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Assessing the regional conservation status of sponges (Porifera): the case of the Aegean ecoregion

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Abstract

Sponges are among the less-studied benthic invertebrates as regards their extinction risk and conservation status. Herein, we evaluate the regional conservation status of sponges in the Aegean ecoregion (Eastern Mediterranean Sea), using the IUCN Red List criteria. We examined 20 sponge taxa falling into three categories: i) threatened species listed in Annex II of the Barcelona Convention, ii) bath sponge species (Annex III of the Barcelona Convention), and iii) Aegean endemics. The regional geographic range of the examined taxa was depicted on detailed distribution maps, based mostly on recent observations by the authors and literature data. When possible, population trends were estimated based on historical data, and threats were identified. The suggested regional conservation status of the examined sponge species is as follows: i) nine species were characterised as 'Data Deficient (DD)' due to limited available information; ii) seven species were assigned to the 'Least Concern (LC)' category; iii) the four harvested bath sponge species were assigned to the Endangered (EN) category, based on their population decline in the Aegean region during the past decades. The present evaluation, besides providing scientific data for the regional protection and management of sponge populations, can form a basis for wider assessment and consequent conservation of Porifera.

Keywords: Invertebrates; protection; assessment; bath sponges; Mediterranean.

Introduction

Benthic invertebrates are among the less-studied marine groups as regards their extinction risk and conservation status, and are underrepresented in the IUCN Red List of Threatened Species (Stuart *et al*., 2010), with few marine invertebrate taxa having been assessed for their conservation status to date (e.g. HELCOM, 2013). This is partly because of the scarce and scattered information on their populations and distribution, which makes it difficult to assess the risk of extinction (HELCOM, 2013). A recent initiative targeting Mediterranean anthozoans (Otero *et al*., 2017) revealed that 13% of the assessed species were threatened with extinction: 7 species were assigned to the Vulnerable (VU), 11 to the Endangered (EN) and 1 to the Critically Endangered (EN) category. Another 10 species (7%) were listed as Near Threatened (NT), 69 species (51%) were assessed as Data Deficient (DD), constituting potentially threatened species, and 40 species (29%) were assessed as of Least Concern (LC). Sponges (phylum Porifera) are a dominant animal group in sessile benthic communities of the world's oceans, playing a critical role in the functioning of marine ecosystems (Bell, 2008). Although sponge assemblages are often acknowledged for their high conservation value, the conservation status of individual species has not yet been assessed (Costello *et al*., 2015), and relevant conservation and management studies are quite rare (Rondinini *et al*., 2014; Schönberg, 2017). Furthermore, sponges are rarely considered in large-scale monitoring programs (Bell *et al*., 2017). A recent review of the global conservation status of sponges (Bell *et al*., 2015) revealed that only 20 out of the approximately 8800 known species (Van Soest *et al*., 2017), all from the Mediterranean Sea and the North-eastern Atlantic Ocean, are currently protected by legislation. As far as the Mediterranean province (*sensu* Spalding *et al.*, 2007) is concerned, 11 sponge species (Table 1) have been included on the lists of endangered and threatened species (Annex II) of the Bern Convention on the conservation of European wildlife

Table 1: Mediterranean sponges included on the lists of endangered and threatened species (Annex II) and species whose exploitation is regulated (Annex III) under the Bern and Barcelona conventions.

Sponge species	Bern Convention	Barcelona Convention
Aplysina aerophoba (Nardo, 1833)		II
Aplysina cavernicola (Vacelet, 1959)	II	II
Axinella cannabina (Esper, 1794)		II
Axinella polypoides Schmidt, 1862	II	II
Geodia cydonium (Linnaeus, 1767)		II
Hippospongia communis (Lamarck, 1814)	III	III
Lycopodina hypogea (Vacelet & Boury-Esnault, 1996)	II	II
Petrobiona massiliana Vacelet & Lévi, 1958	II	II
Sarcotragus foetidus Schmidt, 1862		II
Sarcotragus pipetta (Schmidt, 1868)		II
Spongia lamella (Schulze, 1879)	III	III
Spongia officinalis Linnaeus, 1759	III	III
Spongia zimocca Schmidt, 1862	III	III
Tethya aurantium (Pallas, 1766)		II
Tethya citrina Sarà & Melone, 1965		II

and natural habitats (1979), and the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (Annex II) of the Barcelona Convention (2013). The four Mediterranean commercially exploited bath sponges, *Hippospongia communis*, *Spongia lamella*, *S. officinalis* and *S. zimocca*, appear on the lists of species whose exploitation is regulated (Annex III of the above conventions). Nevertheless, the criteria according to which sponges were assigned to the above lists are unclear, while some of these species are very common and no data indicating decline of their populations exist for any Mediterranean ecoregion (Pronzato, 2003). At the same time, most endemic and rare species are absent from these lists.

Sponge populations in the Aegean Sea have been known since the Greek antiquity (Voultsiadou, 2007; Voultsiadou *et al*., 2017). With more than 230 species recorded so far (Topaloğlu and Evcen, 2014; Voultsiadou *et al*., 2016), the sponge fauna of the Aegean ecoregion (*sensu* Spalding *et al*., 2007) is the best-studied in the Eastern Mediterranean and one of the most thoroughly studied in the Mediterranean Sea (Coll *et al*., 2010). The characteristics of this ecoregion include the presence of endemic sponge species (Voultsiadou *et al*., 2016 and references therein), whose populations have not been adequately studied. On the other hand, available historical and current data indicate that the bath sponge populations of the Aegean ecoregion exhibit substantial declining trends (Voultsiadou *et al*., 2013). The experience from the Aegean Sea could serve as a reference for assessing the conservation status of sponges for two further reasons: a) it is one of the few regions with available time-series on sponge fisheries, having been the cradle of this practice since antiquity, b) recent marine spatial and conservation planning initiatives have highlighted protected sponge species as important biodiversity features and examined their distribution and population status in this area (Katsanevakis *et al*., 2017; Sini *et al*., 2017).

