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Did the smalleye hammerhead ever inhabit the Mediterranean Sea? A reappraisal of the only Italian record of *Sphyrna tudes* (Valenciennes, 1822)

Alberto Collareta[1,2] * and Simone Farina[2]

[1] *Department of Earth Sciences, University of Pisa, Pisa, Italy*
[2] *Natural History Museum, University of Pisa, Calci, Italy*

Abstract: Three species of *Sphyrna* (*S. lewini*, *S. mokarran* and *S. zygaena*) are known to inhabit the present-day Mediterranean Sea, whereas uncertainties exist about the presence of *S. tudes* in the same basin. Indeed, the presence of this typically western Atlantic shark in the Mediterranean Sea is supported by as few as two historical specimens that were captured at Nice (southeastern France) and Leghorn (northern Tyrrhenian coast of central Italy). Here, we provide a redescription and an updated taxonomic identification of the Leghorn specimen of smalleye hammerhead, which is currently kept in the zoological collection of the Natural History Museum of the University of Pisa and is believed by some authors to represent a misidentified representative of *S. lewini*. Based on first-hand observations, we confirm the taxonomic identification of this specimen as belonging to *S. tudes*. Considering the ontogenetically young nature of both the Nice and the Leghorn specimens of *S. tudes*, parturition in the Mediterranean Sea is hypothesised, which in turn may evoke the occurrence of a population of smalleye hammerheads inhabiting this basin at least as recently as the early 19th century.
***Keywords*:** shark; biodiversity loss; biogeography; Elasmobranchii; Sphyrnidae; Carcharhiniformes; historical collections

Sažetak: DA LI JE MALOOKI MLAT IKADA NASTANJIVAO SREDOZEMNO MORE? PONOVNO VREDNOVANJE JEDINOG TALIJANSKOG NALAZA VRSTE *SPHYRNA TUDES* (VALENCIENNES, 1822.). Tri vrste roda *Sphyrna* (*S. lewini*, *S. mokarran* i *S. zygaena*) nastanjuju današnje Sredozemno more, no postoje nejasnoće oko prisutnosti vrste *S. tudes* u istom području. Prisutnost ovog tipično zapadno-atlantskog morskog psa u Sredozemnom moru podupiru samo dva povijesna primjerka uhvaćena kod Nice (jugoistočna Francuska) i Leghorna (sjeverna tirenska obala središnje Italije). U ovom radu iznosi se ponovni opis te ažurirana taksonomska identifikacija primjerka malookog mlata iz Leghorna, koji se trenutno čuva u zoološkoj zbirci Prirodoslovnog muzeja Sveučilišta u Pisi, a za kojeg neki autori vjeruju da predstavlja pogrešno identificiranog predstavnika vrste *S. lewini*. Na temelju izravnih promatranja, autori potvrđuju taksonomsku identifikaciju analiziranog primjerka kao pripadnika vrste *S. tudes*. S obzirom da su primjerci vrste *S. tudes* iz Nice i Leghorna mlade jedinke, pretpostavlja se da su okoćeni na području Sredozemog mora što može sugerirati prisutstvo populacije ove vrste na tom području barem do početka devetnaestog stoljeća.
Ključne riječi: morski pas; gubitak biološke raznolikosti; biogeografija; Elasmobranchii; Sphyrnidae; Carcharhiniformes; povijesne zbirke

INTRODUCTION

Sharks included in the carcharhiniform family Sphyrnidae consist of wide-ranging, tropical to temperate sharks that occur over and around continental and insular shelves, foraging mainly on fishes, cephalopods and crustaceans, but also feeding on other types of prey (Compagno, 1984). Sphyrnids are characterised by mallet-shaped lateral expansions of the head; hence their vernacular name, "hammerhead sharks" (or simply "hammerheads") (e.g., Compagno *et al.*, 2005; Ebert *et al.*, 2021). During their evolutionary history, hammerheads have developed highly specialised ecological traits and complex behaviours that have increased their vulnerability to human exploitation, which in turn makes conservation efforts particularly complicated (Gallagher *et al.*, 2014). As a consequence of this, sphyrnids are currently regarded as comprising one of the most imperiled groups of large sharks worldwide (Gallagher and Klimley, 2018).

