Unravelling the sponge diversity of the Tuscan Archipelago National Park (Tyrrhenian Sea, Italy)

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Abstract
Porifera are considered key components of benthic communities, being typical inhabitants of both shallow and deep waters, from the mesolittoral to the bathyal zone. Although sponges are one of the most common organisms in Western Mediterranean ecosystems, in many areas the knowledge on this taxon is still very limited. In the current study, we aim to analyse and compare the sponge communities characterising the hard bottoms of two islands, Montecristo and Giglio, belonging to the Tuscan Archipelago National Park (TANP, Italy), in relation to a bathymetric gradient. A total of 340 samples were collected, 13 orders and 48 species (46 Demospongiae and 2 Calcarea) identified, with Chondrosia reniformis representing the most recorded species, being found at all sites at almost all depths. Depth was the only significant factor in the observed pattern, while the sponge community is shared between the two Islands. In addition, our data were analysed together with data available in the literature on sponges of the Tuscan Archipelago, to assess the sampling effort. Among all the Islands of the Archipelago, Giglio and Montecristo showed the higher mean species diversity. Nonetheless, the sampling effort resulted not sufficient for each Island and future studies targeting Porifera are needed. Our work is the first summarising the sponge diversity of the entire Tuscan Archipelago, and one of the few focusing entirely on the sponge fauna. These results provide new important information on the area of the TANP, aimed to become a future Marine Protected Area, adding new records, and highlighting the high diversity of a poorly known area.

Keywords: Porifera, sampling effort, western Mediterranean, MPA

Introduction
Porifera are considered key components in many benthic ecosystems (Bell 2008), supporting rich biodiversity levels and, in many cases, representing a secondary substrate for a specialized associated fauna (Ilan et al. 1994; Koukouras et al. 1996; Bo et al. 2012). They are crucial ecosystem engineers in many habitats worldwide, but they can also act as bioeroders, especially in the coralligenous and coral reefs, behaving as intermediate disturbers and representing the main driving force in the turn-over of bioconstructions (Van Soest et al. 2012; Maldonado et al. 2017). Being suspension-feeders, sponges are a significant trophic link between the benthos and the water column, deeply impacting the benthic-pelagic coupling of inorganic nutrients (e.g., dissolved carbon, various nitrogen compounds and silicates) through a complex combination of metabolic processes and the elaboration of biogenic silica (Maldonado et al. 2012).

Due to the fundamental functional role covered by sponges in marine ecosystems (Bell 2008; Maldonado et al. 2012, 2017), several species are under the protection of the international legislation. For example, for the Mediterranean Sea, a total of 15 sponge species are listed in the Annexes of the Bern and Barcelona Conventions, as well as many are included in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, being
considered severely endangered or threatened (IUCN 2021). The importance of sponge protection and conservation is also related to the economic value associated with their seawater filtration rates, estimated by Pham et al. (2019) as nearly double the market value of the fish catch.

The simple body organization and the high plasticity, together with the symbiotic association with a complex community of microorganisms, allowed sponges to adapt to different environmental conditions (Schmitt et al. 2007; Van Soest et al. 2012). Sponges are typical inhabitants of both shallow and deep waters, from the mesolittoral to the circalittoral zones, including crucial habitats as *Posidonia* meadows, coral reefs, marine caves and coralligenous assemblages, and in the bathyal zone, where they can create the so-called “sponge grounds” (Corriero et al. 2000; Bo et al. 2012; Calcinai et al. 2015; Padiglìa et al. 2018; Hawkes et al. 2019; Pawlik & McMurray 2020). Most of sponge species generally present a wide bathymetric distribution (Van Soest et al. 2012), in some cases making difficult the identification of a vertical zonation at a narrow depth range. However, various factors can contribute to the bathymetric distribution of Porifera, such as light (especially for species hosting symbionts, e.g., *Cliona viridis* and *Petrosia* (*Petrosia* ficiformis), sedimentation rates, nutrients availability, water movements and predation (Wilkinson & Evans 1989; Rosell & Uriz 1991; Arillo et al. 1993).

Porifera represents one of the most common organisms of the Mediterranean benthic communities, for which 785 valid species have been listed by now (de Voogd et al. 2022). Although among the seven Mediterranean ecoregions (Spalding et al. 2007), the Western Mediterranean shows the highest number of sponge species (422) (de Voogd et al. 2022), the sampling effort results insufficient, being focussed only on a few areas, with many biocenoses still under-sampled (UNEP-MAP RAC/SPA 2010). In fact, different areas are interested by various studies targeting sponges, as for example the Portofino Marine Protected Area (MPA), from where almost 300 species have been described (Cerrano et al. 2001; Bertolino et al. 2013; Calcinai et al. 2015), while many other areas are still under investigated.

Aim of the current study is to analyse and compare the sponge communities characterising the hard bottoms of two Islands belonging to the Tuscan Archipelago (Italy), planned to become a future MPA. In particular, we explored if the sponge species composition changes in relation to a bathymetric gradient, from 0 to 40 m. In addition, our data were evaluated with reference to data available in the literature on sponges of the Tuscan Archipelago, to determine if the sampling effort applied is sufficient to describe the diversity of the area.

