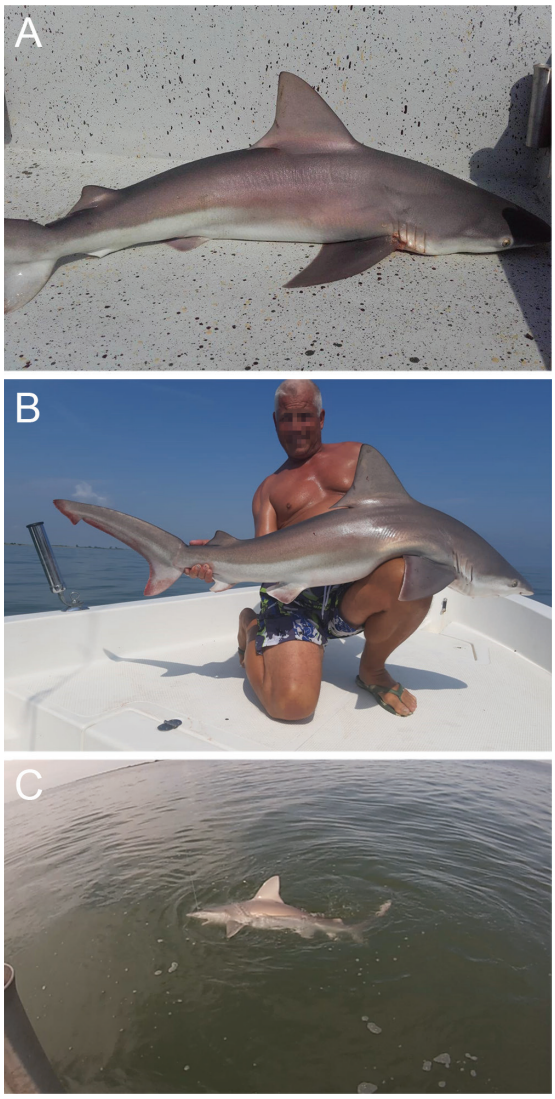

Fig. 1: Sandbar sharks (*Carcharhinus plumbeus*) caught in the Po delta, Italy. Reports are inventoried in the MECO database under the following identification numbers: (A) MECO #DE2019_0039, (B) MECO #DE2019_0038, and (C) MECO #DE2019_0040. Detailed information about each observation number is shown in Table 1. Picture courtesy of Michael Kinzer & Robert Engel.

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Between July 23 and August 17, 2019, four sandbar sharks (*C. plumbeus*) were caught by recreational fishermen close to the Po delta in the Northern Adriatic Sea (44.975833°N, 12.559722°E) and reported to the citizen science initiative known as the MECO (Mediterranean Elasmobranch Citizen Observations) Project. Pictures of three specimens were taken prior to releasing the sharks alive back into the water (Fig. 1). The species was identified based on the following features: (1) stout body, grey-brown or bronze in colour on the dorsal side and white on the ventral side; (2) no obvious markings on the tips and posterior edges of the fins; (3) moderately long rounded snout; (4) presence of an interdorsal ridge; (5) very large erect first dorsal fin with origin over or slightly ahead of the large pectoral fins insert (Ebert *et al.*, 2013).

Additionally, a database of sandbar shark occurrences in the Adriatic Sea was assembled based on published data, sightings reported to the MECO Project, entries from the sharkPulse web platform (Ferretti *et al.*, 2020), and historical data from museum collections. *Carcharhinus plumbeus* is the only confirmed species of this genus in the Adriatic Sea (Kovačić *et al.*, 2020). Therefore, sharks reported as *Carcharhinus* sp. in the sharkPulse app were also included in our database, and if the image allowed identification on a species level, they were reassigned to *C. plumbeus* accordingly. All entries in the MECO database and the sharkPulse web platform are underlain with images and were validated by the authors. Following Saïdi *et al.* (2005), we distinguished between four life-history stages, which were determined based on the shark's total length: (1) neonate (♀ 50–65 cm, ♂ 45–65 cm and/or with unhealed umbilical scar); (2) juvenile (♀ 65–164 cm, ♂ 65–138 cm); (3) subadult (♀ 164–171.5 cm, ♂ 138–160 cm); (4) adult (♀ > 171.5 cm, ♂ > 160 cm).