Two genera of Sphyrnidae occur in the present-day global ocean, i.e., the monotypic *Eusphyra* and the more speciose *Sphyrna*. The latter includes the smalleye hammerhead *Sphyrna tudes*, a scarcely known, small-sized (maximum total body length around 122–150 cm) inshore shark of the continental shelf (Compagno, 1984; Ebert *et al.*, 2021). As regards the Mediterranean Sea, three species of *Sphyrna* (namely, *S. lewini*, *S. mokarran* and *S. zygaena*) are rather commonly encountered in this broad marine region (e.g., Serena, 2005; Serena *et al.*, 2014), whereas whether or not *S. tudes* is also part of the Mediterranean elasmobranch fauna is at present uncertain (Compagno *et al.*, 2005; Mancusi *et al.*, 2020; Serena *et al.*, 2020; Ebert *et al.*, 2021). In fact, the presence of the smalleye hammerhead in the Mediterranean Basin is supported by as few as two historical specimens

**Corresponding author:* alberto.collareta@unipi.it
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that were captured at Nice (southeastern France) and Leghorn (Tyrrhenian coast of central Italy), respectively. Consisting of a very young, 346 mm long individual, the former was described by Valenciennes (1822) as one of the syntypes of the then new species *Zygaena tudes* (= *S. tudes*), of which it now comprises the lectotype (Gilbert, 1967). The Leghorn specimen consists of a slightly larger individual that was recognized as belonging to *Sphyrna bigelowi* (a junior synonym of *S. tudes*; Gilbert, 1967) by Tortonese (1949-1950) and then explicitly transferred to *S. tudes* by the same author (Tortonese, 1950).

Considering that *S. tudes* is currently known as a quintessentially western Atlantic species whose verified range stretches along the eastern coasts of South America from Venezuela to Uruguay (Compagno *et al.*, 2005; Ebert *et al.*, 2021), the aforementioned historical records from the Mediterranean Basin have lately been regarded with scepticism. Doubts have especially grown about the Nice specimen, concerning both its taxonomic identification (Cadenat and Blache, 1981; but see also the more updated revision by McEachran and Séret, 1987) and its geographic provenance (Castro, 1989; but see also the different assessment by Kovačić *et al.*, 2021). As a consequence of this, some recent works regard *S. tudes* as an extra-Mediterranean species (e.g., Pollom *et al.*, 2020), whereas others state that old records from the Mediterranean Sea require confirmation (e.g., Compagno *et al.*, 2005; Serena *et al.*, 2020).

Here, we aim at contributing to the ongoing debate on the presence of the smalleye hammerhead in the Mediterranean Sea by providing a redescription and updated taxonomic identification of the largely overlooked Leghorn specimen, which some recent authors believe to represent a misidentified individual of scalloped hammerhead, *S. lewini* (e.g., Pollom *et al.*, 2020; *contra* Serena *et al.*, 2020).

MATERIAL AND METHODS

We retrieved information on the specimens of *Sphyrna* preserved in the Natural History Museum of the University of Pisa (hereinafter: NHMUP) by comparing their historical labels with both historical (Borri, 1934) and recent (Carnevale *et al.*, 2007) catalogues of the extant chondrichthyan specimens kept at the NHMUP. Furthermore, three studies on the systematics of Sphyrnidae by Tortonese (1949-1950, 1950, 1951), all of which dealt with material stored at the NHMUP, were the basis for reconstructing how the hammerhead specimens mentioned by Borri (1934) have subsequently been redetermined through time.