An attempt is made herein a) to evaluate the extinction risk of the already protected/threatened and endemic sponge species in the Aegean ecoregion, based on the IUCN Red List criteria; and b) to identify threats relevant to sponges in this ecoregion since such information could be critical for future conservation status assessments. The present assessment may serve as a baseline for future evaluations of sponge conservation status.

Methods

Scope and criteria of the assessment

The regional conservation status of 20 sponge taxa (9% of the Aegean sponge fauna) was assessed. Specifically, we examined: i) all species included in Annex II of the Bern and Barcelona conventions (Table 1), except for *Lycopodina hypogea*, which has not been recorded from the Aegean ecoregion so far, ii) the four bath sponge species (Annex III of the Barcelona Convention), and iii) seven species with a limited distribution range, endemic to the study area: *Axinyssa michaelis*, *Coscinoderma sporadense*, *Hemiasterella aristoteliana*, *Hymedesmia anatoliensis*, *Ircinia paucifilamentosa*, *Phorbas posidoni*, and *Topsentia vaceleti*. Although focusing on the Aegean ecoregion, this assessment actually covers the global –so

far known– distribution range of the endemic species and the main distribution area of the four Mediterranean bath sponge species. The protected species *Aplysina aerophoba* and *A. cavernicola* were considered as one taxon in this assessment (*Aplysina* spp.), due to their questionable distinction in the Aegean ecoregion (Voultsiadou-Koukoura, 1987; authors' unpublished data).

The assessment was made following the IUCN Red List Categories and Criteria (IUCN, 2012b) and the guidelines for application of the IUCN Red List Criteria at regional and national levels (IUCN, 2012a). All species were evaluated against 5 criteria in such a way that meeting any of those criteria qualified a species for listing at a specific level of threat. Only the criteria for the highest category of threat that the taxon qualifies were listed (IUCN-SPSC, 2014). The five criteria are: A, Declining population (past, present or projected); B, Geographic range size, fragmentation and decline; C, Small population size and fragmentation, decline; D, Very small or isolated population; E, Probability of extinction based on modelling estimations. These criteria were applied in the case of Aegean sponges as follows:

Criterion A: population trends

Different sources were reviewed for information on the population trends of the 20 examined taxa through time, revealing a general lack of quantitative data, except for the commercial bath sponges. Landings of bath sponges from 1970 to 2014 (in tonnes of processed product) were used as a proxy for their population abundance in the Aegean Sea (see sub-section "Population trends in commercial bath sponges" for documentation and description of the approach). Data was acquired from the General Fisheries Commission for the Mediterranean (GFCM) through the Food and Agriculture Organisation (FAO) database (FAO-GFCM, 2016). Since all commercial varieties are listed collectively under the broad category "Sponges" in the dataset, no species-specific information could be extracted. Additional data regarding Aegean sponge production for the years 1948 through 1964 were retrieved from Bernard (1987).

Criterion B: geographic range

A considerable amount of data on the distribution of the species included in Annex II of the Barcelona Convention was derived from the dataset of the MARISCA project (Sini *et al*., 2017); this includes data retrieved from scientific and grey literature, new records collected through an extended underwater survey in the Aegean Sea, interviews with SCUBA divers (records were verified by the authors), and online databases. This information was enriched with field data collected by the authors, as well as with bibliographic information on the adjacent Aegean coasts of Turkey. For the remaining species, we performed an exhaustive review of the existing literature sources. Complementary data was derived from unpublished scientific sources (i.e. observations by the authors within the framework of previous research projects and participation in commercial sponge fishing trips) and online web-sources and databases (e.g. GBIF). To estimate temporal trends in research effort and/or potential changes in distribution range of the studied sponges, occurrence records for each species were ranked according to 4 chronological periods: 1900-1970, 1971-1990, 1991-2010 and 2011-today. The collected information was digitized and organized under a common coordinate reference system (WGS 84) to produce distribution maps. All maps were created using QGIS 2.8.1 Software.

Criteria C, D and E: Small population size and quantitative analysis

Actually, no information was available to apply these criteria to the species studied since population dynamics (e.g. number of mature individuals and rate of population decline), as well as the possibility of having very small areas of occupancy, are hardly measurable parameters for sponges, given their biological characteristics and the lack of models for estimating extinction probability.

Identification of threats

During our survey, we collected information on threats relevant to sponges in the Aegean ecoregion using all literature sources reviewed for sponge occurrence data. Furthermore, while diving in several areas of the Aegean ecoregion during the last decade, within the framework of previous research projects, we came across numerous sponge necrosis incidences. These incidences are recorded herein since such information could be critical for future conservation status assessments, given the current lack of relevant data from the Aegean ecoregion.

Results and Discussion

Species distribution patterns

A total of 1529 occurrence records were collected for the 20 sponge taxa (Figs. S1-S20 and Table 2), spanning across the entire Aegean ecoregion and corresponding to different time periods (Fig. 1). These records included unpublished *in situ* observations by the authors within the last decade (49%), data from scientific literature sources (42%), citizen science records (7%), and web sources (2%) (Fig. 2). The most numerous occurrence data were available for the sponges *Aplysina* spp. (441), *Sarcotragus foetidus* (435), *Axinella cannabina* (213) and *Spongia officinalis* (100). All other species had less than 100 records, with 9 of them having less than 10 records (Table 2).

