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Sponges of economical interest in the Eastern Mediterranean: an assessment of diversity and population density

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The aim of this paper was to investigate diversity and population density of sponges with manifest or potential economical interest for the first time in the Eastern Mediterranean. For this purpose, the area of Dodecanese, an Aegean area traditionally harvested for sponges was surveyed for bath sponges and species known as sources of bioactive compounds. Twenty stations of diverse orientation, substrate inclination and type of substratum, located on seven islands, were surveyed and totally 36 demosponge species were found. The data, collected with a non-destructive method, were subjected to multivariate analysis which showed that sponge diversity was higher in areas with vertical cliffs. A considerable spatial variation was revealed by the formation of two groups of stations, according to sponge species presence/absence: one including vertical cliffs and a second one, including moderately inclined cliffs, *Posidonia* meadows and detritic biogenic bottoms. Bath sponges occurred at a restricted number of stations and although in relatively low population densities, they revealed a sign of recovery after the devastating epidemic events. Higher stock availability was found for six biotechnologically promising species which were distributed all over the study area. The above results are encouraging for a future sustainable stock exploitation and open a new perspective for sponge mariculture in the area.

Keywords: demosponges; diversity; population density; bath sponges; natural products; Aegean Sea

Introduction

Bath sponges have been harvested for commercial purposes since antiquity. The sponge market has been always very demanding and the production of sponges through fishing was never sufficient to satisfy demands (Verdenal and Verdenal 1987). The availability of Mediterranean commercial bath sponges was dramatically decreased by the depletion of natural banks due to both high fishing pressure and devastating epidemic events (Vacelet 1991; Pronzato 1999; Corriero et al. 2004; Castritsi-Catharios et al. 2005).

Research on marine natural products has expanded rapidly over the last 20 years. Several recent publications highlight the biotechnological significance of marine sponges (e.g. Takur and Müller 2004; Blunt et al. 2005). Sponge originated bioactive compounds are already in the market as pharmaceuticals or in the stages of clinical trials (Sipkema et al. 2005a). The growing interest to satisfy this demand has led to research on the feasibility, technical and economic potential of the various methods for producing sponge metabolites. Several common Mediterranean sponges

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with economic potential due to their bioactive products, such as species of *Acanthella*, *Agelas*, *Aplysina*, *Axinella*, *Cacospongia*, *Chondrosia*, *Crambe*, *Dysidea*, *Jaspis*, *Ircinia*, *Petrosia* and *Suberites*, have been tested for in situ or ex situ cultivation (Pronzato et al. 1999; Brümmer and Nickel 2003; Sipkema et al. 2005b). The absolute need for detailed ecological knowledge on the habitat conditions of the species designated for cultivation has been highlighted.

The absence of data about the density of wild sponge banks has been stressed by various authors (e.g. Vacelet 1991; Pronzato et al. 1999) and the need for studies focusing on the distribution and stock availability of both the traditional commercial and the biotechnologically promising species is obvious. Such studies can contribute, on one hand, to effective stock exploitation and conservation, and, on the other, to the investigation of possibilities for in situ or ex situ cultivation of suitable species.

Considering all the above, the purpose of the present work was to give a preliminary report of diversity and stock assessment of species with known or potential economic importance in the Dodecanese Archipelago. The Dodecanese, which has been traditionally harvested for bath sponges, is one of the less studied areas in the Aegean, since most of the islands have not, to date, been searched for sponges. To achieve this goal, the diversity and population density of bath sponges, as well as the most abundant among the species known as sources of bioactive compounds, were estimated inside the limits of the fishing grounds exploited by sponge fishermen in the area.

Materials and methods

Study area and sponge species

This work was conducted in the area of the Dodecanese located in the south Aegean (Figure 1), which is a distinct sub-area of the Aegean Sea due to its geographical, physical, chemical and biological characteristics (see Voultsiadou 2005a). As part of the south Aegean it receives the warm, salty Levantine Intermediate Water, carrying a limited supply of nutrients; its warm and saline, oligotrophic waters lead to a differentiation in the diversity and distribution of benthic organisms (Chintiroglou et al. 2005; Kontoyiannis et al. 2005; Voultsiadou 2005a; Zervakis et al. 2005, etc.). Seasonal CTD measurements (SBE19, Sea-Bird Electronics) at 11 stations around Astypalaia Island showed an annual temperature range of 16.2–23.6°C at 15 m of depth and 16–19.2°C at 50 m, while salinity was stable at 39 psu (authors' unpublished data). Accordingly, more to the south, on the coasts of Rhodes Island, Kontoyiannis et al. (2005) have given an annual temperature range of 17.7–27°C at the surface and 16.5–19.5°C at 50 m, the salinity being around 39 psu, according to measurements taken in 2003.

