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Sponges as feeding resource for the white seabream *Diplodus sargus* (Linnaeus, 1758) from the Mediterranean Sea

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Abstract
Sponges play a significant role in many marine environments. In tropical regions, the relationship between Porifera and spongivorous organisms, including fish, has been extensively studied. In the Mediterranean Sea, the dominant predators of sponges are sea stars, sea urchins and nudibranches, while knowledge of fish feeding on sponges is limited to sporadic events. This study aimed to investigate sponges as part of the diet of the white seabream *Diplodus sargus*. The results revealed that sponges were abundantly present in seabream stomachs, reaching up to 79.7% of the total biomass ingested by a single individual. Five different species were found in fish stomachs. The presence and organization of the spicular component seemed to affect the biting strategy of fish. Sponges with a prevalent organic component, such as *Chondrosia reniformis* Nardo, 1847, and *Chondrilla nucula* Schmidt, 1862, were ingested as fragments, while specimens of the *Tethya citrina* Sarà & Melone, 1965, characterized by a globular body, were engulfed entirely. Data from this study represent the first effort to investigate the trophic relationship between fish and Porifera in the Mediterranean Sea.

Keywords: *Porifera*, *Sparidae*, *spongivory*

Introduction

Sponges constitute a significant component of benthic communities in the Mediterranean Sea, both in terms of biomass and species diversity, as they enhance habitat three-dimensionality and provide shelter for various organisms (Bell 2008; Enrichetti et al. 2020). In tropical areas, sponges represent an important trophic source for a wide range of marine organisms, such as sea turtles, fishes, nudibranch mollusks, asteroids, echinoids, and various small crustaceans (Wulff 2006; Bell 2008).

Sponges have evolved different defensive mechanisms in response to predation. Some species produce unpleasant secondary metabolites to deter predators (Pawlik et al. 1995; Becerro et al. 2003; Sokolover & Ilan 2007). Other species tolerate some level of predation through high rates of reproduction, growth, or wound healing (Walters & Pawlik 2005; Pawlik et al. 2008). Based on these strategies, three categories of sponges have been identified (Pawlik 1997; Pawlik et al. 2008): (1) chemically defended sponges, avoided by generalist predators; (2) palatable sponges, undefended but fast-growing to overcome tissue loss due to predation; and (3) palatable sponges, rapidly consumed by predators and consequently inhabiting

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cryptic refuges (Dunlap & Pawlik 1996; Wulff 1997; Pawlik 1998).

Several tropical fishes, such as pufferfishes (*Arothron* spp.), butterflyfishes (*Chaetodon* spp.), and broom filefishes (*Amanses* spp.), are typical sponge eaters (Dawson et al. 1955; Hiatt & Strasburg 1960). Randall and Hartman (1968) analyzed the stomach contents of 212 species of Caribbean fishes from the genera *Holacanthus*, *Pomacanthus*, and *Cantherhines*, finding sponges in over 50% of the observed species. These authors hypothesized that the thick layer of mucus covering the stomach walls of these fishes allows them to avoid irritation from ingesting silica spicules. The same hypothesis was proposed for the presence of spicules in the digestive tracts of *Chaetodon auriga* Forsskål, 1775, *Ctenochaetus striatus* (Quoy & Gaimard, 1825), *Lutjanus bohar* (Forsskål, 1775), and *Rhinecanthus aculeatus* (Linnaeus, 1758) (Dawson et al. 1955).

In the Mediterranean Sea, the main spongivorous organisms are nudibranches (Becerro et al. 2003; Gemballa & Schermutzki 2004), sea urchins (Maldonado & Uriz 1998; Sokolover & Ilan 2007; Bo et al. 2012), sea stars (Sarà & Vacelet 1973; Garcia-Raso et al. 1992), and the loggerhead sea turtle *Caretta caretta* (Linnaeus, 1758) (Tomas et al. 2006; Casale et al. 2008; Baldi et al. 2023), while fish eating sponges have been sporadically described. According to the current literature, only the omnivorous species *Parablennius gattorugine* (Linnaeus, 1758), *Diplodus puntazzo* (Walbaum, 1792), and *Diplodus sargus* have been recorded as occasional sponge feeders (Sala & Ballesteros 1997; Stergiou & Karpouzi 2002; Sabatini et al. 2008).

Although the sponge-eating ability of the Mediterranean white seabream is known, no data are available on the exploited sponge species. This study aims to describe the Porifera found in the digestive tracts of *Diplodus sargus* from three localities in southern Italy, analyzing the feeding modalities.