The depiction of species distributions revealed a higher number of occurrence records for particular species in certain areas, as well as spatial information gaps. For instance, *Tethya aurantium* and *T. citrina* were mainly

Table 2: Distribution patterns, population trends, threats, and regional extinction risk assessment for the 20 examined sponge taxa. Number of records: SL, Scientific literature; Un, Unpublished scientific data; CS, Citizen science records; WS, Data from web sources. Habitats: R, Rocky beds; S, Soft substrata; P, *Posidonia* meadows; Cr, Coralligenous; Rh, Rhodolith beds; Ca, caves and overhangs; H, Hydrothermally active areas. Threats and observed necrosis: Sh, Sponge harvesting (Voultsiadou *et al*., 2011); Tr, Trawling (Voultsiadou-Koukoura, 1986); Net, Fishing nets (authors, pers. observ.); Ga, Gagava (Kefalas *et al*., 2003b; Kefalas and Castritsi-Catharios, 2007; 2012); La, Lagamna (Kefalas *et al*., 2003a); Gn, Ghost-nets (authors, pers. observ.); Ne, necrosis (authors, pers. observ.). Data quality for current population trend: Sus, Suspected; Inf, Inferred. IUCN Red List categories: DD, Data Deficient; LC, Least Concern; EN, Endangered. Criteria: A2, Population reduction; B1, Geographic range. Authors' personal observations were made by Thanos Dailianis, Vasilis Gerovasileiou and Maria Sini.

Sponge taxa	Number of records				Bathymetric distribution (m)	Habitat	Threats and observed necrosis	Current population trend / Data quality	Regional assessment (criterion)
	SL	UN	CS	WS					
Aplysina spp.	95	273	67	6	0-280	R, S, P, Cr, Rh, Ca	Tr, Ga, La, Gn, Ne	Stable / Sus	LC (B1)
Axinella cannabina (Esper, 1794)	63	91	46	13	0-160	R, S, P, Cr, Rh, Ca, H	Tr, Net, Ga, Gn, Ne	Stable / Sus	LC (B1)
Axinella polypoides Schmidt, 1862	28	11		5	0-280	R, S, Rh, Ca	Tr, Ga, Gn, Ne	Stable / Sus	LC (B1)
Axinyssa michaelis Kefalas & Castritsi-Catharios, 2007	1				35-75	Rh	Ga	Unknown	DD
Coscinoderma sporadense Voultsiadou-Koukoura, van Soest & Koukouras, 1991	7				3-40	R, Cr, Ca	-	Unknown	DD
Geodia cydonium (Linnaeus, 1767)	69	16			0-270	R, S, P, Cr, Rh, Ca, H	Tr, Ga, La, Gn	Stable / Sus	LC (B1)
Hemiasterella aristoteliana Voultsiadou-Koukoura & van Soest, 1991	2				12-22	R, Ca	-	Unknown	DD
Hippospongia communis (Lamarck, 1814)	49	11			0-85	R, S, P, Cr	Sh, Tr, Ga, La, Gn, Ne	Decreasing / Inf	EN (A2)
Hymedesmia anatoliensis Gözcelíoglu, Van-Soest, Alvarez & Konuklugíl, 2015	1				10-30	R, S	-	Unknown	DD
Ircinia paucifilamentosa Vacelet, 1961	8				1-40	R, Ca	-	Unknown	DD
Petrobiona massiliana Vacelet & Lévi, 1958	1	1			0-12	Ca	-	Unknown	DD
Phorbas posidoni Voultsiadou-Koukoura & van Soest, 1991	1				30	S	Tr	Unknown	DD
Sarcotragus foetidus Schmidt, 1862	120	315			0-230	R, S, P, Cr, Rh, Ca, H	Tr, Net, Ga, La, Gn, Ne	Stable / Sus	LC (B1)
Sarcotragus pipetta (Schmidt, 1868)	1				30	R	-	Unknown	DD
Spongia lamella (Schulze, 1879)	16	3			0-110	R, S, P, Cr, Rh	Sh, Tr, Ga, Gn, Ne	Decreasing / Inf	EN (A2)
Spongia officinalis Linnaeus, 1759	89	21			0-150	R, S, P, Cr, Rh, Ca, H	Sh, Tr, Ga, La, Gn, Ne	Decreasing / Inf	EN (A2)
Spongia zimocca Schmidt, 1862	13	4			5-110	R, S, P, Cr, Rh	Sh, Ga, La, Ne	Decreasing / Inf	EN (A2)
Tethya aurantium (Pallas, 1766)	50	2			0-150	R, S, P, Rh, Ca	Tr, La, Gn	Stable / Sus	LC (B1)
Tethya citrina Sarà & Melone, 1965	28	1			0-150	R, S, P, Rh	Tr, Net, La, Gn	Stable / Sus	LC (B1)
Topsentia vaceleti Kefalas & Castritsi-Catharios, 2012	1				70	Rh	Ga	Unknown	DD