The sponges studied for their population density were the four commercial bath sponges *Spongia agaricina* Pallas, 1766, *S. officinalis* Linnaeus, 1759, *S. zimocca* Schmidt, 1862 and *Hippospongia communis* (Lamarck, 1814), as well as the common Aegean species, producing compounds of proven bioactivity, *Agelas oroides* (Schmidt, 1864), *Aplysina aerophoba* Schmidt, 1862, *Axinella cannabina* (Esper, 1794), *Dysidea avara* (Schmidt, 1862), *Ircinia fasciculata* (Pallas, 1766), *Petrosia ficiformis* (Poiret, 1798), *Sarcotragus foetidus* Schmidt, 1862.

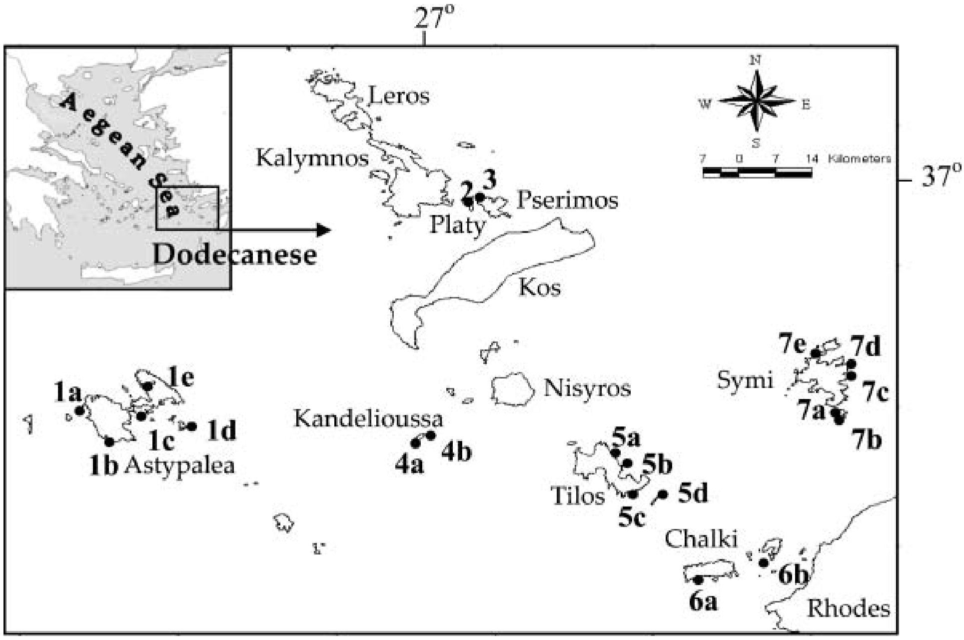

Figure 1. Dodecanese area showing sampling stations.

Data collection

For the purposes of the study, seven islands in the southern Dodecanese were surveyed. Twenty stations were selected along the coastlines of these islands (Figure 1), to cover the greatest habitat diversity, taking into account orientation, inclination, type of substratum in the bathymetric zone being exploited by sponge fishermen (Table 1). Sampling was carried out during summer 2004 and 2005 in depths between 15 and 50 m by one scientist and two sponge fishermen, the same every time, using SCUBA apparatus or the "nargileh" method by which air is provided through a compressor located on the boat, and more time for each dive is allowed.

At each station sampling involved a combination of in situ counting and underwater photography, during a 50 min dive. The method of randomly placed frames was employed to obtain numerical abundance data (Elliot 1971; Bakus 1990). Thus, the number of individuals contained in 10 frame samples, 1×1 m each, was recorded (Antoniadou et al. 2006).

Data analysis

From data collected, the population density for the 11 species under examination was estimated semiquantitatively (Uriz et al. 1992), according to an index of relative abundance ranging from 1 to 5 as follows: 1=present (relative abundance not estimated); 2=1–2 specimens/m^2; 3=3–5 specimens/m^2; 4=6–10 specimens/m^2; 5=>10 specimens/m^2. Qualitative samples were randomly collected to estimate sponge diversity; in this case the presence of sponge species at sampling stations is recorded without any population density estimation. The collected material was

Table 1. Description of sampling stations.