**Materials and methods**

**Sample’s collection and identification**

Samplings were carried out by SCUBA diving during June 2019 and 2020 in Montecristo and Giglio, two Islands belonging to the Tuscan Archipelago National Park (TANP, Italy) (permission #00068010) (Figure 1). Montecristo is an Integral Nature Reserve since 1971, under the surveillance of the Italian Carabinieri Corps and Coast Guard, and all maritime activities are strictly forbidden (Angeletti et al. 2010; Bo et al. 2014). Conversely, Giglio hosts 1,500 residents and three villages (Campese, Giglio Castello and Giglio Porto), and its adjacent waters do not have any protection (IslePark 2021). The two Islands present a similar mineralogical composition, being mainly composed by granitic rocks (Alvisi et al. 1994; Innocenti et al. 1997).

A total of 14 sites were sampled (Table S1) and samples of Porifera were collected on rocky bottom assemblages at five depths: 0.5, 10, 20, 30 and 40 m. At each depth, two scuba operators spent about 6 minutes, covering an area of 20 m × 1 m (20 m²) each and applying a visually oriented sampling method to collect the highest number of species of the area (Calcinai et al. 2011). For each sponge sample, a small portion was collected, thus allowing the regeneration of the specimen. The visually oriented sampling data were expressed as the presence/absence of sponges at each sampling time at each site.

The collected material was fixed in ethanol 95%. Specimens were processed following the standard methods for slides’ preparations (Rützler 1978), and when possible, identified at species level, using a Nikon Eclipse Ni compound microscope. The slides used for the identification were stored in a reference collection deposited at the Zoology Laboratory at DiSVA (Department of Life and Environmental Sciences), Polytechnic University of Marche (Ancona, Italy). The taxonomic identification was conducted using “Systema Porifera” (Hooper & Van Soest 2002), “Fauna d’Italia” (Pansini et al. 2011), “Proposal for a revised classification of the Demospongiae (Porifera)” (Morrow & Cárdenas 2015) and the World Porifera Database (de Voogd et al. 2022).

**Literature collection**

A comparison with the previous literature on the area of the TANP has been carried out. The
literature research was conducted following the rules given by Pautasso (2013) for literature review. Since the considered area is limited, the present compilation is the result of an extensive bibliographic research on different databases (e.g., Google Scholar, JSTOR search, Scopus, Web of Science, Biodiversity Heritage Library), entering different keywords (“sponge” OR “Porifera”) AND (“Island name” OR “Tuscany” OR “Northern Tyrrhenian Sea”). An additional manual research was conducted on the references of the found documents, to include the possible literature on the area that could have been missed with the online search. The literature considered in this work includes journal articles and grey literature, as congress proceedings and technical reports. We did not include the paper of Roveta et al. (2020) by choice, since specimens used in that study were also considered in the present analysis. In addition, we checked for duplicate records and standardized the nomenclature using the World Porifera Database (de Voogd et al. 2022).

Experimental design and statistical analyses

The experimental design aiming at testing differences in the sponge communities at varying depth included two crossed factors: Island (fixed, 2 levels: Montecristo, Giglio) and depth (fixed, 5 levels: 0.5, 10, 20, 30, 40). Using a similarity matrix of presence-absence data (based on Jaccard similarity), data were analysed with Permutational Multivariate Analysis of Variance (PERMANOVA; Anderson 2001), with 9999 permutations. Permutational analysis of multivariate dispersions (PERMDISP) was used to test the homogeneity of samples dispersion from their group centroids (Anderson et al. 2008). A posteriori pairwise comparisons were conducted in case of significance in the PERMANOVA. The analysis of Similarity Percentages (SIMPER) (Clarke 1993) was used to determine species contributions to the variability in sponge assemblages within Islands and depths.

Occurrences of sponge species obtained from the literature (considering documents in which the sampled Island(s) was specified) and our data were included in a presence/absence matrix, which was used as a similarity matrix. Dissimilarities among Islands was calculated using the Jaccard semimetric distance to perform a hierarchical clustering using the R package Vegan (Oksanen et al. 2020). The same dataset was used to estimate the sampling effort applied at each Island. A rarefaction curve per Island was built using the iNEXT R package (Chao et al. 2014), based on sampling-unit-incidence data (presence/absence), and the Hill number was measured in relation to the species richness \( (q = 0) \) of each Island. To standardize our data, we outrun a similarity matrix per Island, acquiring site and sponge species collected in every study toward the definition of the sampling unit and the species diversity respectively. If a document did not specify in which sampling site species were found, all sponge species were considered as found.
in a single site. In the analysis, if a species was indicated as sp. or spp. in different studies, they were grouped together to minimize bias.

Results

Considering all sites, a total of 340 samples were collected, with 13 orders and 48 species (46 Demospongiae and 2 Calcarea) of Porifera identified (Table I). A table containing further information (Island, site code, latitude, longitude, depth, and the list of all the identified species) is reported in the supplementary material as Table S2. Most of species belong to the orders of Poecilosclerida (14), Dictyoceratida (9) and Haplosclerida (8), and to the genera Hymedesmia (8) and Haliclona (5) (Table I).

Due to the small amount of material available, in few cases (Crella sp., Dictyonella sp., Fasciospongia sp., Ircinia sp., Sycon spp., Calcarea indet., Haplosclerida indet.) identification to species level was prevented (Table I).