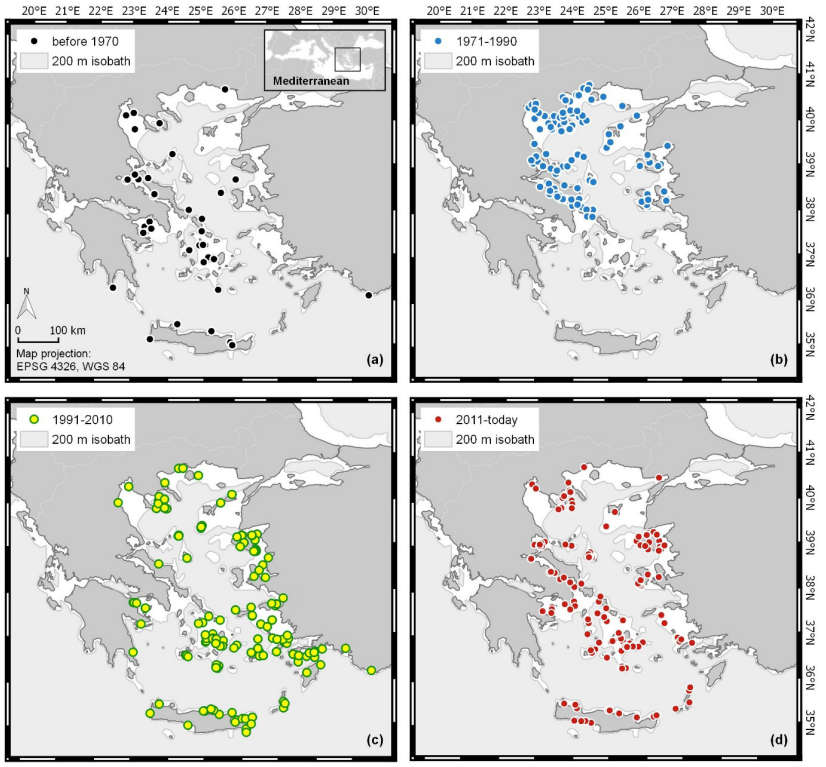

Fig. 1: Occurrence of the 20 examined sponges across the Aegean ecoregion recorded in the periods 1900-1970 (a), 1971-1990 (b), 1991-2010 (c), and 2011-today (d).

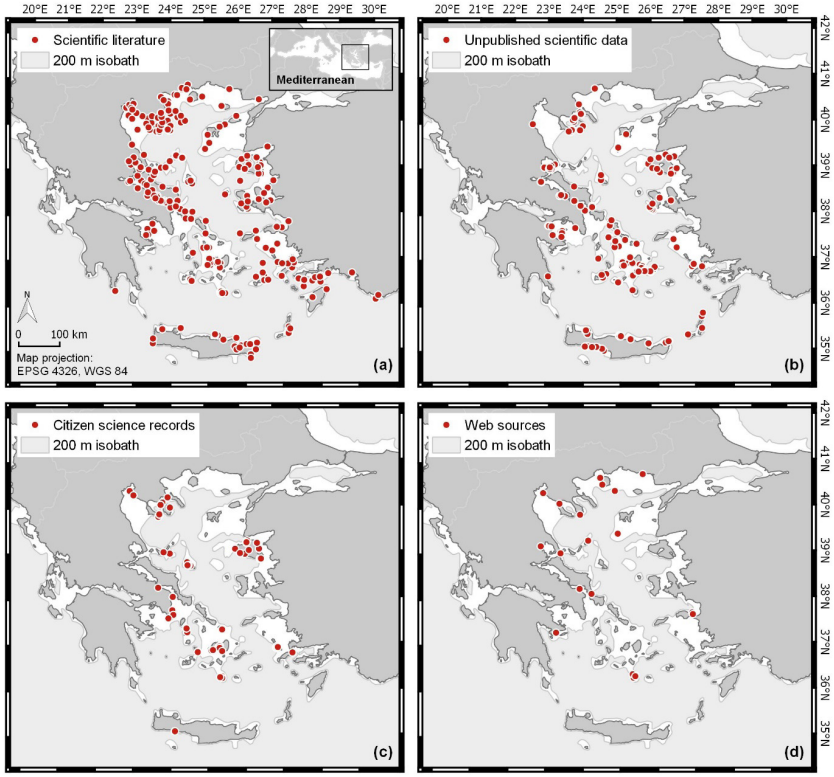

Fig. 2: Occurrence records of the 20 examined sponges across the Aegean ecoregion according to data from the scientific literature (a), unpublished scientific data (b), citizen science records (c), and web sources (d).

reported from large, semi-enclosed bays in the North Aegean Sea, while the bath sponges *Spongia lamella* and *S. zimocca* were mainly distributed in the South-eastern Aegean.

Most occurrence records were from depths shallower than the 200 m isobath (Figs. 1-2 and S1-S20), thus highlighting the limited knowledge on the deep-sea sponge fauna of the Eastern Mediterranean. This gap is further augmented by the fact that most records were obtained from the depth zone that is accessible to conventional SCUBA diving (0-40 m), while deeper records were obtained mostly from trawling, which is limited to soft bottom habitats. Thus, deep coralligenous formations and mesophotic reefs, which may potentially host rich sessile assemblages, remain largely unstudied.

At the temporal scale, more than half of the total species occurrences (53%) were recorded during the current decade (2011-today) (Fig. 1). Approximately 4% of the overall occurrences were recorded before 1970. Thereafter, there was an increase in research effort, as the number of records reported in 1971-1990 and 1991-2010 doubled compared to the previous periods. Recent records exist for most of the examined sponges, except for few Aegean endemics and the protected sponge *Sarcotragus pipetta*.