Station	Island	Coordinates	Orientation	Depth (m)	Substratum
1a	Astypalea	36°34′498″N 26°15′287″Å	W	20–50	vr
1b	Astypalea	36°30′459″N 26°19′856″E	W, SW	20–50	vr
1c	Astypalea	36°33′299″N 26°23′999″E	S	20–50	osr, p
1d	Astypalea	36°31′733″N 26°28′317″E	S, SE	20–35	vr
1e	Astypalea	36°36′702″N 26°23′481″E	SW	20–35	ir, p, d
2	Platy	36°57′102″N 27°05′471″E	W, SW	15–50	ir, p
3	Pserimos	36°57′418″N 27°06′891″E	N, NE	15–40	ir, p
4a	Kandelioussa	36°29′817″N 26°58′235″E	W, SW	25–40	vr
4b	Kandelioussa	36°29′817″N 26°58′235″E	W, SW	25–50	vr
5a	Tilos	36°26′747″N 27°23′390″E	N, NE	25–50	vr
5b	Tilos	36°25′717″N 27°23′715″E	N, NE	25–50	ir, d
5c	Tilos	36°23′298″N 27°25′735″E	S, SE, SW	25–50	ir, d
5d	Tilos	36°21′918″N 27°27′688″E	N, NE	30–50	vr
6a	Chalki	36°13′010″N 27°38′774″E	N, S, E	15–50	vr
6b	Chalki	36°21′918″N 27°27′688″E	N, S, E	12–50	osr, d
7a	Symi	36°31′238″N 27°51′041″E	S, SW	15–40	vr
7b	Symi	36°31′132″N 27°51′836″E	S, SE	12–50	ir, p, d
7c	Symi	36°36′303″N 27°52′824″E	S, SE	15–40	vr
7d	Symi	36°37′132″N 27°52′259″E	S, SW	12–50	ir, d
7e	Symi	36°38′106″N 27°48′983″E	N, NW	12–50	ir, d

Note: vr, vertical rock (80–90°); ir, inclined rock (50–80°); p, *Posidonia oceanica* meadow; d, detritic bottom; osr, open sea reef.

preserved in 10% formalin solution and identified down to species level in the laboratory.

Presence/absence data obtained per sampling station were analysed using hierarchical cluster analysis and multidimensional scaling techniques, based on the Bray-Curtis similarity measure, with the PRIMER package (Clarke and Warwick

1994). Significance of the multivariate results was assessed using ANOSIM testing. SIMPER analysis was applied in order to identify the percent contribution of each species to the overall similarity within a group of stations and the dissimilarity among groups. Also, the BIOENV procedure was used to examine which environmental parameters were related to the observed biotic pattern and the degree of this relation (Clarke and Warwick 1994). The parameters examined for this purpose were orientation, depth (stations were separated according to maximum depth into two categories: down to 35 m and down to 50 m), type of substratum, geographic location of stations. The same analyses were performed taking into account only the seven sponges with known bioactivity, as well as the four bath sponges, on the basis of the index of relative abundance.

Results

Samplings revealed the presence of 36 demosponge species in the surveyed area (Table 2, Figure 2). The sampling stations were classified in three groups according to sponge species richness: 1=high richness sites (number of species >70% of the total sponge species recorded), i.e. stations 1a, 1d and 5d; 2=intermediate richness sites (number of species between 40% and 70% of the total sponge species recorded), i.e. stations 1b, 1e, 2, 3, 4a, 4b, 5a, 5b, 6a, 6b, 7a, 7b, 7c, 7d, 7e; and 3=low richness sites (number of species <40% of the total sponge species recorded), i.e. stations 1c and 5c.

Hierarchical cluster and multidimensional scaling performed on the presence/absence matrix (Table 2) identified two main groups of stations at a similarity level of over 60%, whereas station 1c was placed alone at a similarity level of 35% with the two groups (Figure 3). This discrimination was confirmed by one-way ANOSIM test (global $R=0.87$ at a significance level of $p<0.001$). All stations with vertical hard substratum, i.e. rocky walls, were grouped together in group A. Stations characterized by *Posidonia oceanica* meadows together with inclined rocks and various soft sediment clusters (mostly coarse sand, gravel and biogenic bottoms) formed group B. The BIOENV procedure showed that bottom inclination was the factor most strongly related to the observed pattern ($Sr=0.722$), followed by the type of substratum ($Sr=0.6$). SIMPER analysis (Table 3) showed that the same nine species contributed around 53% to in-group similarity of group A and 68% to in-group similarity of group B. These species, practically appearing at all stations, were *I. fasciculata*, *P. ficiformis*, *P. tenacior*, *S. foetidus*, *A. oroides*, *A. cannabina*, *C. viridis*, *C. crambe* and *C. reniformis*. Moreover, 14 different species were responsible for about 70% dissimilarity between the two groups. Among these species, *S. domuncula* and *G. cydonium* were observed exclusively at stations of group B, while *A. polypoides* was observed only in stations of group A. The species *A. acuta*, *C. nicaeensis*, *D. fragilis* and *D. bistellata* were more frequently collected at stations of group A, with *D. avara* and *C. nucula* being more frequently collected at stations of group B (Table 2).

The four bath sponges were collected at a total of 10 stations (Table 2). *Hippospongia communis* and *S. officinalis* were the most abundant species, followed by *S. zimocca* and *S. agaricina*. The highest population density of *H. communis* and *S. officinalis* was observed at stations 1c, 5d and 6b, reaching 3–5 specimens/m^2 (Figure 2).