Considering the investigated depths, the total number of taxa showed a general increase with depth, with 17 species at 0.5 m, 18 at 10 m, 24 at 20 and 30 m, and 27 at 40 m (Table S2). Some species were found at only one depth, in particular three species were only recorded at 0.5 m (Cacospongia mollior, Fasciospongia cavernosa, Ircinia sp.), 2 at 10 m (Halisarca dujardini, Penares helleri), 4 at 20 m (Acanthella acuta, Callyspongia subcornea, Fasciospongia sp., Spongia (Spongia) officinalis), 2 at 30 m (Aplysina cavernicola, Crella sp.), and 6 at 40 m (Dictyonella sp., Halichondria (Halichondria) contorta, Hymeniacidon perlevis, Haliclona (Reniera) mediterranea, Hymedesmia (Hymedesmia) consanguinea, Hymedesmia (Soestella) arenata) (Table S2).

Overall, Chondrosia reniformis was the most widely distributed species, being found at all sites and at almost all depths (Table S2). Other common species were Cliona viridis, Haliclona (Halichoclonia) fulva, Hemiymcale columella and Hymedesmia (Hymedesmia) baculifera (Table S2).

Four species listed in Table I (Aplysina aerophoba, A. cavernicola, Sarcotragus foetidus, Spongia (Spongia) officinalis) are included in the Annexes II and III of the SPA/BD Protocol of Barcelona Convention, while three species (Agelas oroides, A. cavernicola, Hymedesmia (Hymedesmia) rissoi) are endemic to the Mediterranean Sea (Table I).

Among the 48 species, 40 were recorded at Montecristo and 34 at Giglio (Table I). Two orders (Agelasida and Chondrillida) and 14 species were recorded only at the Montecristo Island, while one order (Bubarida) and 8 species were uniquely found at Giglio. The site with the highest number of species was M-07 (23), followed by M-05 (15), G-01 and G-05 (14), while G-02 (5), M-01 and M-03 (7) were the sites with the lowest number of taxa recorded (Table S2). Considering the sampled depths at each Island, the number of species is almost constant within depths (Table S2).

PERMANOVA showed statistical differences only within depths (Table II), and the pairwise comparison highlighted differences in the sponge species composition between the shallower depths (0.5, 10 and 20 m) and the deeper ones (30 and 40 m) (Table III). However, the PERMDISP indicated a similar average dispersion within depths (Table IV), making the dispersion not significant (F4,65 = 2.1736; p = 0.1269).

The SIMPER analysis revealed that the similarity within Islands was given only by a few species. The average similarity is higher at Giglio (21.39%) with the contribution of Chondrosia reniformis (44.48%) and Hemiymcale columella (30.04%), while the lower similarity at Montecristo (18.20%) was given by C. reniformis (40.50%) and Cliona viridis (20.23%), together with Haliclona (Halichoclonia) fulva (8.87%) and Hymedesmia (Hymedesmia) baculifera (7.41%). Dissimilarities were calculated within depthsin particular, the ones which showed a significant difference in the pairwise comparison (see Table III). The highest average dissimilarity in species composition was between 10 and 40 m depth (92.31%) and the lowest between 10 and 30 m depth (86.05%) (Table S3). Dissimilarities between 0.5 and 30 m (89.31%) were mainly given by H. columella (10.74%), C. reniformis (9.90%) and C. viridis (8.36%), between 0.5 and 40 m (90.18%) by C. viridis (11.37%), H. columella (9.82%) and C. reniformis (8.71%) (Table S3). Species responsible for dissimilarity between 10 and 30 m and between 10 and 40 m depth were mainly explained by C. reniformis (13.87%), C. viridis (8.80%), H. (H.) baculifera (8.72%), and C. reniformis (13.96%), C. viridis (12.11%), H. (H.) fulva (8.53%), respectively (Table S3). While between 20 and 40 m depth (91.87%), the average dissimilarity was mostly related to C. viridis (12.50%), C. reniformis (9.43%) and H. (H.) fulva (8.08%) (Table S3).

From all the analysed literature, including a total of 73 documents (Tables S4 and S5), 84 Demospongiae, 8 Calcarea and 4 Homoscleromorpha have been listed (Table V), with the highest number of species recorded at Montecristo (34), followed by Capraia (30), Elba and Giglio (29), while the other Islands showed only a few species (13, 4 and 8 at Giannutri, Gorgona and Pianosa respectively) (Table V; Figure 2). Most of the listed species belong to the orders Poecilosclerida (24), Dictyoceratida (16) and Haplosclerida (10) (Table V). Table V also includes
### Table I. List of Porifera taxa identified for Montecristo and Giglio Islands.

E = endemic Mediterranean species; M* = new records for the Montecristo Island; G* = new records for the Giglio Island; P = species included in the Annexes II and III of SPA/BD of Barcelona Convention.

