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

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Abstract: Three species of Sphyra (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 Tyrrenian 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, partition 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

INTRODUCTION

Sharks included in the carcharhiniform family Sphyridae 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). Sphyrids 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 particular compounded (Gallagher et al., 2014). As a consequence of this, sphyrids are currently regarded as comprising one of the most imperiled groups of large sharks worldwide (Gallagher and Klimley, 2018).

Two genera of Sphyridae occur in the present-day global ocean, i.e., the monotypic Eusphyra and the more speciose Sphyra. The latter includes the smalleye hammerhead Sphyra 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 Sphyra (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.
that were captured at Nice (southeastern France) and Leghorn (Tyrrenian 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 Sphyrrna 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 Sphyrmidae 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 Sphyrrna tudes rather represents Sphyrrna 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 Sphyrrna 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%).

**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 sphyrid specimens:

- Sphyrrna 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. 1. The liquid-preserved specimen of Sphyrrna tudes in the zoological collection of the Natural History Museum of the University of Pisa (P73).](image-url)
Did the smalleye hammerhead ever inhabit the Mediterranean Sea?

preserved, female, juvenile, total length: 0.50 m, Leghorn (see the corresponding historical inventory card in Fig. 2);
- *Sphyra tudes* (Cuv.) [sic], inventory number 406, formalin-preserved, male, juvenile, total length: 0.48 m, Lagos;
- *Sphyra 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, *Sphyra mokarran* (Compagno, 1984).

Tortonese (1949-1950) confirmed the presence of the aforementioned specimens of *Sphyra* 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 diaplaena* 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 *S. tudes* specimen from Leghorn (inventory number 1384) as belonging to *Sphyrna zygaena* (as per Tortonese, 1950, 1951, Carnevale *et al.*, 2007 and Serena *et al.* 2020).

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 *Sphyra 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...
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 broadly arched; anterior teeth with moderately long, slender, smooth cusps, posterior teeth cupidate and not keeled and molariform. First dorsal slightly falcate, its origin slightly anterior to upper symphysis of mouth; mouth rather narrowly arched; anterior teeth with moderately long, slender, smooth cusps, posterior teeth cupidate and not keeled and molariform. First dorsal slightly falcate, its origin slightly anterior to upper symphysis of mouth; mouth rather narrowly arched; anterior teeth with moderately long, slender, smooth cusps, posterior teeth cupidate and not keeled and molariform. First dorsal slightly falcate, its origin slightly anterior to upper symphysis of mouth; mouth rather broadly arched; 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 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; the rear ends of eyes are placed slightly behind the upper symphysis of mouth; 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. |
|-------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| **Total body length** | **BORRI (1934)** | **TORTONESE (1949-1950)** | **CARNEVALE et al. (2007)** | **this work** |
| | 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 |
Did the smalleye hammerhead ever inhabit the Mediterranean Sea?

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 symphysial region, where we recorded a single symphysial tooth (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 symphysial 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 sphyrid 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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Did the smalleye hammerhead ever inhabit the Mediterranean Sea?


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