Table 2. Complete data matrix for all sponge species found in Dodecanese area.

Species	Relative abundance at sampling stations																			
	1a	1b	1c	1d	1e	2	3	4a	4b	5a	5b	5c	5d	6a	6b	7a	7b	7c	7d	7e
Aaptos aaptos (Schmidt, 1864)	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
Acanthella acuta Schmidt, 1862	1	1	0	1	0	1	1	1	1	1	0	0	1	1	0	1	0	1	0	0
Agelas oroides (Schmidt, 1864)	4	4	1	5	2	5	4	4	5	4	5	4	5	5	4	5	4	4	3	4
Aplysina aerophoba Nardo, 1843	0	0	0	0	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Axinella cannabina (Esper, 1794)	2	2	2	3	4	4	3	1	2	2	3	1	3	2	3	2	3	2	1	2
Axinella damicornis (Esper, 1794)	1	0	0	1	0	0	0	0	0	1	1	0	1	1	0	1	0	1	0	0
Axinella polypoides Schmidt, 1862	1	1	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	1	0	0
Axinella verrucosa (Esper, 1794)	1	0	0	1	0	0	0	1	0	0	0	0	1	0	1	1	0	1	0	0
Calyx nicaeensis (Risso, 1862)	1	1	0	1	0	1	1	1	0	1	0	0	1	1	0	1	0	1	0	0
Chondrilla nucula Schmidt, 1862	1	1	0	1	1	1	1	0	0	1	0	1	1	0	1	0	1	0	1	0
Chondrosia reniformis Nardo, 1847	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ciocalypta penicillus Bowerbank, 1864	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1
Cliona celata Grant, 1826	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Cliona viridis (Schmidt, 1862)	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Crambe crambe (Schmidt, 1862)	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Diplastrella bistellata (Schmidt, 1862)	1	1	0	1	1	1	1	1	1	0	0	1	1	1	0	1	0	1	0	0
Dysidea avara (Schmidt, 1862)	0	0	0	0	2	4	4	0	0	2	4	0	2	0	0	3	3	0	0	4
Dysidea fragilis (Montagu, 1818)	1	1	0	1	0	1	0	0	1	1	0	0	1	1	0	1	0	1	0	1
Geodia cydonium (Jameson, 1811)	0	0	1	0	1	1	1	0	0	0	1	0	0	0	1	0	1	0	1	1
Haliclona mediterranea Griessinger, 1971	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Hippospongia communis (Lamarck, 1814)	0	0	3	0	0	0	0	0	2	2	0	0	3	0	3	0	0	0	0	2
Ircinia fasciculata (Pallas, 1766)	3	2	0	2	3	2	2	2	2	2	2	3	3	2	1	2	2	2	3	3
Oscarella lobularis (Schmidt, 1862)	1	0	0	1	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1	0
Petrosia ficiformis (Poiret, 1798)	3	2	1	3	2	2	1	3	3	2	2	1	2	1	3	1	2	1	1	2

Table 2. Continued.

Species	Relative abundance at sampling stations																			
	1a	1b	1c	1d	1e	2	3	4a	4b	5a	5b	5c	5d	6a	6b	7a	7b	7c	7d	7e
Phorbas tenacior (Topsent, 1925)	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Raspailia viminalis Schmidt, 1862	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Sarcotragus foetidus Scmidt, 1862	3	3	0	3	2	2	2	3	3	3	3	3	3	2	3	2	3	3	2	3
Scalarispongia scalaris (Schmidt, 1862)	0	1	0	1	0	0	1	1	0	0	0	0	1	1	0	1	0	1	0	0
Spirastrella cunctatrix Schmidt, 1868	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Spongia agaricina Pallas, 1766	1	0	0	1	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0
Spongia officinalis Linnaeus, 1759	1	1	3	0	1	0	0	0	0	0	0	0	2	0	2	0	0	0	0	1
Spongia nitens (Schmidt, 1862)	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1
Spongia zimocca Schmidt, 1862	1	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1
Stryphnus mucronatus (Schmidt, 1868)	0	0	0	1	0	0	0	1	1	0	0	0	1	0	1	0	0	1	0	0
Suberites domuncula (Olivi, 1792)	0	0	1	0	1	1	1	0	0	0	1	0	0	0	1	0	1	0	1	1
Tethya aurantium (Pallas, 1766)	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0

Note: Coded abundances: 0=absent; 1=present (relative abundance not estimated); 2=1–2 specimens/m^2; 3=3–5 specimens/m^2; 4=6–10 specimens/m^2; 5=>10 specimens/m^2.