| Porifera            | Status    | Montecristo Island | Giglio Island |
|---------------------|-----------|--------------------|---------------|
| **Demospongiae**    |           |                    |               |
| **Agelasida**       |           |                    |               |
| *Agelas orides* (Schmidt, 1864) | E, M* | X                |               |
| **Axinellida**      |           |                    |               |
| *Axinella damicornis* (Esper, 1794) | M* | X                | X             |
| **Bubalida**        |           |                    |               |
| *Acanthella acuta* Schmidt, 1862 | G* | X                |               |
| **Dictyonella** sp. |           |                    |               |
| **Chondrillida**    |           |                    |               |
| *Halisarca dujardinii* Johnston, 1842 | M* | X                |               |
| **Chondrosida**     |           |                    |               |
| *Chlonia viridis* (Schmidt, 1862) | M* | X                | X             |
| **Clionida**        |           |                    |               |
| *Spirastrella cunctatrix* Schmidt, 1868 | M* | X                | X             |
| **Dixicoceratida**  |           |                    |               |
| *Cacospongia mollior* Schmidt, 1862 | M* | X                |               |
| *Fasciospongia cavernosa* Schmidt, 1862 | M* | X                |               |
| **Haliclona**       |           |                    |               |
| *Haliclona (Halichoclona) fulva* Topsent, 1893 | M* | X                |               |
| *Haliclona (Reniera) arenata* Griessinger, 1971 | G* | X                |               |
| *Haliclona (Soestella) mucosa* Griessinger, 1971 | G*, M* | X | X |
| **Haplosclerida**   |           |                    |               |
| *Spongia (Spongia) officinalis* Linnaeus, 1759 | P, M* | X                |               |
| **Hemimycale**      |           |                    |               |
| *Hemimycale columnella* Bowerbank, 1874 | G*, M* | X | X |
| **Poecilosclerida** |           |                    |               |
| *Crambe crambe* Schmidt, 1862 | M* | X | X |
| **Crelia** sp.      |           |                    |               |
| *Crelia (Crelia) elegans* Schmidt, 1862 | G* | X | X |
| **Hymeniacidon**    |           |                    |               |
| *Hymeniacidon perlevis* Montagu, 1814 | M* | X | X |
| **Phorbas**         |           |                    |               |
| *Phorbas tenacior* Topsent, 1925 | M* | X | X |
| **Suberitida**      |           |                    |               |
| *Aaptos aaptos* Schmidt, 1864 | M* | X | X |
| **Tetractinellida** |           |                    |               |
| *Penares euastrum* Schmidt, 1868 | G*, M* | X | X |
| **Verongiida**      |           |                    |               |
| *Aplysina aerophoba* Nardo, 1833 | P | X | X |

(Continued)
Table I. (Continued).

| Porifera                          | Status    | Montecristo Island | Giglio Island |
|----------------------------------|-----------|--------------------|---------------|
| *Aphysina cavernicola* (Vacelet, 1959) | E, P, M*  | X                  |               |
| Calcarea                         |           |                    |               |
| Calcarea indet.                  |           |                    |               |
| Leucosolenida                    |           |                    |               |
| Sycon spp.                       | M*        | X                  | X             |
| TOT Porifera x Island            | 40        | 34                 |               |

Table II. Results of the two-way PERMANOVA. Analysis of sponge community variation considering Islands and depths. df = degrees of freedom; SS = sum of squares; MS = mean squares; Pseudo-F = F-ratio; P (perm) = probability; Up = unique perms.

| Source       | df | SS    | MS   | Pseudo-F | P(perm) | Up  |
|--------------|----|-------|------|----------|---------|-----|
| Depth (De)   | 4  | 22,270| 5567.4| 2.0658   | 0.0002  | 9845|
| Island (Is)  | 1  | 3203.3| 3203.3| 1.1886   | 0.2562  | 9915|
| De x Is      | 4  | 12,783| 3195.7| 1.1858   | 0.1587  | 9842|
| Residuals    | 60 | 161,700| 2695 |          |         |     |
| Total        | 69 | 199,960|      |          |         |     |

Table III. Results of the a posteriori pairwise comparisons within depths. t = t-test; P (perm) = probability; Up = unique perms. Significant p-values (p < 0.05) are given in bold.

| Groups | t       | P(perm) | Up  |
|--------|---------|---------|-----|
| 0.5–10 | 1.3258  | 0.0633  | 9935|
| 0.5–20 | 1.1911  | 0.1387  | 9936|
| 0.5–30 | 1.5495  | 0.0011  | 9908|
| 0.5–40 | 1.8474  | 0.0001  | 9916|
| 10–20  | 0.94994 | 0.5252  | 9911|
| 10–30  | 1.5374  | 0.0048  | 9917|
| 10–40  | 2.1225  | 0.0001  | 9917|
| 20–30  | 1.0521  | 0.3433  | 9911|
| 20–40  | 1.4679  | 0.0102  | 9912|
| 30–40  | 0.90663 | 0.6386  | 9923|

Table IV. Results of the PERMDISP analyses at the different depths (0.5, 10, 20, 30, 40 m). SE = standard error.

| Group | Size | Average | SE    |
|-------|------|---------|-------|
| 0.5   | 14   | 49.242  | 1.9882|
| 10    | 14   | 44.381  | 2.8533|
| 20    | 14   | 51.301  | 2.3144|
| 30    | 14   | 52.091  | 1.6693|
| 40    | 14   | 51.507  | 1.6711|

six species (*Aphysina aerophoba, A. cavernicola, Axinella polyoides, Sarcotragus fasciculatus, Spongia (Spongia) officinalis, Tethya aurantium*) reported in the Annexes II and III of the SPA/BD Protocol of Barcelona Convention. In addition, four species (*A. oroides, A. cavernicola, Delectoma ciconiae, Eurypon vesicularis*) are endemic to the Mediterranean Sea (Table V).

Comparing the species extrapolated from the literature with the ones identified in this study, we found that 24 species were shared between the two datasets and 17 were new records for the area of the Tuscan Archipelago (Tables I and V). Considering Montecristo and Giglio separately, 9 and 10 species, respectively, were already recorded, while 30 and 21, respectively, were new records for the two Islands (Tables I and V).