Results

The three sandbar shark specimens reported from the Po delta were all females. Images allowed the total lengths of two of them to be estimated at 140 and 160 cm, respectively. Therefore, they are within the reported size spectrum for juvenile sandbar sharks in the Mediterranean Sea (65–164 cm) but are close to the subadult stage. There are two additional records from the Po delta from sharkPulse: On July 25, 2017, and July 19, 2018, two sandbar sharks were caught and released by recreational fishermen. No data on size or sex are available for these two specimens (Fig. 2, Table 1).

The established database incorporates 47 records of sandbar sharks in the Adriatic Sea from 1879 to 2020. The majority of the entries arose from citizen science reports (38.3%; n=18), while 31.9% (n=15) were from museum collections, and 29.8% (n=14) were from published data. In the period between 2000 and 2020, 26 records were collected; 69.2% (n=18) were from citizen science initiatives, 30.8% (n=8) were published, and none came from museum collections (Fig. 2, Table 1).

Information about ontogenetic stages and sex are available for 34 and 26 specimens, respectively. The vast majority (82.4%) were neonates and juveniles (41.2%, n=14 each), while subadults and adults only constituted 8.8% (n=3) each.

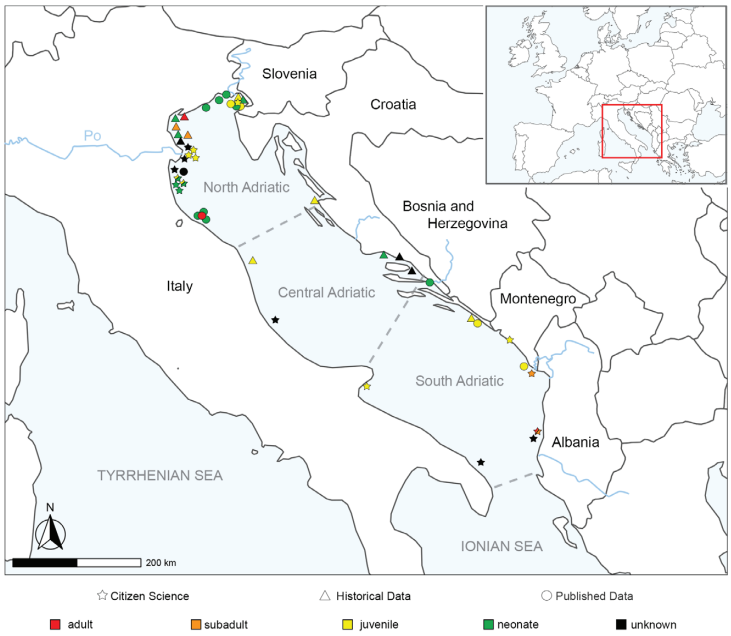

Fig. 2: Spatial distribution of different ontogenetic stages of the sandbar shark *(Carcharhinus plumbeus)* in the Adriatic Sea. Observations were gathered from historical, citizen science, and published data. Detailed information about each observation is shown in Table 1.

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Table 1. Records of sandbar sharks (*Carcharhinus plumbeus*) from the Adriatic Sea. Entries were rallied from published data, museum collections, and citizen science initiatives (MECO Project, sharkPulse). Data from the MECO database came from social media platforms or were communicated directly to scientists involved in the MECO Project. Abbreviations: MSNM, Museo Civico di Storia Naturale di Milano; MCSNT, Museo Civico di Storia Naturale di Trieste; MCSNV, Museo Civico di Storia Naturale, Venezia; MZF, Museo Zoologico "La Specola", Firenze; NHMW, Naturhistorisches Museum Wien; PMD, Prirodoslovni Muzej Dubrovnik; PMR, Prirodoslovni Muzej Rijeka; PMS, Prirodoslovni Muzej Split.