Considering the seven sponge species of known bioactivity, *A. oroides*, *A. cannabina*, *I. fasciculata*, *P. ficiformis* and *S. muscarum* were recorded at almost all sampling sites, and *D. avara* and *A. aerophoba* at nine and three stations, respectively (Table 2, Figure 2). Population density of *A. oroides* was generally high at almost all stations, often more than 10 specimens/m^2, whereas that of the other three species varied, reaching up to 10 specimens/m^2 for *A. cannabina* and *D. avara*, and up to 5 specimens/m^2 for *I. fasciculata*, *P. ficiformis* and *S. foetidus*.

Cluster analysis performed on the semiquantitative data for the 11 species did not show any meaningful grouping of the studied sites according to sponge diversity. However, the species were separated into two groups by cluster analysis performed on both semiquantitative and presence/absence data (Figure 4). This grouping reflects their diversity and stock availability in the different sampling areas. The three most common shallow water bath sponges (*S. officinalis*, *S. zimocca* and *H. communis*) were grouped together, while six of the species characterized by their bioactive compounds (*A. cannabina*, *A. oroides*, *D. avara*, *I. fasciculata*, *P. ficiformis* and *S. foetidus*) formed a separate group, in both cases at a similarity level of almost 55%. The species *A. aerophoba* and *S. agaricina*, which were seldom observed, were separated from the two groups.

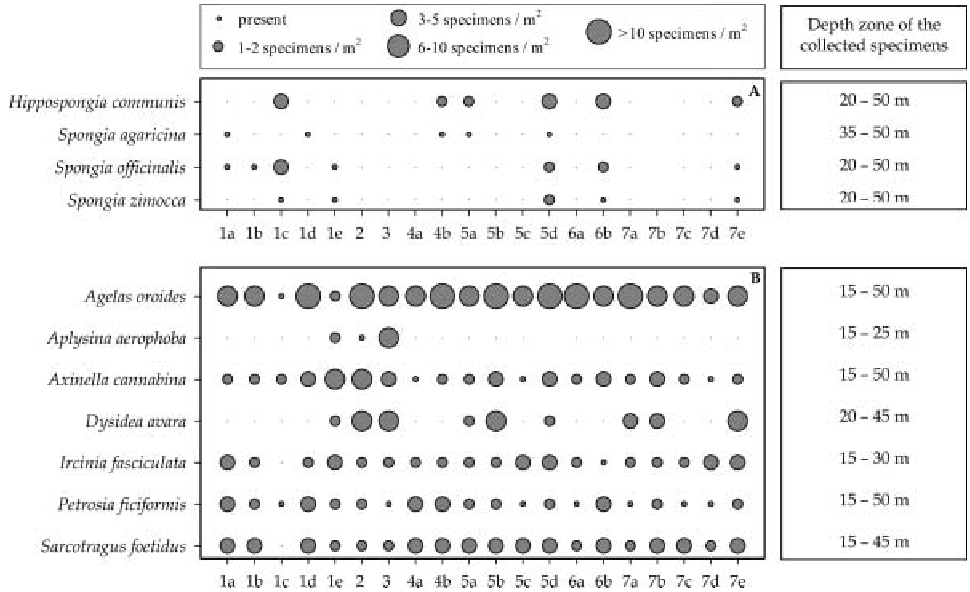

Figure 2. Bubble plot illustrating the population density of the 11 sponge species at each sampling station, and the depth zone in which the specimens were recorded.

Discussion

Studies on sponge diversity and distribution in the Eastern Mediterranean revealed the presence of 200 demosponge species recorded to date from the Aegean Sea (Voultsiadou 2005b), with only 52% having a confirmed presence in the southern sector (Voultsiadou 2005a). According to the latter publication, an apparent dissimilarity has been shown between the north and the south Aegean, on the basis of their sponge fauna, with the latter being closer, in terms of demosponge diversity, to the oligotrophic Levantine Sea; however, the number of species recorded in the two areas was positively correlated with the number of studies, thus indicating a lack of research activity in the southern part of the Aegean.

Concerning the diversity and distribution of demosponges in the Dodecanese, very restricted information has been given in fewer than 10 publications (e.g. Pansini et al. 2000; Kefalas et al. 2003), whereas practically no data exist on the population density and stock availability of sponges. The present survey of seven islands of the Dodecanese complex revealed the presence of 36 demosponges, 35 of which are common Mediterranean species, previously reported from the Aegean Sea (Voultsiadou 2005a). The Atlanto-mediterranean species *C. penicillus* which had been found on the coasts of Egypt and Israel was reported for the first time as an element of the Aegean fauna.