The recent study by Pollom *et al.* (2020), according to which the Leghorn specimen of *Sphyrna tudes* rather represents *Sphyrna lewini*, acted as the catalyst for measuring and redescribing this purported smalleye hammerhead specimen (preserved at the NHMUP with inventory number P73), as well as for reappraising its taxonomic affinities. Our updated taxonomic identification of P73 (Fig. 1) was based on the diagnostic keys and features reported by Compagno (1984) and Compagno *et al.* (2005) as well as on comparisons with the Mediterranean species *Sphyrna zygaena*, *S. mokarran* and *S. lewini*. Measurements were taken by using a measuring tape and a standard analog caliper after temporarily removing the specimen from the liquid in which it is preserved (ethanol 70%).

Fig. 1. The liquid-preserved specimen of *Sphyrna tudes* in the zoological collection of the Natural History Museum of the University of Pisa (P73).

RESULTS

Specimen history

Specimen P73 has a long and troubled taxonomic and curatorial history. In his catalogue of the extant cartilaginous fish specimens kept at the NHMUP, Borri (1934) reported the presence of five sphyrnid specimens:

- *Sphyrna zygaena* (L.), inventory number 1583, skin, male, adult, total length: 1.53 m, Leghorn;
- *S. zygaena* (L.), inventory number 1518, skin, male, juvenile, total length: 0.58 m, Palermo;
- *S. zygaena* (L.), inventory number 1384, formalin-

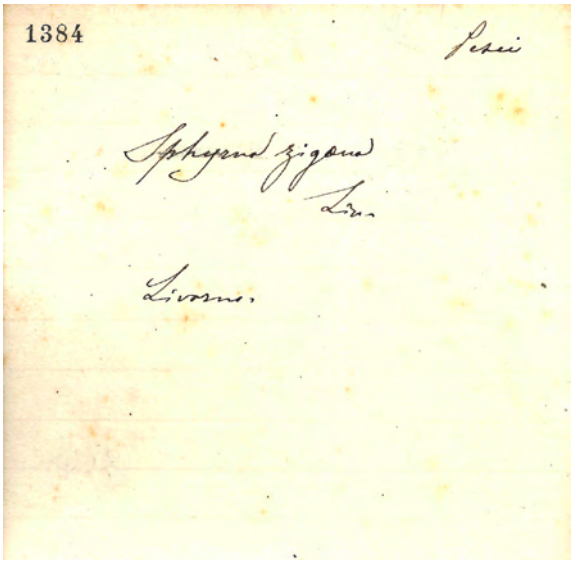

Fig. 2. Historical inventory card of the liquid-preserved Leghorn specimen mentioned by Borri (1934) and assigned therein to *Sphyrna zygaena*; that specimen is the same as P73, which is identified herein as belonging to *Sphyrna tudes* (as per Tortonese, 1950, 1951, Carnevale *et al.*, 2007 and *Serena et al.* 2020).

preserved, female, juvenile, total length: 0.50 m, Leghorn (see the corresponding historical inventory card in Fig. 2);
- *Sphyrna tudes* (Cuv.) [*sic*], inventory number 406, formalin-preserved, male, juvenile, total length: 0.48 m, Lagos;
- *Sphyrna tiburo* (L.), inventory number 1671, formalin-preserved, female, juvenile, total length: 0.39 m, Bahia.

It is worth noting that at the time of Borri, the name *S. tudes* was commonly applied to the great hammerhead, *Sphyrna mokarran* (Compagno, 1984).

Tortonese (1949-1950) confirmed the presence of the aforementioned specimens of *Sphyrna* in the NHMUP collection but redetermined the specimen from Lagos (inventory number 406) and the liquid-preserved specimen from Leghorn (inventory number 1384) as belonging to *Sphyrna diplana* and *Sphyrna bigelowi*, respectively. In addition, he provided drawings of the latter in his figures 9 and 10. Unfortunately, Tortonese (1949-1950) made two factual mistakes (i) by reporting that both the specimen from Lagos and the liquid-preserved specimen from Leghorn had been assigned by Borri (1934) to *S. tudes*, and (ii) by identifying the latter as a male (*contra* Borri, 1934; see also our sex determination below). After a reappraisal of Valenciennes's (1822) smalleye hammerhead specimens in Paris, the same author recognised *S. bigelowi* as a junior synonym of *S. tudes* (Tortonese, 1950). In doing so, he reassigned the liquid-preserved specimen from Leghorn (inventory number 1384) to *S. tudes* (Tortonese, 1950), which he regarded as occurring both in the Atlantic Ocean and, rarely, in the Mediterranean Sea (Tortonese, 1951).