Country	Region	Date	Size [cm]	Weight [kg]	Sex	Ontogeny	Source
Albania	Fier, Divjakë	30.06.2016	-	-	female	(sub)adult	sharkPulse source: alb365.com
	Fier, Divjakë	04.05.2019	-	-	male	-	MECO #DE2019_0041
Croatia	Dubrovnik-Neretva, Dubrovnik	1960 – 1979	92	-	-	juvenile	PMD-6
	Dubrovnik-Neretva, South Dubrovnik	28.05.1952	123	10.3	female	juvenile	Kirinčić & Lepetić (1955)
	Split-Dalmatia, Brač Channel	-	-	-	-	-	PMS
	Split-Dalmatia, Makarska Riviera	-	-	-	-	-	PMS
	Split-Dalmatia, Split	04.1895	56	-	male	neonate	NHMW-61349
	Split-Dalmatia, Zaostrog	23.11.2009	78.5	3.65	female	neonate^{+}	Dragičević *et al.* (2010)
	Zadar, Zadar	1903	78	-	male	juvenile	PMR-04408
Italy	Adriatic Sea	-	174	-	-	adult	MCSNT-ic2901
	Abruzzo, Ortona	09.2017	-	-	-	-	sharkPulse source: sharkPulse*
	Apulia, Frigole	25.05.2020	-	-	-	-	MECO #DE2020_0008
	Apulia, Manfredonia	05.06.2014	150	100	-	juvenile	sharkPulse source: sharkyear.com
	Emilia-Romagna, Porto Garibaldi	2006-2008	-	-	-	-	Fortuna *et al.* (2010)
	Emilia-Romagna, Porto Garibaldi	22.08.2018	-	-	-	-	sharkPulse source: Fabio Reca
	Emilia-Romagna, Ravenna	26.07.2017	-	-	-	neonate/juvenile	sharkPulse source: CESTHA
	Emilia-Romagna, Ravenna	18.10.2017	-	-	-	neonate/juvenile	sharkPulse source: CESTHA
	Emilia-Romagna, Ravenna	01.08.2018	50	-	-	neonate	sharkPulse source: CESTHA
	Emilia-Romagna, Ravenna	01.08.2018	50	-	-	neonate	sharkPulse source: CESTHA
	Emilia-Romagna, Riccione	summer 1981	200	70	female	adult	Travaglini (1982)
	Emilia-Romagna, Riccione	05.09.1999	46.5	0.46	male	neonate^{+}	Costantini & Affronte (2003)
	Emilia-Romagna, Riccione	09.09.2000	60	1.36	male	neonate^{+}	Costantini & Affronte (2003)
	Emilia-Romagna, Riccione	16.09.2000	52	0.94	male	neonate^{+}	Costantini & Affronte (2003)
	Friuli Venezia Giulia, Gulf of Trieste	-	49	-	-	neonate	MCSNT-ic0071

Continued

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Table 1 continued

Country	Region	Date	Size [cm]	Weight [kg]	Sex	Ontogeny	Source
Italy	Friuli Venezia Giulia, Gulf of Trieste	1955	80	-	-	juvenile	MSNM-Pi 3389
	Friuli Venezia Giulia, Marano Lagunare	03.09.1998	67.9	1.94	male	neonate[+]	Costantini & Affronte (2003)
	Friuli Venezia Giulia, Marano Lagunare	23.09.1998	68.8	2.04	female	neonate[+]	Costantini & Affronte (2003)
	Marche, Civitanova Marche	17.09.1884	-	-	male	juvenile	MZF-5872
	Veneto, Caorle	21.08.1999	67.5	2.42	male	neonate[+]	Costantini & Affronte (2003)
	Veneto, Chioggia	29.07.1908	-	-	male	-	MCSNV-4863
	Veneto, Po delta	23.07.2019	140	-	female	juvenile	MECO #DE2019_0038
	Veneto, Po delta	14.08.2019	-	-	female	juvenile	MECO #DE2019_0039
	Veneto, Po delta	17.08.2019	160	-	female	juvenile	MECO #DE2019_0040
	Veneto, Porto Barricata	19.07.2018	-	-	-	-	sharkPulse source: Barricata Tuna Club
	Veneto, Porto Levante	25.07.2017	-	-	-	-	sharkPulse source: Andrea Grassi
	Veneto, Venice	-	50	-	female	neonate	MCSNV-2670
	Veneto, Venice	02.1879	-	-	-	adult	MZF-6351
	Veneto, Venice	04.1879	-	-	-	subadult	MZF-6330
	Veneto, Venice	08.09.1898	51	-	female	neonate	MCSNV-2665
	Veneto, Venice	-	152	-	male	subadult	MCSNV-21342
Montenegro	Budva, Budva	01.2009	-	-	-	juvenile	MECO #MNE-117
	Ulcinj, Ada Bojana	14.05.2017	110	2.8	female	juvenile	Ćetković (2018)
	Ulcinj, Ada Bojana	29.08.2020	150	35	male	subadult	MECO #MNE-135
Slovenia	Piran, Gulf of Trieste	17.10.2000	71	2.6	female	juvenile	Lipej *et al.* (2000)
	Piran, Gulf of Trieste	27.10.2000	81.5	3.6	-	juvenile	Lipej *et al.* (2000)
	Piran, Gulf of Trieste	14.10.2007	70.5	2.34	male	neonate[+]	Lipej *et al.* (2008)
	Piran, Gulf of Trieste	25.12.2019	83	4	female	juvenile	MECO #DE2019_0042