Materials and methods

White seabream specimens were collected from three locations along the Apulia coast (Figure 1) in Autumn 2009. The selected sites were the Marine Protected Area of Torre Guaceto (TG) (south Adriatic Sea), the Marine Protected Area of Porto Cesareo (PC) (Ionian Sea) and the coast of the Brindisi area (BR) (Adriatic Sea). The seabed morphology along the coast is comparable in all three sampling areas, featuring a rocky

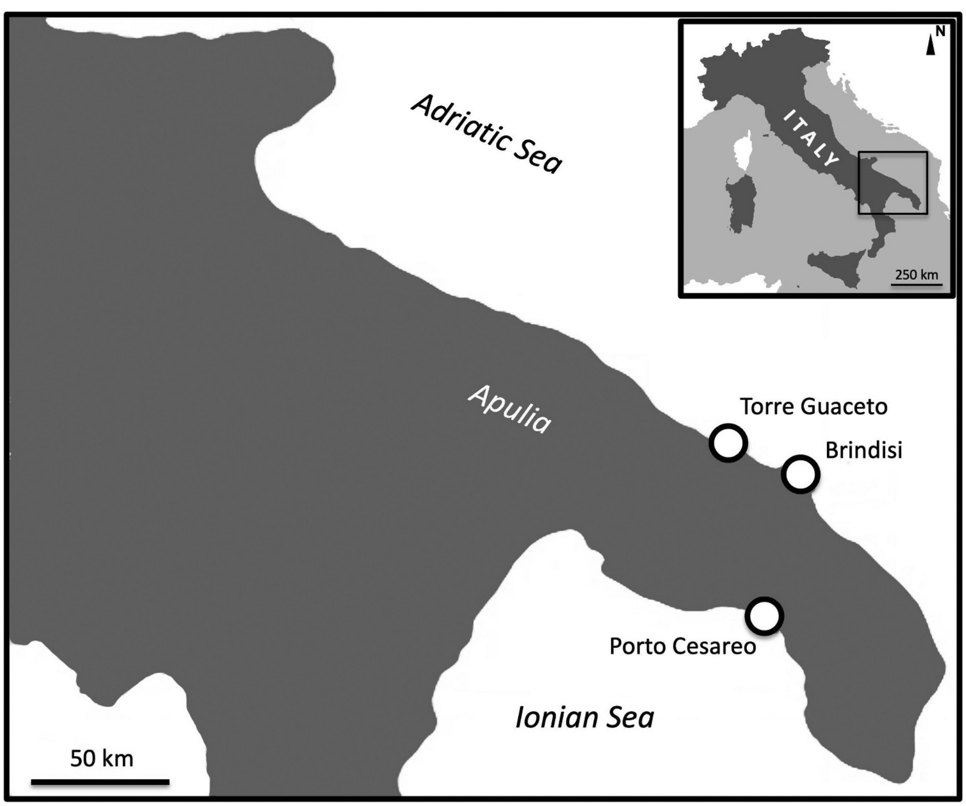

Figure 1. Map of the study area.

substrate from the surface to about 8–15 m depth, transitioning to a sandy bottom. The composition of sessile benthos is similar and characterized by the predominant presence of encrusting coralline algae, erect algae, sponges, and encrusting bryozoans (Felline et al. 2012).

Sampling was carried out using a speargun at 5 m depth in the TG area and at 15 m depth in both the PC and BR areas. Sacrifice of fish was performed following European guidelines (European Commission 2010). Immediately after capture, the specimens were placed in dry ice inside polystyrene containers and then transported to the laboratory where they were weighed and measured individually.

For each fish, the stomach and intestine were excised and emptied, and their contents preserved in 70% ethyl alcohol. The sponge samples were separated, under stereomicroscope, from the mass of digestive content and counted. The wet weight was assessed by analytical balance, and sponges were measured using ImageJ software (Rasband 1997). The spicule complement of each sponge specimen was analyzed according to Núñez-Pons et al. (2022) for species identification.

A Two-Way ANOVA for unbalanced design, followed by Tukey's test, was applied to test for differences in the size of sponge fragments, considering the species of sponge. The comparison between the weight of sponge fragments of different species was analyzed by Kruskal–Wallis test. Statistical analyses were conducted using R software.

Results

A total of 47 fish were collected: 15 from Torre Guaceto (TG), 15 from Porto Cesareo (PC), and 17 from the Brindisi area (BR). The morphometric characteristics of the specimens varied across the different localities (Table I). The average weight was 512.1 ± 175.8 g for samples from TG, 421.0 ± 207.5 g for samples from BR, and 256.9 ± 81.2 g for samples from PC. The length of the fish followed the same pattern, with average values of 28.6 ± 2.8 cm, 25.8 ± 4.3 cm, and 22.8 ± 2.3 cm for TG, BR, and PC, respectively.