The most updated catalogue of the extant chondrichthyan specimens kept at the NHMUP (Carnevale *et al.*, 2007) features only four specimens of *Sphyrna*, as the specimen from Lagos appears to be lost. Carnevale *et al.* (2007) recorded the liquid-preserved specimen from Leghorn with a new inventory number (Pe 0073) and regarded it as belonging to *S. tudes*. (Note that the inventory number Pe 0073 has subsequently been changed to P73 for aligning its format to that of other entries of the NHMUP ichthyological catalogue.) Photographs of the head of P73 in dorsal and ventral views were also published by Carnevale *et al.* (2007).

Recently, Serena *et al.* (2020) reported on the presence of a specimen of *S. tudes* in the zoological collection of the NHMUP. As also done by Serena (2005), Serena et al. (2020) mentioned that specimen (which is the same as P73; Serena 2023, pers. comm.) by using the catalogue number 2347 and rightly identified it with Tortonese's (1951) Leghorn specimen of *S. tudes*. Actually, the number 2347 has never been associated with the sphyrnid specimen P73, nor with any other hammerhead, being in turn assigned to a specimen of *Labrax lupus* (= *Dicentrarchus labrax*, a seabass) from the Arno River according to a historical inventory card. That said, this number is nonetheless present on a paper tag that is stuck on the jar containing P73. This is most likely due to a jar exchange that occurred during the second half of the 20th century and led P73 to occupy the jar that once hosted the aforementioned seabass specimen.

Serena *et al.* (2020) also hypothesised that P73 had been bought by Tortonese at the Leghorn fish market, thus considering its alleged Mediterranean origin as somewhat doubtful. However, P73 was present in the NHMUP as early as fifteen years before being described by Tortonese (1949-1950) (Borri, 1934); thus, in our opinion, there is no positive indication whatever that Tortonese was implied in the acquisition of P73. What can confidently be said about the locality data of this remarkable specimen is that P73 was regarded as originating from Leghorn by the earliest author who mentioned it (i.e., Borri, 1934), and that such a purported Mediterranean origin was subsequently embraced by Tortonese (1949-1950, 1950, 1951).

Specimen description and comparisons

A reappraisal of specimen P73 (Figs. 3, 4) allowed us to verify that it matches Tortonese's (1949-1950) description and illustrations of the Leghorn specimen, which he later assigned to *Sphyrna tudes* (Tortonese, 1950, 1951). Crucially, its dorsal fin features the same kind of damage affecting the ceratotrichia as figured by Tortonese (1949-1950) (Fig. 3) and the specimen dimensions correspond to those reported by the same author, with the significant exception of the total body length. Differences in the latter measurement could reflect the stiffness and persistent torsion-deformation of the specimen, which make accurate total body length measurements difficult. Our measurements of specimen P73 are reported in Table 1, along with those recorded by Borri (1934), Tortonese (1949-1950) and Carnevale *et al.* (2007).

Following the template provided by Compagno (1984) and Compagno *et al.* (2005), specimen P73