**Carcharhinus* sp.

[+]visible umbilical scar reported

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Most records came from the Northern Adriatic Sea (67.4%, n=31), followed by the Southern Adriatic Sea (21.7%, n=10) and the Central Adriatic Sea (10.9%, n=5). One historical record of an adult sandbar shark, deposited in the Natural History Museum Trieste (MCSNT-ic2901), is labelled as being caught in the Adriatic Sea but without further information about the locality.

Sandbar sharks were present in the Adriatic Sea throughout the whole year, with March being the only month without any record. Thirty-six records provided detailed temporal information (month of capture/sighting), of which the majority were encountered between April and October (88.9%, n=32). Occurrences peaked in May and June in the Southern Adriatic Sea (n=5) and from July to October in the Northern Adriatic (n=21). Only three records in the Central Adriatic Sea had temporal information: a juvenile caught near Split, Croatia, in April and two sandbar sharks caught near Ortona and Civitanova Marche, Italy, in September (Fig. 3, Table 1).

Records of the sandbar shark Carcharhinus plumbeus in the Adriatic Sea by country

Albania

Two sandbar sharks were reported from Albania. One was from a local newspaper article shared on social media, while the second one came from sharkPulse. To our knowledge, these very recent reports (2016 and 2019) are the only known records from the Albanian coast. Both sharks were caught by recreational fishermen near the town of Divjakë. Unfortunately, no measurements were taken. However, the record from sharkPulse indicates that the shark was similar in size to the fisherman and, therefore, represents either a subadult or adult female (Table 1).

Bosnia and Herzegovina

There are no records available from the 20-km-long coastline of Bosnia and Herzegovina.

Croatia

Seven records were collected from Croatia between 1895 and 2009. Most of them came from museum collections (n=5), while only two sightings, one from Dubrovnik (Kirinčić & Lepetić, 1955) and one from Zaostrog (Dragičević *et al.*, 2010), were published. No citizen science data are available for this region. Three specimens were juveniles, two were neonates, and two did not have a known ontogenetic stage. The northernmost occurrence was recorded in Zadar, while the remaining occurrences were from Split-Dalmatia (n=4) and Dubrovnik (n=2) (Table 1).

Italy

With 31 records, more than half (66%) of all sandbar shark records in the Adriatic Sea came from Italy. The database entries cover the years from 1879 to 2020. Most of the entries came from citizen science initiatives (41.9%, n=13), followed by museum collections (32.3%, n=10) and published data (25.8%, n=8). The vast majority of all individuals with a known ontogenetic stage were either neonates or juveniles (79.2%; n_{neo}=11, n_{juv}=6, $n_{neo/juv}$=2), while two were subadults, three were adults, and seven did not have a known ontogenetic stage. One of the adults was reported to be a pregnant female (Travaglini, 1982), while there are no data on the sex of the other two specimens. Three main hotspots for sandbar shark occurrences