In the complex eight fishes (17%) showed fragments of sponges in their digestive tracts. The percent of involved fishes varied from Torre Guaceto (20%) to Porto Cesareo (6.6%).

Five different species of demosponges were found. Three of these Heteroscleromorpha: *Tethya citrina* Sarà & Melone, 1965, *Geodia cydonium* (Linnaeus, 1767), and *Mycale* (*Aegogropila*) *tunicata* (Schmidt 1862). The other two Verongimorpha: *Chondrilla nucula* Schmidt, 1862, and *Chondrosia reniformis* Nardo, 1847 (Figure 2).

In each fish, the sponge fragments belonged to the same species, with the exception of one TG specimen that had both *T. citrina* and *C. nucula* in its intestine and stomach, respectively. *Tethya citrina* and *C. reniformis* were found in fish from more than one site; *Tethya citrina* occurred in specimens from TG and BR, while *C. reniformis* was present in fish from both BR and PC (Table I). Overall, *T. citrina* was the species most frequently found in eating sponge fish (3 out of 8), while *C. nucula* and *C. reniformis* were both recorded in 2 out of 8 fish, and only 1 fish ingested fragments of *G. cydonium*, as well as for *M.* (*A.*) *tunicata*.

Torre Guaceto was the site with the highest diversity of sponges found in fish stomachs, presenting 3 out of the 5 total species: *T. citrina*, *C. nucula*, and *G. cydonium*. *Geodia cydonium* and *M.* (*A.*) *tunicata* were found only in one fish each, from TG and BR, respectively (Table I).

At TG, sponges accounted for an average of 32% (±28.8) of the stomach contents (dry weight, DW), with a maximum of 79.7%. A similar average value (34.9 ± 14.8% DW) was obtained for BR, while in the only fish from PC that had sponges in the stomach, these accounted for 15.5% of the entire content.

The engulfed specimens of *T. citrina* were small entire sponges with an average size of 0.58 ± 0.06 cm. The other species were always recorded as fragments of different size ($p = 1.9e\text{-}06$), depending on the species.

Table I. Table of the characteristics of fish with sponges in their gastral contents and the data related to it.

Site	Sampling Depth (m)	Fish Lenght (cm)	Fish Weight (g)	Gastral content (g)	Sponge Weight (g)	Sponge species
Torre Guaceto	5	28.0	442.6	1.82	0.51	*Tethya citrina* *Chondrilla nucula*
	5	29.0	484.0	6.40	0.27	*Geodia cydonium*
	5	23.8	286.0	0.93	0.15	*Tethya citrina*
	5	28.0	475.0	5.23	4.17	*Chondrilla nucula*
Brindisi	15-20	22.4	268.9	0.25	0.13	*Tethya citrina*
	15-20	30.0	587.3	1.53	0.41	*Mycale (Aegogropila) tunicata*
	15-20	20.0	181.7	0.77	0.20	*Chondrosia reniformis*
Porto Cesareo	15-20	23.0	251.7	1.81	0.28	*Chondrosia reniformis*