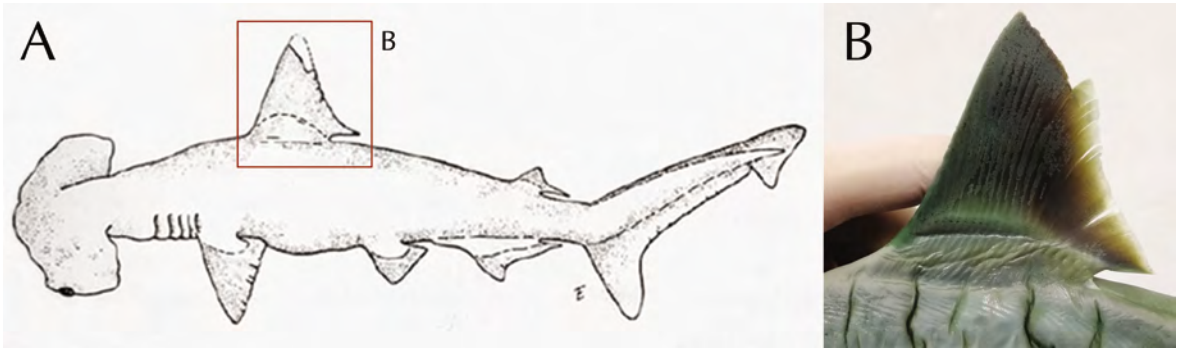

Fig. 3. Tortonese's (1949-1950) original drawing of the liquid-preserved Leghorn specimen which he assigned to *Sphyrna bigelowi* (**A**). Photograph of the first dorsal fin of the liquid-preserved *Sphyrna tudes* specimen P73 (**B**) (note the same kind of damage affecting the ceratotrichia as figured in panel A).

Fig. 4. Ventral view of the head of the liquid-preserved *Sphyrna tudes* specimen P73. The scale bar equals 5 cm.

can be described in the following terms. Expanded prebranchial head hammer-shaped and very wide but longitudinally fairly long, its width 29.9% of total length (145 mm / 485 mm); distance from tip of snout to rear insertions of posterior margins of expanded blades 45.5% of head width (66 mm / 145 mm); anterior margin of head broadly arched, with prominent medial and lateral indentations; posterior margins of head wide, transverse, and broader than mouth width; well-developed prenarial grooves present anteromedial to nostrils; preoral snout 29.6% of head width; rear ends of eyes slightly anterior to upper symphysis of mouth; mouth rather narrowly arched; anterior teeth with moderately long, slender, smooth cusps, posterior teeth cuspidate and not keeled and molariform. First dorsal slightly falcate, its origin slightly behind pectoral insertions, its free rear tip about over pelvic origins; second dorsal fin fairly high, less than anal height, with a moderately concave posterior margin; its inner margin moderately long, but less than twice fin height (24 mm *versus* 17 mm), and ending well in front of upper caudal origin; pelvic fins not falcate, with essentially straight posterior margins; anal fin larger than second dorsal fin and rather long, its base about 11% of total body length (54 mm / 485 mm), its origin well ahead of second dorsal origin, its posterior margin moderately concave; upper precaudal pit present.

Specimen P73 clearly differs from *Sphyrna zygaena*, in which the expanded prebranchial head is longitudinally short; the anterior margin of head is very broadly arched and features no medial indentation; the posterior margins of head are angled posterolaterally; the rear ends of eyes are placed slightly behind the upper symphysis of mouth; the first dorsal originates over the pectoral insertions, its free rear tip being well anterior to the pelvic origins; the inner margin of the second dorsal fin is long, about twice the fin height; and the anal fin is slightly larger than the second dorsal and rather long, its base being 4.3 to 5.7% of total body length, its origin slightly ahead of second dorsal origin, its posterior margin deeply notched (Compagno, 1984).

Specimen P73 further differs from *Sphyrna mokarran*, in which the expanded prebranchial head is longitudinally short (distinctly shorter than 30% head width); the posterior margins of head are angled posterolaterally (in juveniles) and about as broad as mouth width; the prenarial grooves are absent or hardly developed; the mouth is rather broadly arched; the anterior teeth have moderately, long, stout cusps with serrated edges; the first dorsal is strongly falcate, its free rear tip being well anterior to pelvic origins; the second dorsal is roughly as high as the anal, with a strongly concave posterior margin, its inner margin being short, about equal to fin height; the pelvic fins are strongly falcate, with strongly

Table 1. Measurements of the *Sphyrna tudes* specimen P73 according to the present work and previous studies.