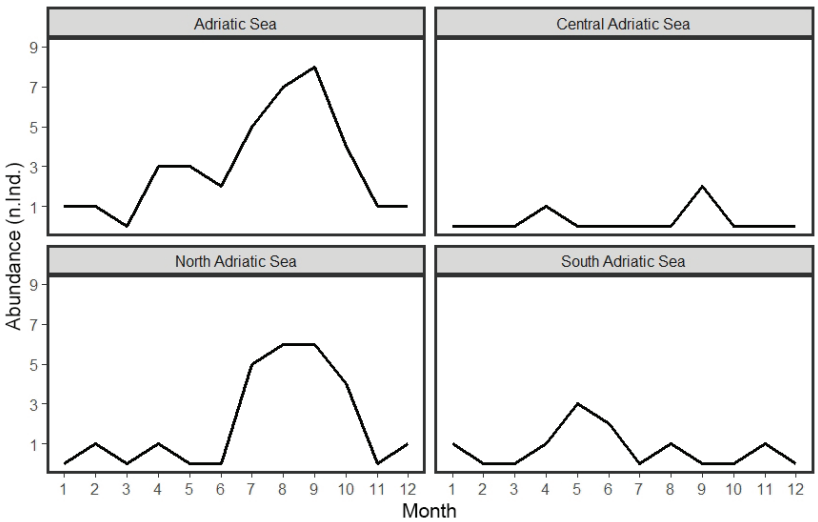

Fig. 3: Temporal distribution of sandbar sharks (*Carcharhinus plumbeus*) observed in the Adriatic Sea. The number of observations is low during the winter months and starts to increase in spring, reaching a peak in summer/autumn, and it rapidly decreases at the end of autumn.

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could be detected, all of which are situated in the northern part of Italy: (1) the Emilia-Romagna region, (2) the Veneto region, and (3) the Gulf of Trieste (Table 1).

Montenegro

Three records were collected from Montenegro between 2009 and 2020. Two specimens were juveniles caught in gillnets in depths between 20–40 m, while the third one was a male subadult caught close to the Albanian border (Table 1). This species is considered rare in Montenegrin waters (Ćetković, 2018).

Slovenia

Four specimens caught in the Gulf of Trieste were landed in Piran, Slovenia. Three records came from published data (Lipej *et al.,* 2000; 2008), and one came from a local newspaper article in 2019. Three of the specimens were described as juveniles and one as a large neonate (70.5 cm) with an unhealed umbilical scar.

Discussion

The presence of the sandbar shark in the Adriatic Sea has been well known since the 19th century (Nardo, 1827; Faber, 1883; Brusina, 1888). Paradoxically, published data on its occurrence in this region have remained scarce, probably due to misidentification with other shark species (Lipej *et al.*, 2000). The present study reports new records of the sandbar shark *C. plumbeus* in the Adriatic Sea, including the first occurrences off Albania, and gives a thorough revision of this species' distribution in this area. Sandbar sharks were previously regarded to be rare in the Adriatic Sea (Faber, 1883; Brusina, 1888; Kirinčić & Lepetić, 1955; Lipej *et al.*, 2009), even though this was questioned by various other authors (Lipej *et al.*, 2004; Lipej *et al.*, 2008; Dragičević *et al.*, 2010). Our results confirm the continuous presence of the sandbar shark in the Adriatic Sea and add 18 new records since 2009, 16 of which were from the last five years (Fig. 4).

Spatial patterns and occurrence hotspots

The vast majority of the records came from the North Adriatic basin and could be assigned to three hotspots along the Italian-Slovenian coast: (1) the Emilia-Romagna region, (2) the Veneto region, and (3) the Gulf of Trieste. These regions held a high concentration of neonate and juvenile sandbar sharks, and only two neonates were caught outside these hotspots; Dragičević *et al.* (2010) reported the capture of a female neonate sandbar shark near Zaostrog (Split-Dalmatia) in autumn. With a total length of 78.5 cm, this specimen was well outside the usual size range for neonates (45–65 cm). However, an unhealed umbilical scar was still visible, and therefore,