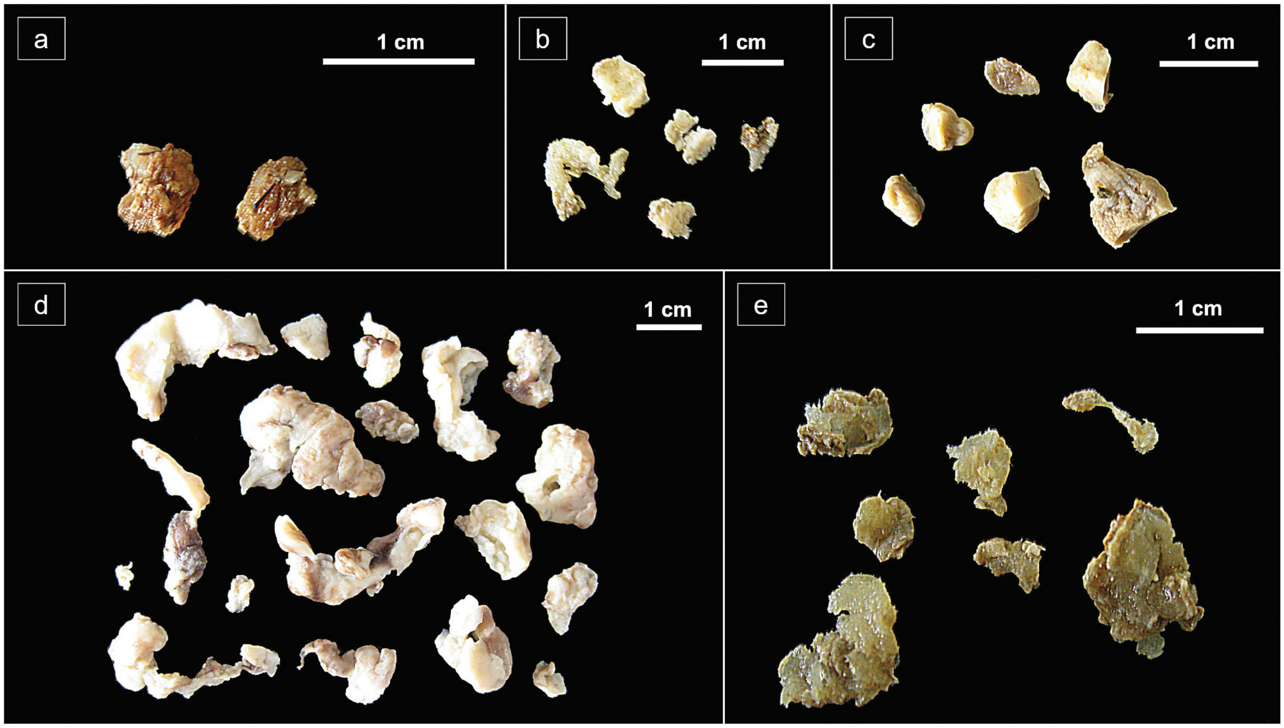

Figure 2. Samples of sponges collect from fish digestive tracts. a) specimens of *tethya citrina*; b) fragments of *Geodia cydonium*; c) fragments of *Chondrosia reniformis*; d) fragments of *Chondrilla nucula*; e) fragments of *Mycale* (*Aegogropila*) *tunicata*.

Specifically, the post-hoc test revealed that the size of *C. nucula* fragments (1.55 ± 0.17 cm) was significantly larger than those of all the other species that reached a maximal size of 0.82 ± 0.11 cm in *M.* (*A.*) *tunicata*.

When looking at the total abundance of each sponge species collected, *C. nucula* was found in considerably larger quantities than the others (Figure 3), reaching a weight of 4.17 g in a single specimen from TG. This was followed by *C. reniformis* and *M.* (*A.*) *tunicata*, with a total weight of 0.48 g and 0.41 g, respectively (Figure 3). The least abundant was *G. cydonium*, presenting a weight of 0.27 g (Figure 3).

Discussion

Species of the family Sparidae, including the white sea bream (*Diplodus sargus*), are of high economic value, widely exploited by the fishing industry and

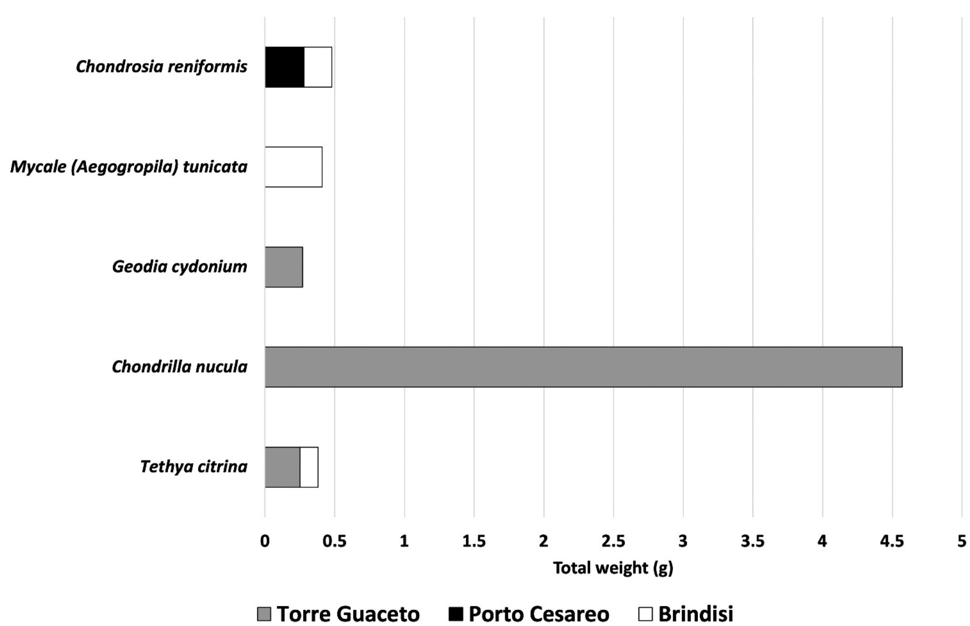

Figure 3. Graphic showing the abundance of sponge species found in different sites in terms of weight.