Species diversity was generally higher on vertical cliffs, thus strengthening the observations of other authors who attributed this preference to the sedimentation constraint, along with the constructive effect of reduced light conditions (Glasby 1999; Pansini et al. 2000; Bell and Smith 2004; Antoniadou et al. 2006). Faunistic similarity was generally high among the studied sites, with the exception of the very

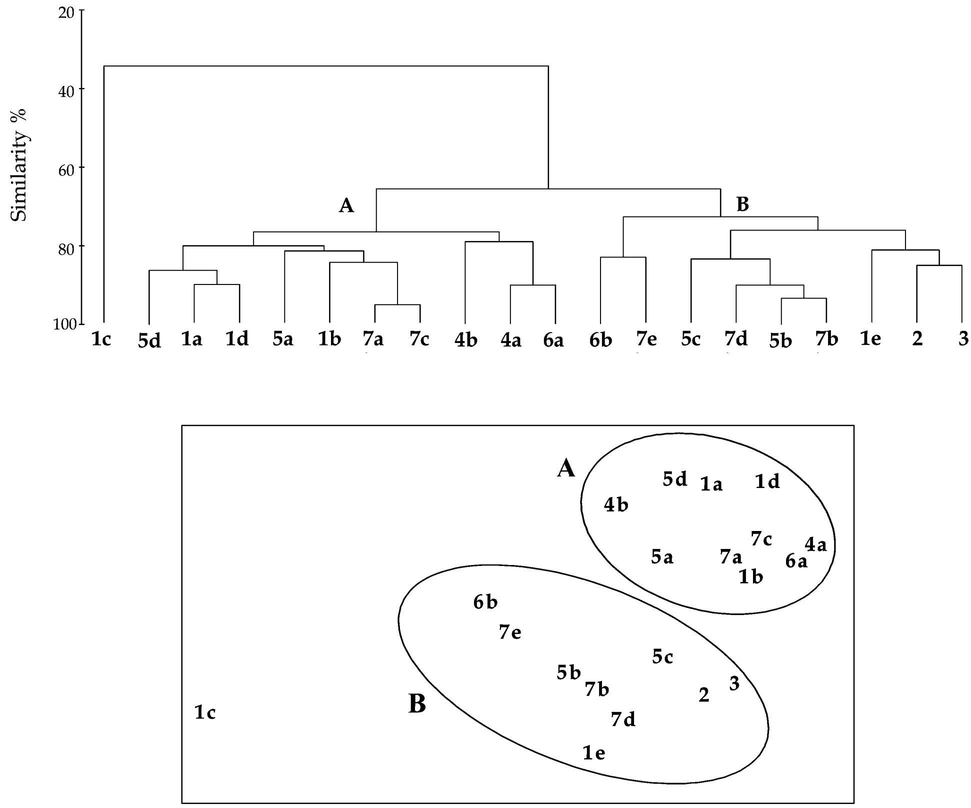

Figure 3. Cluster analysis and Multi Dimensional Scaling showing sponge faunistic relationships among the sampling stations.

impoverished station 1c. The rest of the stations formed two distinct groups, revealing a considerable spatial variation. This separation was based on the geomorphological characteristics of the sampling stations rather than on their geographical vicinity, and was related to substratum inclination, which has been considered as one of the determining factors for sponge distribution (Pansini et al. 2000; Bell and Smith 2004; Preciado and Maldonado 2005; Antoniadou et al. 2006). The first group was recorded on vertical cliffs and the second on moderately inclined cliffs, interspersed either on a *Posidonia* meadow or on a detritic biogenic bottom. The importance of the cliff profile has been indicated by various authors (Vacelet 1969; Boury-Esnault 1971; Uriz et al. 1992) in the past.

Population densities of the four bath sponges were generally low. This was expected, since the Mediterranean sponge bank densities have long been decreasing, especially after the epidemic of 1986 (Ben Mustapha and Vacelet 1991; Vacelet 1991; Pronzato 1999; Castritsi-Catharios et al. 2005). The Dodecanese area has been one of the most harvested areas through time, and according to Gaino and Pronzato (1992) harvested sponge banks are subject to particularly high mortality rates, and overfishing could possibly be responsible for weakening sponge resistance to bacterial infection. It has been reported that before the last epidemic, not-exploited commercial sponge banks reached densities of about 10 specimens/10 m^2 but about

Table 3. Species contribution to in-group similarity and among groups dissimilarity.