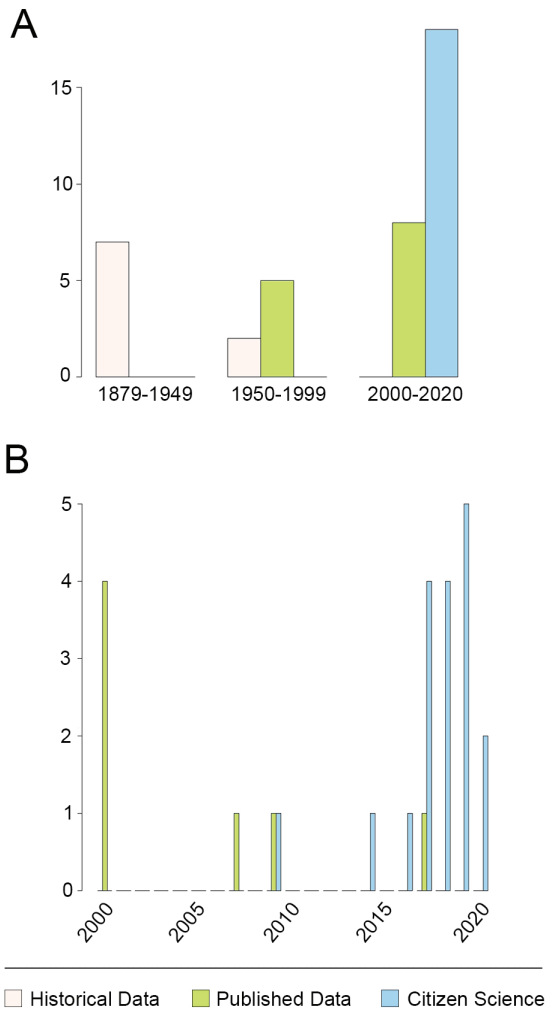

Fig. 4: Records of sandbar sharks (*Carcharhinus plumbeus*) in the Adriatic Sea gathered from specimens deposited in museum collections, published data, and citizen science initiatives from the last (A) 150 years; (B) 20 years.

we kept its original assignment as a neonate. The second neonate specimen recorded outside the North Adriatic basin was significantly smaller (56 cm) and was caught in Split in spring 1895. Whether these specimens migrated there from the North Adriatic or this region represents another critical area for this species in the Adriatic Sea cannot be answered yet. Lipej *et al.* (2000) mentioned that sandbar sharks are commonly found at fish markets in different Dalmatian towns in the Middle Eastern Adriatic but are often misidentified and rarely published. This is also indicated by our data, which clearly demonstrate the presence of this species along the Croatian coast but are based mainly on historical data from museum collections. Recent occurrences are rare in this region (Kirinčić & Lepetić, 1955; Dragičević *et al.*, 2010), and therefore, we urge for a thorough revision of the presence of this

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species in this area, including strengthening the efforts of citizen science to find critical habitats for this species along the eastern Adriatic coast.

Records of subadult and adult specimens were generally scarce in the Adriatic Sea and restricted to the South Adriatic basin off Albania and the western shores of the North Adriatic basin. Only one report came from this region, which was of a 2-m-long pregnant female sandbar shark that was caught 15 km off Riccione (Italy, North Adriatic) and was carrying nine still-living embryos (Travaglini, 1982). Although the prevalence of neonate and juvenile specimens indicate the presence of a possible nursery area in this region, an explanation for this apparent lack of pregnant females in this heavily fished area is still pending.

Temporal trends

The presence of sandbar sharks in the Adriatic Sea was reported throughout the whole year. Sightings increased between May and June in the southern part of the Adriatic Sea and from July to October in the northern part. Most sightings of neonate and juvenile sandbar sharks occurred in the western part of the Northern Adriatic Sea during the summer months (July to September) and later in October in the Gulf of Trieste in the east. Whether neonates stayed there or migrated further south cannot be answered with certainty yet due to the rare reports in winter. We cannot exclude that the low number of records during the winter months is an artefact, as the Adriatic coast is more crowded during summer, making sightings by citizen scientists more likely during this time. Thus, a year-round survey would be necessary to confirm such an increase during the summer months. However, a similar timing for the occurrence of neonate sandbar sharks was reported in the Gulf of Gabès (Tunisia, Central Mediterranean; Bradaï *et al.*, 2005) and Yumurtalık Bight (Turkey, Levantine Sea; Başusta *et al.*, 2021), indicating a true trend rather than an observational bias. Both regions are considered to be nursery areas, where pregnant females migrate to give birth in late spring to early summer and neonate sandbar sharks appear between July and October (Bradaï *et al.*, 2005; Enajjar *et al*., 2015), coinciding with the emergence of neonate sandbar sharks in the Northern Adriatic Sea.