aquaculture (Pavlidis & Mylonas 2011). In the Mediterranean Sea, *D. sargus* predominantly inhabits shallow rocky infralittoral zones up to 50 m deep (Corbera et al. 1996). This species exhibits an opportunistic feeding behavior with a highly diversified diet encompassing various taxa such as Mollusca, Crustacea, Macrophyta, and Porifera, among others (Benchalel et al. 2010). Traditionally, the presence of sponges in their gut contents has been considered incidental (Joubert & Hanekom 1980; Coetzee 1986; Mann & Buxton 1992; Osman & Mahmoud 2009). However, a previous study indicated that sponges might play a more significant role in their diet, with a higher IRI % (index of relative importance) for sponges than for other common prey like bivalves, decapods, and gastropods (Felline et al. 2012).

Our results agree with these data, revealing that sponges can constitute a substantial portion of the diet, reaching up to 79.7% of the total ingested food by a single individual.

Three sponge species, *Chondrosia reniformis*, *Chondrilla nucula*, and *Tethya citrina*, were the most frequently ingested. *Tethya citrina* was found in multiple fish from TG and BR, although not from PC. This species is common in the Mediterranean, including the Ionian and southern Adriatic Seas (de Voogd et al. 2024), generally living in sheltered habitats (Sarà & Melone 1965). *Mycale* (*Aegogropila*) *tunicata* was found abundantly in one fish from BR, despite not being previously reported in this area (Longo et al. 2018). *Chondrosia reniformis* and *C. nucula* were common across all sites, with *Geodia cydonium* being frequent at TG (Corriero et al. 2004; Longo et al. 2018; Mercurio et al. 2021). None of these species is known to host autotrophic symbionts that could be the primary target of predation as in case of the nudibranch *Peltodoris atromaculata* Bergh, 1880, feeding on the ectosome of *Petrosia* (*Petrosia*) *ficiformis* (Poiret, 1789) rich of cyanobacteria (Sarà et al. 1998). The specificity of ingested sponges is yet to be investigated further, even for fish that are known to feed abundantly on these organisms. Indeed, the wide variety of Porifera species ingested by spongivorous fish probably depends on several factors, including the diverse biodiversity of the area and the association of sponges with other prey organisms.

The spicular composition of these sponges varies significantly. *Chondrosia reniformis* lacks a spicular skeleton but incorporates foreign siliceous bodies for reinforcement (Wilkie et al. 2004). *Chondrilla nucula* has a simple spicular structure with small star-like spicules (Schmidt 1862; Klautau et al. 1999). *Tethya citrina* features a complex spicular skeleton with long strongyloxeas and a thick collagenous ectosome reinforced by star-like spicules (Sarà & Melone 1965). Also, *G. cydonium* has a cortex composed by asters, and small oxeas and/or styles that are supported by radial bundles of choanosomal long oxeas and triaenes (Diehl-Seifert et al. 1985; Almeida et al. 2021). Unlike the other species, *M.* (*A.*) *tunicata* has a detachable ectosome with megasclere spicules organized into fibers reinforced with spongin (Hooper & Van Soest 2002; Gugel et al. 2006).

The spicule concentration and the resulting structure of the sponge skeletons did not influence their likelihood of being preyed upon by *D. sargus* but did affect the biting strategy of the fish. *Chondrilla nucula* and *C. reniformis* have very hard textures but no organised skeletal structure (Schmidt 1862), and *D. sargus* used its strong incisors (Vandewalle et al. 1995) to detach portions from larger sponges; indeed, these species were found in fragments inside stomachs. Also *G. cydonium* and *M.* (*A.*) *tunicata* were recorded as small fragments. On the contrary, the hard and radial skeletal structure of *T. citrina* prevented any cutting (Sarà & Melone 1965), and the spherical sponges were swallowed whole and probably digested slowly in the fish intestine. For this reason, *D. sargus* may exploit only small, young specimens that can be engulfed entirely.

In conclusion, this study provides evidence that several sponges species are a food source for *D. sargus*, but research is needed to understand the nutritional contributions of sponges and their role in the feeding ecology of white seabreams.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data are available from the authors upon reasonable request.

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