Population trends in commercial bath sponges

Since temporal variation in sponge assemblages has rarely been considered in sponge monitoring (Bell *et al.*, 2017), we were able to derive quantitative data on population trends only for commercial bath sponges. Although bath sponges constitute an important natural resource, their population characteristics and dynamics are effectively unknown (Pronzato and Manconi, 2008). Bath sponge stocks used to be very abundant in particular sub-regions of the Mediterranean, such as the Aegean Sea, the Adriatic, and the southern Central Mediterranean (von Eckhel, 1873). However, existing data suggest a persistent declining trend in the Mediterranean, and in the Aegean Sea in particular, for the greatest part of the 20th century (Fig. 3). This trend has been documented in detail for the Aegean by Voultsiadou *et al*. (2011; 2013), and is attributed to continuous, unregulated harvesting pressure. After 1986, the decline became severe in the Aegean, following the first of a series of recurring mass mortality events (Rivetti *et al*., 2014). Landings data analysed and presented herein (Fig. 3) show that sponge harvesting in the Aegean diminished thereafter, dropping from an average annual production of 88.9 tonnes between 1948 and 1986 down to 7.1 tonnes between 1987 and 2014.

Lacking any extended series of monitoring data, landings datasets are currently the only reliable proxy for the assessment of commercial sponge population data. Global demand for Mediterranean bath sponges –even as a niche luxury product nowadays– has not diminished, although prices have substantially increased due to the decrease in production (Pronzato, 1999). Since the 1986 decline, the crews of the remaining active sponge-fishing vessels cover multiple sub-regions of the Aegean during a single year's trip, effectively screening all known bath sponge stocks available for potential exploitation (Voultsiadou *et al*., 2011 and authors' pers. observ.). A decline in the commercial sponge stocks is further supported by the results of a recent experimental sponge fishery survey covering an extended part of the Aegean Sea (Anonymous, 2008); in this survey, out of the 92 locations selected, based on the presence of rich sponge banks in the past, bath sponges even in modest abundances (i.e. more than 10 individuals per hour of diving) were found at only 17 locations. Hence, the documented decline in sponge

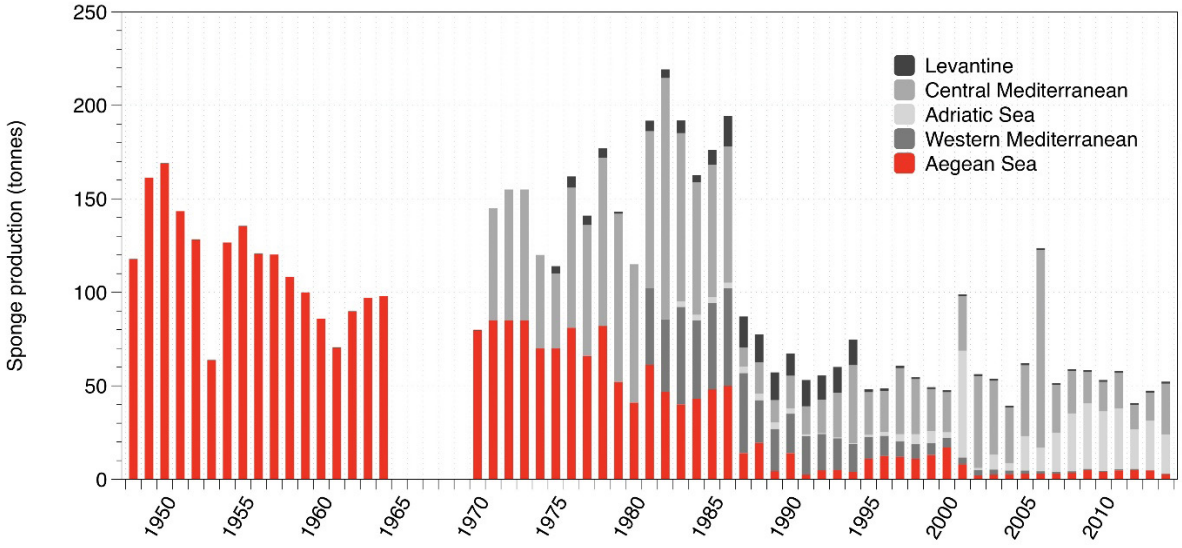

Fig. 3: Landings of bath sponges (in tonnes of processed product) from different Mediterranean regions. Data retrieved from Bernard (1987) for the years 1948 to 1964 and FAO-GFCM (2016) for the years 1970 to 2014.

production cannot be fully attributed to reduced fishing pressure but reflects the declining trend of their stocks and, thus, can be used as a surrogate for stock abundance, at least in the Aegean ecoregion. Nevertheless, two main limitations should be taken into account when considering commercial sponge landings data: i) No species-specific information is included in the landings datasets, and there is no safe way to assess differential trends; however, it is safe to assume that data cover all commercial types. Judging from the current population composition on the Aegean sponge beds (Voultsiadou *et al.*, 2011), *S. officinalis* and *Hippospongia communis* should be considered as the main species, followed by *S. lamella* and –to a lesser extent– *S. zimocca*; ii) Landings data refer to the weights of the processed sponge product. In this way, the total biomass of the catch is underestimated, since a processed sponge weighs only a fraction of the live specimen. It is not possible, however, to estimate the numbers of harvested individuals or size distribution, both of which would be essential for an actual population assessment.