In Table S4 we included all documents providing species listed in Table V, with all details (Porifera – with changes in species names –, authors, title, publication year, DOI/reference, Island, document type, application field). Species (35) reported in documents with no information on the sampling area/Island, that cannot be listed in Table V and thus used for statistical analysis, are also included in Table S4. Moreover, we would have added to the list other two endemic species (*Clathria (Clathria) toxistrica, Haliclona (Rhizoniera) sarai*) and four protected ones (*Geodia cydonium, Hippopospongia communis, Sarcotragus foetidus, Tethya citrina*) (Table S4). Since many documents (26) did not specify the taxon collected but referred to sponges with the general terms “Porifera” or “sponge(s)”; these studies were not considered for statistical analysis but included in the Supplementary Material as Table S5, together with all document’s information (authors, title, publication year, DOI/reference, Island, document type, application field). Due to the low number of species and sampling units listed for the Islands of Giannutri, Gorgona and Pianosa (Tables V and S4), the cluster analysis and the extrapolation curves were not statistically reliable and thus, these Islands were excluded. However, for the sake of completeness, a cluster analysis, with the corresponding levels of dissimilarity, and the rarefaction curves considering all Islands are presented in the Supplementary Material as Figures S1 and S2.

Considering the joined dataset, obtained gathering data from this study and the scientific literature, the cluster analysis indicated that Montecristo and Giglio formed a group at a dissimilarity level of 0.64, while Caprera resulted related to the previous group.
**Table V. List of Porifera taxa extrapolated from the literature collection.**

| Porifera                  | Status | CA | EL | GN | GI | GO | MO | PI |
|---------------------------|--------|----|----|----|----|----|----|----|
| **Demospongiae**          |        |    |    |    |    |    |    |    |
| Agelasida                 |        |    |    |    |    |    |    |    |
| *Agelas ovoides* (Schmidt, 1864) | E      | X  | X  | X  | X  | X  |    | X  |
| **Axinellida**            |        |    |    |    |    |    |    |    |
| *Axinella damicornis* (Esper, 1794) |       | X  | X  | X  |    |    |    |    |
| *Axinella polyoides* Schmidt, 1862 | P      |    |    |    | X  |    |    |    |
| *Axinella verrucosa* (Esper, 1794) |       |    |    |    | X  |    |    |    |
| *Eurypon lacazei* Topsent, 1891 |       |    |    |    |    |    |    |    |
| *Eurypon vesiculare* Sara & Siribelli, 1960 | E      | X  |    |    |    |    |    |    |
| *Raspaciona aculeata* (Johnston, 1842) |       |    |    |    |    |    |    |    |
| **Bubarida**              |        |    |    |    |    |    |    |    |
| *Acanthella acuta* Schmidt, 1862 |       |    | X  |    |    |    |    |    |
| *Dictyonella incisa* (Schmidt, 1880) |       | X  |    |    |    |    |    |    |
| **Chondrosiida**          |        |    |    |    |    |    |    |    |
| *Chondrosia reniformis* Nardo, 1847 |       | X  |    |    |    |    |    |    |
| *Chondrosia sp.*          |        | X  |    |    |    |    |    |    |
| **Chondrillida**          |        |    |    |    |    |    |    |    |
| *Chondrilla mucula* Schmidt, 1862 |       |    |    |    |    |    |    |    |
| **Clionaida**             |        |    |    |    |    |    |    |    |
| *Cliona celata* Grant, 1826 |       |    |    |    |    |    |    |    |
| *Cliona lobata* Hancock, 1849 |       |    |    |    |    |    |    |    |
| *Cliona sp.*              |        | X  |    |    |    |    |    |    |
| *Cliona viridis* (Schmidt, 1862) |       |    |    | X  |    |    |    |    |
| *Spirastrella cunctatrix* Schmidt, 1868 |       |    |    |    | X  |    |    |    |
| *Spirastrella sp.*        |        | X  |    |    |    |    |    |    |
| **Dendroceratida**        |        |    |    |    |    |    |    |    |
| *Aplysilla rosea* (Barrois, 1876) |       |    |    |    |    |    |    |    |
| **Dictyoceratida**        |        |    |    |    |    |    |    |    |
| *Cacospongia mollis* Schmidt, 1862 |       |    |    |    | X  |    |    |    |
| *Dysidea avara* (Schmidt, 1862) | X      |    |    |    |    |    |    |    |
| *Dysidea fragilis* (Montagu, 1814) |       |    |    |    |    |    |    |    |
| *Dysidea incrustans* (Schmidt, 1862) |       |    |    |    |    |    |    |    |
| *Fasciospongia cavernosa* (Schmidt, 1862) |       |    |    |    |    |    |    |    |
| *Hippospongia communis* Lamarck, 1814 | P      |    |    |    |    |    |    | X  |
| *Ircinia dendroides* (Schmidt, 1862) |       |    |    |    |    |    |    |    |
| *Ircinia spp.*            |        | X  |    |    |    |    |    |    |
| *Ircinia variabilis* (Schmidt, 1862) | X      |    |    |    |    |    |    |    |
| *Pleraplysilla spinifera* (Schulze, 1879) | X      |    |    |    |    |    |    |    |
| *Sarcotragus fasciculatus* Pallas, 1766 |       | P  | X  |    |    |    |    |    |
| *Sarcotragus spinosulus* Schmidt, 1862 |       |    |    | X  |    |    |    |    |
| *Scalarispongia scalaris* (Schmidt, 1862) |       |    |    |    | X  |    |    |    |
| *Spongia* (Spongia) officinalis* Linnaeus, 1759 | P      |    |    |    |    | X  |    |    |
| *Spongia* (Spongia) virgultosa* (Schmidt, 1868) |       |    |    |    |    |    |    | X  |
| **Haplosclerida**         |        |    |    |    |    |    |    |    |
| *Chalinula limbata* (Montagu, 1814) |       |    |    |    |    |    |    |    |
| *Halicoma sp.*            |        |    |    |    |    |    |    |    |
| *Halicoma* (Gellius) angulata* (Bowerbank, 1866) |       |    |    |    |    |    |    |    |
| *Halicoma* (Halichondra) fulva* (Topsent, 1893) |       |    |    |    |    |    |    |    |
| *Halicoma* (Reniera) sp. Schmidt, 1862 |       |    |    |    |    |    |    |    |
| *Halicoma* (Soestella) mucosa* (Griessinger, 1971) |       |    |    |    |    |    |    |    |
| *Halicoma* (Soestella) valliculata* (Griessinger, 1971) |       |    |    |    |    |    |    |    |
| *Haplosclerida*           |        |    |    |    |    |    |    |    |
| *Petrosia* (Petrosia) ficiformis* (Poiret, 1789) |       |    |    | X  |    |    |    |    |
| *Siphonodictyon corallirubri* (Calcinar, Cerrano & Bavestrello, 2007) |       |    |    |    |    |    |    | X  |