Species	Contribution (%)	Species	Contribution (%)
Group A in-group similarity (53%)		**Among groups dissimilarity (69%)**	
Ircinia. fasciculata	5.91	*Suberites domuncula*	6.6
Petrosia ficiformis	5.91	*Geodia cydonium*	6.6
Phorbas tenacior	5.91	*Acanthella acuta*	6.0
Sarcotragus foetidus	5.91	*Dysidea fragilis*	5.5
Agelas oroides	5.91	*Calyx nicaeensis*	5.5
Axinella cannabina	5.91	*Axinella polypoides*	5.2
Chondrosia reniformis	5.91	*Scalarispongia scalaris*	5.0
Cliona viridis	5.91	*Axinella damicornis*	4.8
Crambe crambe	5.91	*Dysidea avara*	4.3
		Axinella verrucosa	4.2
		Diplastrella bistellata	4.1
Group B in-group similarity (68%)		*Chondrilla nucula*	3.9
Ircinia fasciculata	7.55	*Stryphnus mucronatus*	3.7
Petrosia ficiformis	7.55	*Oscarella lobularis*	3.7
Phorbas tenacior	7.55		
Sarcotragus foetidus	7.55		
Agelas oroides	7.55		
Axinella cannabina	7.55		
Chondrosia reniformis	7.55		
Cliona viridis	7.55		
Crambe crambe	7.55		

Note: Group A: station with substrate of vertical cliffs; group B: stations with substrate mostly of inclined rocks, *Posidonia* and detritic bottoms.

10 years later, in around 1998, the mean density did not exceed 5 specimens/10 m^2 (Pronzato 1999). After the outbreak of the disease in the Aegean, the populations of commercial sponge species disappeared from the traditional sponge banks located at depths shallower than 40 m (Castritsi-Catharios et al. 2005). During 1989–1990 in Greece, commercial sponges were fished only by bottom gears at depths of 60–100 m, whereas at shallower depths no commercial sponges were harvested as a result of the disease and overfishing (Vacelet 1991). Densities between 4.9 and 6.6 specimens/10 m^2 for the populations of *S. officinalis* were recorded in the Western Mediterranean (Perez and Capo 2001).

The results of the present study showed a population density reaching, at some sites, 3–5 specimens/m^2 for the common commercial species *H. communis* and *S. officinalis*. The highest densities have been observed in some stations (1c, 5d, 6b), in depths shallower than 50 m, thus indicating a recovery of sponge beds. Two of the stations are characterized by open sea reefs surrounded by several rocky islets where strong currents, more than 10 cm/sec, usually occur (authors' unpublished data). This possibly explains the increased population density of the species *H. communis* and *S. officinalis*, as the strong currents can overcome the detrimental effects of sedimentation on a horizontal substratum, a known negative factor for the development of many sponges (Bell and Barnes 2000; Bell and Smith 2004). The above two species were, however, present in low abundances or even absent from some sites previously considered as rich sponge beds by the sponge fishermen. The