Concerning Criteria D and C, the generation length is difficult to assess accurately for Mediterranean bath sponges, due to the absence of fundamental information regarding their life history parameters. Although clonal reproduction via fragments or budding is a typical reproduction mode for some sponges (Maldonado and Riesgo, 2008), this is not common for bath sponges (Dailianis *et al*., 2012). This suggests sexual reproduction as the main path for proliferation and dispersal of Mediterranean bath sponges. Data on aspects of sexual reproduction have been reported only for *S. officinalis* (Baldacconi *et al*., 2007; Gaino *et al*., 1984) and *H. communis* (Zarrouk *et al*., 2013). However, age of sexual maturity has not been determined for Mediterranean bath sponges, but has been found to be strongly size-dependent in the Pacific commercial dictyoceratid *Coscinoderma mathewsi* (Lendenfeld, 1886) (see Abdul Wahab *et al*., 2012); in that case, a size of ca. 1250 cm^3 was found to be the threshold to sexual maturity, corresponding to an individual roughly 10 cm in diameter. If this trait applies to Mediterranean bath sponges as well, it would correspond to a reproductive age of approximately four years (minimum) according to the estimations of Corriero *et al.* (2014). This, combined with the consecutive reproductive events every year, would suggest a short generation length, but this is an assumption that should be supported by actual empirical data.

Identified threats and observed necrosis

Besides targeted sponge harvesting, which affects the four bath sponge species, other activities and potential threats were identified in the course of our study. Among the 20 examined sponges, 14 have been reported as bycatch of fishing activities using different types of gear (Table 2); specifically, 11 with trawls and fishing nets, 11 with the dragged sponge/bivalve fishing gear "gagava", and 8 with the scallop dredging gear "lagamna". Additionally, our underwater observations in various areas of the Aegean Sea revealed that 10 of the assessed sponges had suffered smothering due to entanglement in nets (Table 2 and Fig. 4a-b). Fishing activities and smothering are among the threats most frequently reported to affect sponge assemblages in European seas (Gerovasileiou *et al*., 2017). It is expected that erect sponges, having an arborescent (e.g. *Antho* spp., *Axinella* spp. and *Raspailia* spp.), massive/tubular (e.g. *Aplysina* spp.) or stalked shape (e.g. *Phakellia* spp.) are more vulnerable to entanglement in nets, while species growing on soft sediments (e.g. *Geodia* spp. and *Suberites* spp.) are more exposed to trawling activities.

Moreover, 8 of the species assessed in this study, as well as the species *Agelas oroides* (Schmidt, 1864), *Calyx nicaeensis* (Risso, 1826), *Chondrosia reniformis* Nardo, 1847, *Ircinia variabilis* (Schmidt, 1862), *Petrosia ficiformis* (Poiret, 1789), and *Sarcotragus spinosulus* Schmidt, 1862 have been recorded to present partial or total necrosis (Tables 2 and 3). The main events in which a considerable number of individuals were observed to be affected by partial or total necrosis are summarized in Table 3. These observations were made during the last decade and span across a broad geographical range within the Aegean ecoregion, from the southernmost Island of Kriti to the mainland coasts of the North Aegean Sea. Necrosed sponges belong to 8 species of massive or massive/tubular growth forms and were observed both on exposed rocky reefs and in sheltered habitats, such as crevices and caves (Fig. 4c-d). Recent studies acknowledge that the frequency of mass mortality events and disease outbreaks of benthic invertebrates has increased during the last decade in the Mediterranean Sea, triggered by a rise in water temperature (Rivetti *et al.*, 2014), severely affecting sponge populations among other (Cebrian *et al*., 2011; Voultsiadou *et al*., 2011).

Within the last years, along with commercial bath sponges, sponge fisheries have started targeting the species *C. reniformis* and *Dysidea avara* (Schmidt, 1862), which are not protected under any legislative framework and are being intensively collected and traded for biotechnological use in some parts of the Aegean ecoregion (pers. comm. with sponge divers). No data on the population status of these species are available to date and their exploitation is not being reported or regulated. Additionally, some of the taxa which were considered in this study (e.g. *Aplysina* spp., *Axinella* spp., and *Sarcotragus* spp.) are likely to attract commercial interest for the biotechnology industry (Voultsiadou *et al*., 2008). However, no data regarding their current population status are available for the Aegean; thus, it is not possible to forecast potential future decline due to exploitation.

Suggested conservation status

The evaluation of species distribution data and population trends described above provides a basis for regional