(Continued)
Table V. (Continued).

| Porifera | Status | CA | EL | GN | GI | GO | MO | PI |
|----------|--------|----|----|----|----|----|----|----|
| Poecilosclerida |        | X | X | X | X | X | X | X |
| Antho (Plocamia) sarasiri Costa, Pancini & Bertolino, 2019 | poecilosclerida | X | X | X | X | X | X | X |
| Batallia inops (Topsent, 1891) | clathridia | X | X | X | X | X | X | X |
| Clathria (Microciona) sp. | clathridia | X | X | X | X | X | X | X |
| Crambe crambie (Schmidt, 1862) | clathridia | X | X | X | X | X | X | X |
| Crella (Pytheas) sigmoida Topsent, 1925 | clathridia | X | X | X | X | X | X | X |
| Crella (Yeisia) sp. (cited as Yeisia sp.) | clathridia | X | X | X | X | X | X | X |
| Forceps (Leptololis) lucensii (Topsent, 1888) | clathridia | X | X | X | X | X | X | X |
| Hamigera hamigera (Schmidt, 1862) | clathridia | X | X | X | X | X | X | X |
| Hemimycally columnella (Bowerbank, 1874) | clathridia | X | X | X | X | X | X | X |
| Hamimycally sp. | clathridia | X | X | X | X | X | X | X |
| Hymedesmia spp. Bowerbank, 1882 | clathridia | X | X | X | X | X | X | X |
| Hymedesmia (Hymedesmia) panus Bowerbank, 1886 | clathridia | X | X | X | X | X | X | X |
| Hymedesmia (Stylopus) corticea (Fristedt, 1885) | clathridia | X | X | X | X | X | X | X |
| Hymedesmia (Stylopus) sp. (cited as Stylopus sp.) | clathridia | X | X | X | X | X | X | X |
| Lissodendoryx sp. | clathridia | X | X | X | X | X | X | X |
| Mycale (Aegogopila) retifera Topsent, 1924 | clathridia | X | X | X | X | X | X | X |
| Mycale (Aegogopila) tunica (Schmidt, 1862) | clathridia | X | X | X | X | X | X | X |
| Myxilla (Myxilla) incrustans (Johnston, 1842) | clathridia | X | X | X | X | X | X | X |
| Phorbas dries (Topsent, 1891) | clathridia | X | X | X | X | X | X | X |
| Phorbas fictitius (Bowerbank, 1866) | clathridia | X | X | X | X | X | X | X |
| Phorbas sp. | clathridia | X | X | X | X | X | X | X |
| Phorbas tenacior (Topsent, 1925) | clathridia | X | X | X | X | X | X | X |
| Todania (Tedania) anhelans (Vio in Olivi, 1792) | clathridia | X | X | X | X | X | X | X |
| Suberitida | clathridia | X | X | X | X | X | X | X |
| Halichondria sp. | clathridia | X | X | X | X | X | X | X |
| Hymeniacidon perlevis (Montagu, 1814) | clathridia | X | X | X | X | X | X | X |
| Terpion gelatinosus (Bowerbank, 1866) | clathridia | X | X | X | X | X | X | X |
| Tethyida | clathridia | X | X | X | X | X | X | X |
| Tethya aurantium (Pallas, 1766) | clathridia | X | X | X | X | X | X | X |
| Tethya meloni Corriero, Gadaleta & Bavestrello, 2015 | clathridia | X | X | X | X | X | X | X |
| Tomea fasciata Topsent, 1934 | clathridia | X | X | X | X | X | X | X |
| Tetractinellida | clathridia | X | X | X | X | X | X | X |
| Delectona ciconiae Bavestrello, Calcinai & Sarà, 1996 | clathridia | X | X | X | X | X | X | X |
| Dercitus (Stoeba) plicatus (Schmidt, 1868) | clathridia | X | X | X | X | X | X | X |
| Penares caustrum (Schmidt, 1868) | clathridia | X | X | X | X | X | X | X |
| Verongiida | clathridia | X | X | X | X | X | X | X |
| Aplysina aerophoba (Nardo, 1833) | clathridia | X | X | X | X | X | X | X |
| Aplysina cavernicola (Vacelet, 1959) | clathridia | X | X | X | X | X | X | X |
| Aplysina sp. | clathridia | X | X | X | X | X | X | X |
| Calcarea | clathridia | X | X | X | X | X | X | X |
| Clathrinida | clathridia | X | X | X | X | X | X | X |
| Ascandra contorta (Bowerbank, 1866) | clathridia | X | X | X | X | X | X | X |
| Clathrina clathrus (Schmidt, 1864) | clathridia | X | X | X | X | X | X | X |
| Leucetta solida (Schmidt, 1862) | clathridia | X | X | X | X | X | X | X |
| Leucosolenida | clathridia | X | X | X | X | X | X | X |
| Leucandra aspera (Schmidt, 1862) | clathridia | X | X | X | X | X | X | X |
| Sycon ciliatum (Fabricius, 1780) | clathridia | X | X | X | X | X | X | X |
| Sycon elegans (Bowerbank, 1845) | clathridia | X | X | X | X | X | X | X |
| Sycon raphanus Schmidt, 1862 | clathridia | X | X | X | X | X | X | X |
| Sycon sp. Risso, 1827 | clathridia | X | X | X | X | X | X | X |
| Homoscleromorpha | clathridia | X | X | X | X | X | X | X |
| Homosclerophorida | clathridia | X | X | X | X | X | X | X |
| Corticium candelabrum Schmidt, 1862 | clathridia | X | X | X | X | X | X | X |
at a level of 0.79 (Figure 3). The Elba Island was the less related Island with the above group, with a dissimilarity of 0.84 (Figure 3).