The Northern Adriatic Sea as a possible nursery area

Sporadic reports of predominantly neonate and juvenile sharks in the shallow North Adriatic basin, led several authors to suggest that it is an important nursery area for this species (Costantini & Affronte, 2003; Lipej *et al.*, 2008). Heupel *et al*. (2007) emphasised that the mere occurrence of juvenile sharks in an area is insufficient evidence to proclaim a nursery area, as such a liberal definition would lead to potentially identifying all coastal waters as nurseries and thus undermine the importance of protecting essential fish habitats. To avoid such a dilution of the term nursery, they defined shark nurseries based on three criteria: (1) Neonate and juvenile sharks are more commonly encountered in the area than in other areas, (2) immature sharks have a tendency to remain in or return to the area for extended periods, and (3) the area is repeatedly used by immature sharks over a period of years. Our accumulated dataset on sandbar shark records in the Adriatic Sea revealed that the presence of juvenile specimens in this region has been known since at least 1884. Data collected by citizen science initiatives that have been established in recent years, like the MECO Project and sharkPulse (Ferretti *et al.*, 2020), indicate an annual occurrence of neonate and juvenile sandbar sharks in the Northern Adriatic Sea. Additionally, immature individuals of different ages (46.5–160 cm) are present in this area, and therefore, all three criteria established for defining shark nurseries are fulfilled by the Northern Adriatic Sea. The absence of adult males is another indicator that this area represents a nursery ground (Castro, 1987; 1993). It must be noted that records of adult sandbar sharks in the Adriatic Sea are generally rare, indicating that they only remain there for a short time (e.g., for parturition) and leave the area quickly after, while immature individuals stay for an extended period. The recurrence of neonate specimens is confined to the Northern Adriatic Sea, while older juveniles are also found further south. This leads us to the conclusion that parturition most likely takes place in the northern basin, as suggested in previous studies (Costantini & Affronte, 2003; Lipej *et al*., 2008; Dragičević *et al.*, 2010).

Our data indicate an unusually high concentration of sandbar sharks in the Venetian region around the delta of the Po river. The mouths of rivers are productive ecosystems that provide abundant food sources, which can facilitate rapid early growth in neonates (Castro, 1987) and, therefore, act as important nursery areas for a number of requiem sharks, including the sandbar shark (Castro, 1993; Grubbs *et al.*, 2007; Ulrich *et al.*, 2007; Bangley *et al.*, 2018). The nutrient-rich freshwater outflow of the Po river is the major contributor to the high production rates in the Northern Adriatic Sea (Degobbis *et al.*, 2000), which is especially pronounced in its western part close to the delta (Kraus & Supic 2011; Giani *et al.*, 2012) and coincides with the spatial distribution of neonates and juveniles between July and September. Both neonates and large juveniles were reported in this area not just historically, but also very recently. Consequently, we consider this region around the Po delta to represent a very promising study area for conducting systematic surveys to fully resolve the abundance, demographic composition, and migration of sandbar sharks in the Northern Adriatic Sea and to prove the existence of a nursery area in this region.

Impact, strengths, and weaknesses of citizen science

Although the citizen science data were collected only opportunistically, they constitute the majority of all sightings since 1879 and suggest that this species is more abundant in this area than previously thought. Citizen science

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programs are growing in number around the world and provide valuable data on species occurrences, changes in distribution, phenology, invasive species, and threatened species and can thus make tangible conservation contributions (Giovos *et al.*, 2016; 2019a, b; 2020; Chin & Pecl, 2018; Taklis *et al.*, 2020). The strength of citizen science in detecting even very elusive species was also demonstrated in previous studies on the rare river sharks *Glyphis* spp. in Papua New Guinea (White *et al*., 2015) and, in the case of the smalltooth sawfish *Pristis pectinata* in the southern United States, even led to the detection of critical habitats for this species, which are now protected (Norton *et al.*, 2012). However, this approach also comes with drawbacks: Although in most cases, images from citizen scientists allowed the approximate size to be estimated and, therefore, an ontogenetic stage to be allocated, exact measurements could not be conducted. This was also an issue in previous studies incorporating citizen science data (e.g., White *et al*., 2015; Panayiotou *et al.*, 2020) and could be overcome by training citizen scientists (e.g., teaching them how to take pictures properly and with a scale for better size estimates) before systematically letting them collect data in the field. Nonetheless, this study shows that the strength of citizen science does not simply lie in its ability to engage the public in research and conservation but also in that it can be an invaluable source of data collection and monitoring species distribution. Nevertheless, systematic scientific surveys should accompany these citizen science initiatives in the future to augment our understanding of the abundance and spatial and seasonal distributions of this species in the Adriatic Sea and to help confirm a possible nursery area in the northern basin. Identifying these critical habitats is crucial to improve the management of fisheries in this area and ensure the survival of the sandbar shark *C. plumbeus* in the Mediterranean Sea.

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