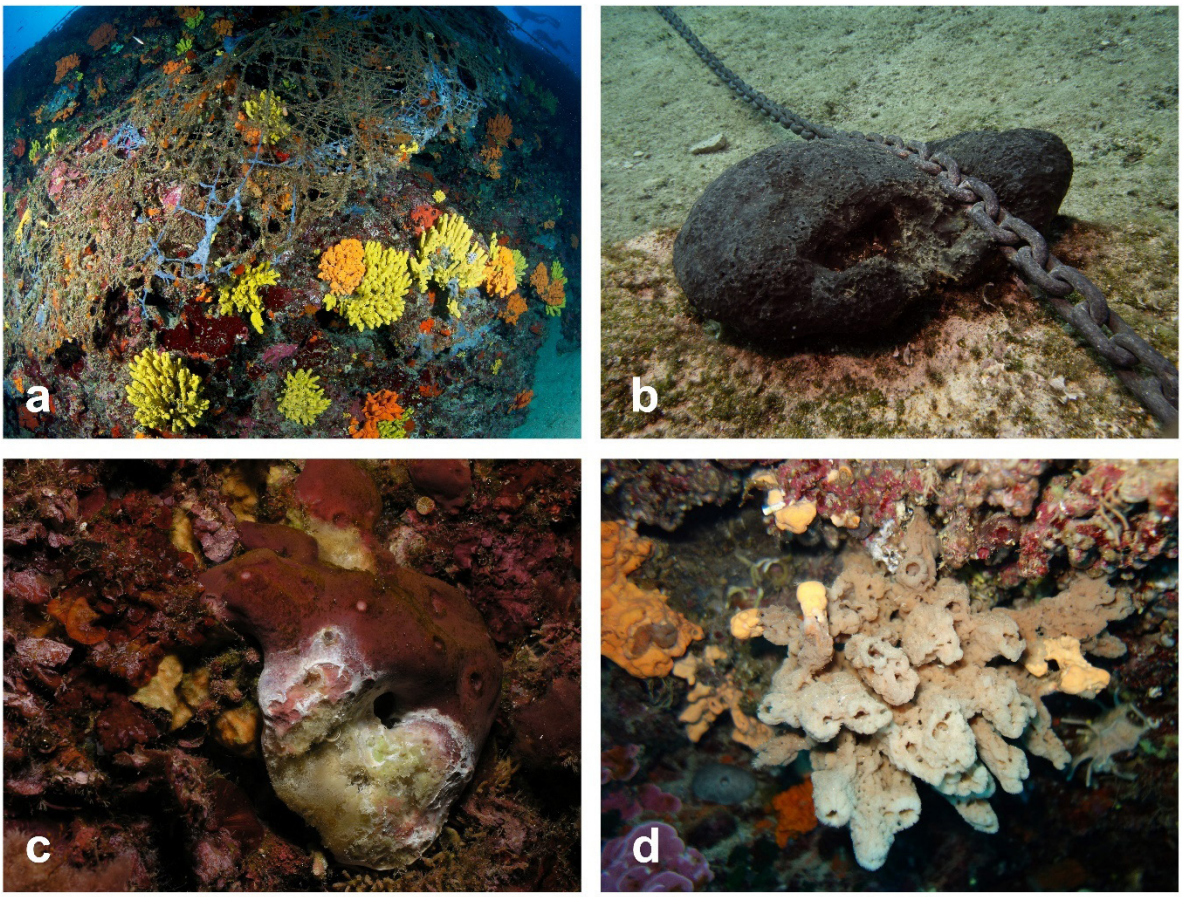

Fig. 4: Smothering of the massive and erect sponges *Agelas oroides* and *Aplysina aerophoba* caused by fishing nets (a) and the sponge *Sarcotragus foetidus* caused by an anchoring chain (b). Necrosis of the sponges *Petrosia ficiformis* (c) and *A. oroides* (d) in Greek Aegean waters. Photos by Thanos Dailianis (a-c) and Vasilis Gerovasileiou (d).

assessment of the examined sponge species in the Aegean Sea. Seven of the examined sponges, namely *Aplysina* spp., *A. cannabina*, *A. polypoides*, *Geodia cydonium*, *S. foetidus*, *T. aurantium* and *T. citrina*, had a considerable number of records distributed across the entire Aegean ecoregion (see Supplementary material). Thus, they were assigned to the LC category (Table 2) due to their broad geographical range and the absence of serious threats, which could drive the species to extinction in the short term.

The limited information on the distribution of Aegean endemics points to a DD assessment status. Of these, the species *A. michaelis*, *H. aristoteliana*, *H. anatoliensis*, *P. posidoni* and *T. vaceleti* have not been recorded since their first finding and taxonomic description. The species *I. paucifilamentosa* has been recorded at only 8 localities across the entire Aegean ecoregion. On the other hand, *C. sporadense* has been reported from only 7 localities (Table 2 and Fig. S5), thus fulfilling condition (a) of the B1/B2 criteria and one of the conditions (severely fragmented or ≤ 10 locations), within a marine area of approximately 20,000 km² (i.e. threshold in extent of occurrence according to criterion B1), indicating a candidate species for a threatened category. However, the lack of data regarding the potential decline/extreme fluctuations (conditions b and c, respectively) in extent of occurrence, area of occupancy, number of locations or subpopulations and number, inhibited such an assignment and it was classified as DD. The rarely reported species *S. pipetta* and *Petrobiona massiliana* (<8 records each), were also classified as DD. The quantitative data derived on the population trends for the harvested bath sponges indicate that all four species (*H. communis*, *S. lamella*, *S. officinalis* and *S. zimocca*) should be evaluated as Endangered (Table 2). This is because they have suffered a massive reduction in population size, which may not have ceased and/or be irreversible, based on landings as a proxy for their abundance and actual levels of exploitation (criterion A2).

Knowledge gaps and suggestions on sponge conservation status assessments

Constraints about the taxonomic identification of sponges and/or sampling bias (e.g. “short-range endemics”) are important challenges hindering conservation status assessments (Bell *et al*., 2015 and references

Table 3: Main necrosis events observed in the Aegean ecoregion within the last decade (Thanos Dailianis, Vasilis Gerovasileiou and Maria Sini pers. observ.; Elina Samara pers. comm.).