Although the number of documents increased significantly in time (Table S4), the extrapolation curves indicate that the sampling effort applied by now to the area is not sufficient (Figure 4). The curves demonstrated that the Montecristo Island is expected to have the highest species diversity, even though it was the Island with the lower number of sampling units, contrary to Capraia where, with almost the same number of sampling units, the number of estimated species was less than the half (Figure 4). In general, Giglio and Montecristo showed a higher mean species diversity than the other two Islands, while Capraia and Elba presented an almost total overlapping between the 95% confidence intervals and the average diversity (Figure 4).

**Discussion**

The species of Porifera identified in the current study are all well-known and typical of Italian and Mediterranean coastal habitats (Hooper & Van Soest 2002; Pansini & Longo 2008). Species recognized as the most frequent (*Chondrosia reniformis*, *Cliona viridis*, *Haliclona* (*Haliclona*) *fulva*, *Hemimycale columnella* and *Hymedesmia* (*Hymedesmia*) *baculifera*) are also described in the literature as among the most common species of shallow waters (Carballo 1994; Ben...
Mustapha et al. 2002; Hooper & Van Soest 2002; Bertolino et al. 2013).

Depth has been previously highlighted to be fundamental in structuring marine benthic assemblages (Samaai et al. 2010). Even though sponges can be characterised by a wide bathymetric range, and a same species can be found from the surface to the bathyal waters (Van Soest et al. 2012), differences in the species composition can be also identified in a narrow vertical range. It is thus not surprising that our analysis showed significant differences in the sponge community composition among the investigated depths. In particular, differences were recorded between the shallower depths (0.5, 10 and 20 m) and the deeper ones (30 and 40 m). In fact, in all sampled sites, around 30 m depth, the shift from the littoral community, mainly characterized by algae, to a pre-coralligenous or coralligenous habitat was observed (Roveta C., Pulido Mantas T., Pica D. personal observation). The 30 and 40 m corresponded to the depths where most of species were recorded, and where typical sponge species characterizing coralligenous assemblages (e.g., Aplysina spp., Axinella spp., Cliona cirella, Crambe crambe, Haliclona spp., Hemiycalae columna, Hymedesmia spp., Penaes euastrum, Phorbas tenacior) (Bertolino et al. 2013; Longo et al. 2018) were the most common (Table S2) and the main responsible for the dissimilarities within the shallower and the deeper populations (Table S3). A similar pattern was already observed in the Tuscan Archipelago by Balduzzi et al. (1995), specifically at Giglio and Capraia Islands, and by Ferdeghini et al. (2000), at the Giannutri Island.

The mineralogic composition of the substrate is known to influence larvae recruitment and, therefore, species composition and distribution (Bavestrello et al. 2000; Canessa et al. 2019, 2020). For example, Canessa et al. (2020) highlighted how coralligenous assemblages can differ between limestone and granite, and that several sponge species, as Sarcotragus foetidus or the ones belonging to the genus Axinella, are more abundant on granitic substrates. This is in line with our observations and the results of the statistical analysis, which did not highlight significant differences in the species composition of the two Islands. In fact, Montecristo and Giglio share the nature of the substrate, being both granitic (SiO₂) (Alvisi et al. 1994; Innocenti et al. 1997), except for Promontorio del Franco in Giglio (an area not considered in this study), mainly composed of limestone (Alvisi et al. 1994, page 25, fig. 1). Together with the mineralogical composition of the substrate, current is another factor that can play an important role in structuring the sponge community composition of the considered Islands. Even though sponge larvae

Figure 4. Sampling-unit-based rarefaction (solid line segment) and extrapolation (dotted line segments) curves with 95% confidence intervals (shaded areas) for sponge data. CA = Capraia; EL = Elba; GI = Giglio; MO = Montecristo.
tend to settle nearby the parental organism due to their limited swimming capacity (Van Soest et al. 2012), water movements can promote larval dispersion (Mariani et al. 2006). Tyrrhenian Sea surface currents move from its southern part to the northern one and, once coastal waters encounter the promontory of Monte Argentario, they are drifted from the coast to the offshore (Iacono et al. 2013, p. 1711, fig. 1). Therefore, it is possible that larvae (and/or propagules) released by sponges at the Giglio Island can be transported to Montecristo, promoting a similar community.