	BORRI (1934)	**TORTONESE (1949-1950)**	**CARNEVALE *et al.* (2007)**	**this work**
Total body length	50 cm	55 cm	50 cm	48.5 cm
Width of head	/	14.5 cm	/	14.5 cm
Height of first dorsal fin (incomplete)	/	7 cm	/	7.0 cm (estimated)
Length of pectoral fin	/	6.1 cm	/	6.1 cm

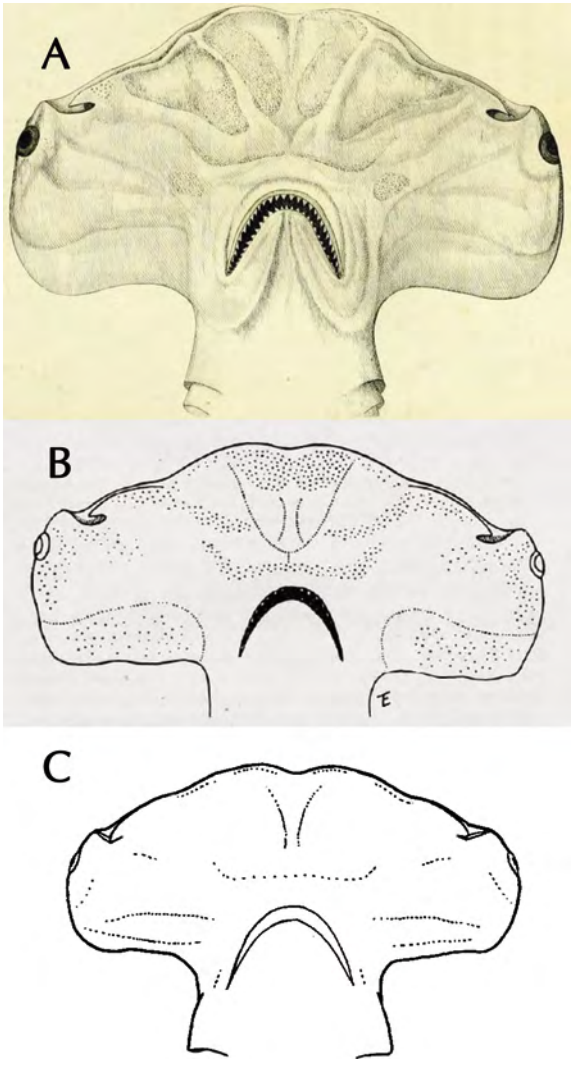

Fig. 5. Comparison between the ventral aspect of the head of the liquid-preserved *Sphyrna tudes* specimen P73 and other representatives of the same species (not to scale). Valenciennes's (1822) original drawing of the Nice specimen (i.e., the lectotype of *S. tudes* according to Gilbert, 1967) (**A**). Tortonese's (1949-1950) original drawing of the liquid-preserved Leghorn specimen which he assigned to *Sphyrna bigelowi*; that specimen is the same as P73, which is identified herein as belonging to *S. tudes* (as per Tortonese, 1950, 1951, Carnevale *et al.*, 2007 and Serena *et al.*, 2020) (**B**). Schematic drawing of a generalised specimen of *S. tudes*, redrawn and modified after Compagno (1984) (**C**).

concave posterior margins; and the base of anal fin is 5.6 to 7.3% of total body length, its posterior margin being deeply notched (Compagno, 1984).

Specimen P73 also significantly differs from *Sphyrna lewini* in which the expanded prebranchial head is longitudinally short; the anterior margin of head is very broadly arched; the posterior margins of the head are angled posterolaterally; the free rear tip of first dorsal is well anterior to pelvic origin; the inner margin of second dorsal is long, about twice the fin height, and ending almost opposite the upper caudal origin; and the base of anal fin is 4.3 to 6.4% of total body length (Compagno, 1984).