Period	Locality	Coordinates	Depth	Species affected	Number of individuals affected andpercentage of sponge necrosis (when available)
October 2007	Elounda, Kriti Island, South Aegean Sea	35.253° N, 25.760° E	5-10 m	*Petrosia ficiformis* *Sarcotragus foetidus*	>10 individuals; up to 80% necrosis
September 2008	Karpathos Island, South Aegean Sea	35.541° N, 27.221° E	10-20 m	*Sarcotragus foetidus* *Sarcotragus spinosulus*	>10 individuals; recovery from partial necrosis
June-July 2010	Akti Kalogrias, Chalkidiki Peninsula, North Aegean Sea	40.175° N, 23.714° E	5-30 m	*Agelas oroides* *Chondrosia reniformis* *Ircinia* spp. *Petrosia ficiformis* *Sarcotragus foetidus*	>30 individuals; up to 100% necrosis
September 2014	Lasithi, Kriti Island, South Aegean Sea	35.303° N, 26.313° E	30-10 m	*Calyx nicaeensis* *Ircinia variabilis* *Sarcotragus foetidus* *Sarcotragus spinosulus*	>10 individuals; partial necrosis up to 60% and recovery from partial necrosis
May 2016	Keros Island, Kyklades Archipelago, South Aegean Sea	36.887° N, 25.683° E	0-25 m	*Chondrosia reniformis* *Sarcotragus foetidus*	>10 individuals; up to 90% necrosis
June 2016	Antiparos, Kyklades Archipelago, South Aegean Sea	36.955° N, 25.078° E	5-25 m	*Agelas oroides* *Chondrosia reniformis*	>10 individuals; partial necrosis
June 2016	Milos Island, Kyclades Archipelago, South Aegean Sea	36.710° N, 24.545° E	5 m	*Sarcotragus foetidus*	>5 individuals; partial necrosis
June 2016	Glaronissi Island, North Evvoikos Gulf, North Aegean Sea	38.522° N, 23.391° E	5-10 m	*Aplysina aerophoba*	5 individuals; up to 80% necrosis
June 2016	Eglezonissi Island, North Evvoikos Gulf, North Aegean Sea	38.500° N, 23.499° E	5 m	*Aplysina aerophoba*	3 individuals; 100% necrosis
June 2016	Skala, Lichadonissia, North Evvoikos Gulf, North Aegean Sea	38.804° N, 22.835° E	5-15 m	*Aplysina aerophoba* *Chondrosia reniformis*	>5 individuals; partial necrosis
June 2016	Agia Vasso, Pelion Peninsula, North Aegean Sea	39.086° N, 23.112° E	0-6 m	*Aplysina aerophoba*	31 individuals; up to 80% necrosis
June 2016	Fidonissi, Kavala Gulf, North Aegean Sea	40.865° N, 24.346° E	5 m	*Aplysina aerophoba*	>10 individuals; partial necrosis
July 2016	Cathedral Cave, Chania, Kriti Island, South Aegean Sea	35.550° N, 24.069° E	13-15 m	*Agelas oroides*	>10 individuals; up to 100% necrosis
July 2016	South Chios Island, North Aegean Sea	38.240° N, 25.872° E	5-15 m	*Sarcotragus foetidus*	>10 individuals; >50% necrosis
May 2017	Alykes, Kriti Island, South Aegean Sea	35.416° N, 24.988° E	5-20 m	*Agelas oroides*	>10 individuals; up to 100% necrosis

therein). For instance, the carnivorous sponge *L. hypogea*, which is currently listed as protected in the relevant legislation (Table 1), was initially described from a single cave with deep-water affinities in Southern France (Vacelet and Boury-Esnault, 1996). However, further research revealed that this species had a wide distribution across the Mediterranean and North-eastern Atlantic (Bakran-Petricioli *et al*., 2007; Chevaldonné *et al*., 2015). Similarly, the sporadic records of the Aegean endemics could be related not only to their rarity but also to the limited research invested in certain marine areas and types of habitats. The recent findings of the Aegean endemics *C. sporadense* and *I. paucifilamentosa* in marine caves and coralligenous habitats (Gerovasileiou and Voultsiadou, 2012; Gerovasileiou *et al*., 2015; Sini, 2015) indicate that further exploration of understudied habitats could expand the known geographic and bathymetric distribution of some species and might modify their conservation status.

Underwater monitoring of species populations involves logistic constraints (e.g. high cost), especially in areas characterized by a lengthy coastline and complex seascape, such as the Aegean ecoregion. In this respect, the combination of satellite imaging analysis, for a rough classification of the main habitat types in shallow waters, with occupancy modelling based on data collected through dedicated surveys was recently suggested as a distribution surrogate for selected benthic species, including sponges, in data-poor regions (Katsanevakis *et al*., 2017). Moreover, citizen science initiatives could significantly contribute to the collection of occurrence data for easily identifiable species and observed threats (e.g. sponge necrosis). However, very few citizen science projects have included sponges so far, at least in the Mediterranean Sea (e.g. CIGESMED for Divers – Gerovasileiou *et al*., 2016; Observadores del Mar – http://www.observadoresdelmar.es/).

Regarding the sponge species of commercial interest (including bath sponges and newly targeted species with biotechnological potential), landings data can be a valuable source of information for the monitoring of species population trends over time, as indicated in this study, and their systematic collection should be further enforced and improved. Despite the limitations of landings or catch data as an indicator of abundance, in the absence of better information, such data can and should be used to infer stock status, at least tentatively; this has been common practice by fisheries researchers worldwide (Pauly, 2013). To improve the landings data, indication of species (variety type) and area of origin should be added to the provided information. Vessel Monitoring Systems (VMS) have also proved efficient in estimating fishing effort and pressure (e.g. Lee *et al*., 2010), besides enforcing spatial management regulations. The mandatory inclusion of VMS transmitters on sponge fishing vessels may be an effective measure both for regulation and acquisition of sponge fishery data, thus allowing the estimation of catch-per-unit-effort, which is a much better indicator of abundance.

Finally, the results of species assessments might differ according to geographical scope. For example, a given species that might be distributed throughout the Mediterranean basin could be threatened or simply less common at regional or local scale (e.g. *Aplysina* spp., *S. officinalis*). Therefore, conservation status assessments at both regional (e.g. ecoregions) and broader geographical scales (e.g. geographic provinces or realms) could safeguard successful protection. Future assessments should also focus on sponges susceptible to specific threats (e.g. trawling and disease outbreaks) and taxa expected to become of commercial interest to the biotechnology industry.

Supplementary data

Supplementary material is available in the online version of the manuscript.

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