Among the sessile fauna of the Tuscan Archipelago, Porifera represents one of the most common groups (Benedetti-Cecechi et al. 2003). However, information on sponges inhabiting the area is scant, fragmentary, and sparse in the literature, and many of the observations derive from sampling not targeting sponges in a systematic way. In fact, species listed for Montecristo derived just from two documents, that are Corriero and Pronzato (1987) and Taviani et al. (2009) – the last one providing only one species (Table S4) –, and the present work. For the other Islands, only a few documents were taxonomical papers, targeting sponges, while most of them were mainly ecological (see Table S4 for references). For Elba, which was the Island with the higher number of documents recorded (36), a considerable amount were biotechnological studies, focussing their attention on the extraction of natural compounds from a few target species and their microbial communities (e.g., *Aplysina* spp., *Axinella* spp., *Chondrosia reniformis*, *Hamigera hamigera*, *Petrosia* (*Petrosia* *ficiformis*, *Sarcotragus fasciculatus*) (see Table S4 for references). In addition, regarding Giannutri, Gorgona and Pianosa, only few documents were found per Island, providing a low number of species, and not allowing us to include them for further analyses.

The cluster analysis suggested a more similar species composition at Giglio and Montecristo, together with Capraia, while Elba resulted as the less related. Once again, the mineralogical composition of the various Islands can partially explain the results obtained with the analysis. Capraia, Giglio and Montecristo are mainly composed of SiO$_2$, with values ranging from 58% to 73%, being Giglio and Montecristo granitic and Capraia volcanic (Innocenti et al. 1997; Westerman et al. 2003; Gasparon et al. 2009), while Elba presents a high mineralogical diversity, being both carbonatic (e.g., limestone) and granitic (Bortolotti et al. 2001). Therefore, the different geomorphology characterizing the analysed Islands can play a role in the similarity of their sponge populations.

In general, many problems were encountered during the literature analysis carried out in the current study: (1) sampled Island(s) and site(s) information were present in the Materials and Methods, but records were not georeferenced; (2) the sampled Island(s) was specified, but not the study site(s) (see Table S4); (3) sampled Island(s) and site(s) were given, but insufficient taxonomical information were provided (different species grouped in relation to their growth form, as “encrusting Porifera”, “massive Porifera”, etc., or merely listed as “Porifera”) (see Tables S4 and S5). As already pointed out for other phyla, studies providing the reader with geographical information of the sampling area(s) and site(s), together with georeferenced records, not only improve the data quality, but also facilitate the literature analysis for other researchers (e.g., timesaving in data compilation) (Ajala-Batista et al. 2020). The lack of taxonomical information, especially in ecological papers, avoid the gathering of datasets regarding pattern of species richness and endemism, and do not allow a better understanding of organisms’ natural history (Ajala-Batista et al. 2020). However, even though we found different high-quality in grey literature studies, crucial for improving our dataset, more complete information would have allowed us to add more species in Table V, and to have more sampling units in the extrapolation of the species diversity, thus leading to a more accurate prediction.

The lack of communication among disciplines has been highlighted not only in ecological papers, which were mainly or exclusively focussed on the application of indexes to evaluate the ecological status of a habitat, without considering any taxonomical aspect (see Tables S4 and S5 for references), but also in pure taxonomical works. Most of them did not present any ecological information (see Table S4 for references), leading to a reduction in value and attractiveness, with all the useful information on species distribution and diversity often lost (Di Camillo et al. 2018).

Although sponges have key ecological and economical roles (Padiglia et al. 2018; Pham et al. 2019), the sampling effort applied on this group in the Tuscan Archipelago is still not sufficient. Due to this underestimation, non-recorded species are probably present within the area, especially for the cryptic nature of many sponges, as underlined by the work of Bertolino et al. (2013) and Calcinai et al. (2015). Thus, sampling of sponges at different depths and on different substrates (e.g., rocky shores, port structures, *Posidonia* meadows, marine caves, and other living organisms, such as macroalgae and other benthic metazoans) should be carried
out to increase the likelihood of their encounter. The increasing of the sampling effort will be crucial for the Tuscan Archipelago National Park, planned to become a future MPA (L. 979/82 art.31 and L. 394/91 art.36), and the Montecristo Island, a Natural Integral Reserve and previously identified as a reference site for ecological quality assessment in the Western Mediterranean (Turicchia et al. 2018), especially considering the presence of the endemic and protected species (SPA/BD) and accordingly to the new European legislation (EC 2020).

To conclude, our work is the first summarising the sponge diversity of the entire Tuscan Archipelago, and one of the few totally focussing on the sponge fauna. These results provide new important information on the area of the TANP, adding new records and highlighting the high diversity of a poorly known area.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

All data are provided within the main text and the supplementary material.

Supplementary material

Supplemental data for this article can be accessed here.

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