In turn, P73 matches well the descriptions and illustrations of *S. tudes* provided by Compagno (1984) and Compagno *et al.* (2005) (see also Fig. 5). The only remarkable difference concerns the length of the anal fin base, which accounts for 11% of the total body length of P73 (*versus* 7.5 to 9.9% in *S. tudes* according to Compagno, 1984). That said, the length range reported for *S. tudes* by Compagno (1984) is still the best match for P73, all the other hammerhead species (including the recently described western Atlantic species *Sphyrna gilberti*; Quattro *et al.*, 2013) being characterized by anal fins with slightly to much shorter bases.

The dental formula shows wide intraspecific variation in hammerheads (see e.g. Quattro *et al.*, 2013 for the recently identified western Atlantic species *S. gilberti*). As regards the dental formula of P73, Tortonese (1949-1950) reported 13-1-13 for the upper teeth and 11-2-11 for the lower teeth. We were able to confirm Tortonese's (1949-1950) observations except for the lower symphyseal region, where we recorded a single symphyseal teeth (note, however, that the jaws were not removed from the specimen and small posterior teeth could have gone unnoticed, thus resulting in lower counts than the actual number of teeth present). Gilbert (1967) mentioned a single lower symphyseal to be present in two specimens of *S. tudes* (including the Nice specimen).

Specimen P73 displays no claspers on the pelvic fins and is therefore identified herein as a female. That P73 is an early juvenile individual is indicated by the observation of remnants of the umbilical scar at the approximate level of the anterior margin of the pectoral fins.

DISCUSSION AND CONCLUSIONS

Our (re)description of P73 allows for confirming its taxonomic identification as *Sphyrna tudes* while discharging any alternative assignment to other hammerhead species, including *Sphyrna lewini*. Furthermore, there is no reason to doubt that P73 is the same as Borri's (1934) and Tortonese's (1949-1950, 1950, 1951) Leghorn specimen, as reported in the associated historical label and confirmed by our observations on its sex, morphology, and preservation state. Crucially, based on the absence of claspers on the pelvic fins, P73 cannot represent Borri's (1934) male specimen of *Sphyrna tudes* from Lagos, which Tortonese (1949-1950) reidentified as belonging to *Sphyrna diplana* (= *S. lewini*). All things considered, Pollom *et al.*'s (2020) affirmation that Tortonese's (1951) Leghorn specimen of *S. tudes* represents a misidentified individual of scalloped hammerhead has no support at all and must be rejected.

Considering also that McEachran and Séret (1987) have provided convincing evidence that the Nice specimen does really belong to *S. tudes* (Fig. 5), two specimens of this species appear to have been collected in historical times from the western Mediterranean Sea, and more specifically from its northernmost regions (i.e., the Ligurian Sea and surrounding areas). Given the

very ontogenetically young nature of both specimens, which in light of their total lengths should be regarded as early juveniles or even newborns (as reported by Compagno, 1984, size at birth is around 30 cm, but smalleye hammerheads have been described as newborns up to more than 47 cm in total body length; see Castro, 1989: fig. 8b), it seems unlikely that they represent vagrant individuals proceeding from the confirmed range of *S. tudes*, which extends along the Atlantic coast of South America from Venezuela to Uruguay (Compagno *et al.*, 2005; Ebert *et al.*, 2021). It seems more plausible that these specimens were born in the Mediterranean Sea, which in turn may evoke the occurrence of a population of smalleye hammerheads inhabiting this basin at least as recently as the early 19th century. The identification of *S. tudes* in Mediterranean waters could have been hindered by confusion with morphologically similar hammerhead species.

Mediterranean hammerheads have declined by more than 99.99% since the late 19th century (Ferretti *et al.*, 2008) as a likely consequence of overfishing (Boudouresque *et al.*, 2017). As for *S. tudes* in particular, extirpation may have recently occurred in the Brazilian state of Ceará, and similar phenomena could eventually lead to the extinction of this critically endangered species unless more stringent conservation actions are taken (Pollom *et al.*, 2020). The reappraisal of historical sphyrnid specimens from natural history collections of the peri-Mediterranean region may lead to rediscovering some hitherto overlooked records of smalleye sharks, which in turn would help to clarify the past and present status of *S. tudes* in the Mediterranean Basin.

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