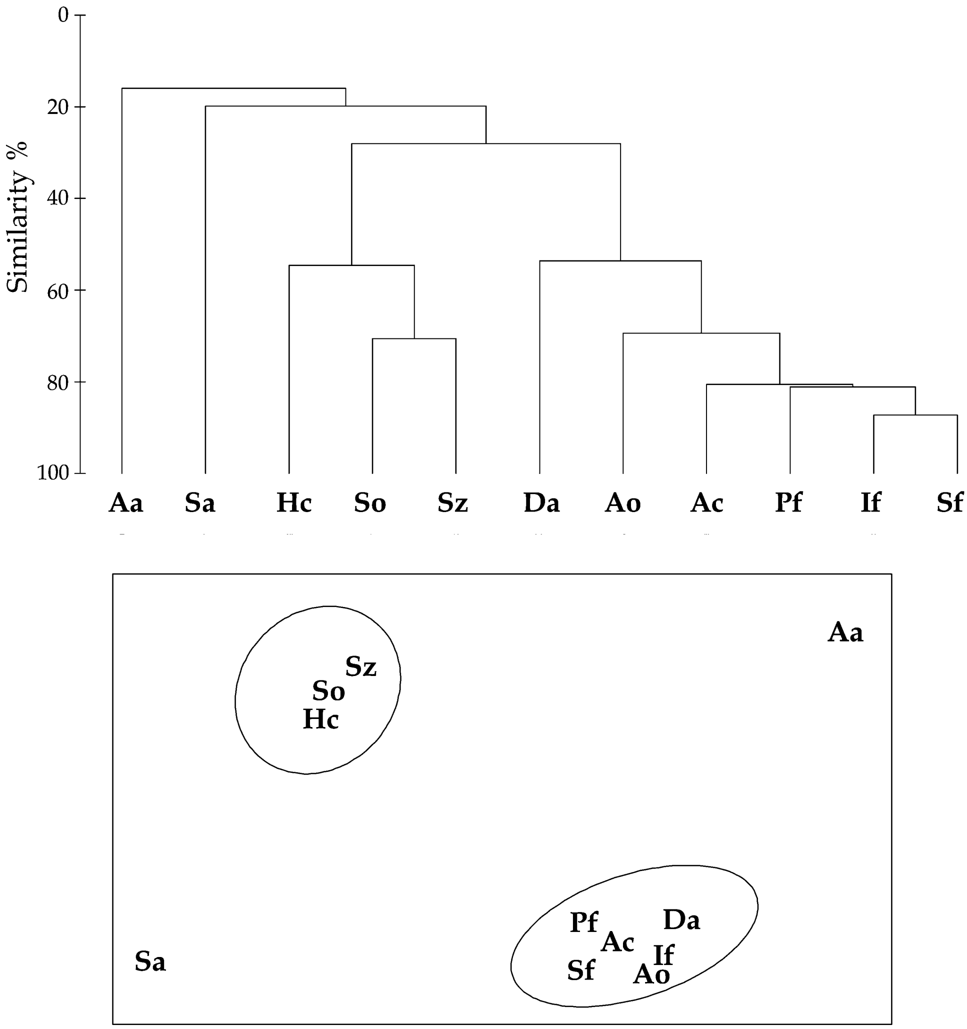

Figure 4. Cluster analysis and multidimensional scaling showing distributional affinities of the eleven sponges studied. Aa, *A. aerophoba*; Sa, *S. agaricina*; So, *S. officinalis*; Sz; *S. zimmoca*; Hc, *H. communis*; Da, *D. avara*; Ao, *A. oroides*; Ac, *A. cannabina*; Pf, *P. ficiformis*; If, *I. fasciculata*; Sf, *S. foetidus*.

species *S. zimmoca* and *S. agaricina* were present at some sampling sites in relatively low abundances, the latter in the deeper part of the examined bathymetric zone. The trend of this species to inhabit deeper bottoms than the other species of the genus *Spongia* has been attributed to its ability to tolerate higher levels of sedimentation due to its "elephant ear" or "vase-shaped" form. This shape enables the collection of suspending sediments from the horizontal water flow by the incurrent surface and the incorporation of foreign material for the development of strong primary cored fibres (Pronzato et al. 1998).

It seems that the coasts of the Dodecanese Islands form a favourable environment for the growth of bath sponges of the family Spongiidae. A reason for that is the warm highly saline waters of the area and the absence of considerable annual fluctuations, especially in depths below 15 m. The wider temperature range and the lower salinity values in the northwest Mediterranean and the north Aegean Sea seem to be the most important factors inhibiting the development of extended spongiferous bottoms. Moreover, exceptional temperature values have been related to bath sponge mortality events (Perez et al. 2000). It is remarkable that the traditional sponge grounds fished by the sponge fishermen are located between 15 and 50 m. As mentioned above, the annual temperature at this depth range in Astypalea Island fluctuated between 3 to 7°C during the study period.

Most of the species found in the Dodecanese have been reported in the literature for their production of bioactive compounds. Cultivation attempts have been made for some of them, which were considered economically promising, including the seven species surveyed for their population density in the present study (see Pronzato et al. 1999; Brümmer and Nickel 2003). The species *A. oroides*, *A. cannabina*, *I. fasciculata, S. foetidus* and *P. ficiformis* appeared widely distributed, with considerable stocks, all over the Dodecanese area, the first clearly surpassing the other four in population density. *Dysidea avara* was found to prefer areas with rocky bottoms of intermediate inclination, *Posidonia* meadows and biogenic substrata coexisted. Small specimens of the species were seldom found in rocky wall crevices. *Dysidea avara*, produces avarol, currently used for a medicine against psoriasis (Sipkema et al. 2005b), and also being a potential antitumour agent (Shen et al. 2003). The former authors concluded that avarol produced by mariculture or ex situ culture could become a viable alternative to the currently used pharmaceuticals for the treatment of psoriasis. Finally, *A. aerophoba*, shows a wide distribution and high abundance in the northern part of the Aegean (Voultsiadou 2005a), but seems poorly distributed in the Dodecanese. It should be mentioned that *Aplysina* individuals were scarcely observed in shallower waters of the study area. It is remarkable that the two species of the genus, *A. aerophoba* and *A. cavernicola*, observed in the Western Mediterranean (Vacelet 1959) do not seem to be distinguished in the Aegean Sea (Voultsiadou-Koukoura 1987), possibly because speciation is still in progress in this area (Pansini 1997). Besides the above seven species, some others, also known for their natural products, such as *C. reniformis*, *C. crambe*, *P. tenacior* and *C. viridis* were very common in the study area. However, their amorphous, encrusting form and the subsequent difficulty in distinguishing separate specimens did not permit an accurate estimation of population density on the same basis as for the other species.

Summarizing, the distribution pattern and stock availability of the two sponge categories studied, the "bath" and the "bioactive" sponges, presented some clear differences. The first category included species occurring in a restricted number of stations and in relatively low population densities. The second category included species distributed all over the study area and in relatively high densities (with the exception of *A. aerophoba*).

This first attempt to assess sponge population densities in an area traditionally harvested for sponges, revealed a sign of recovery of the traditionally commercial sponge species after the devastating epidemic events, and a high stock availability of six biotechnologically promising species. These results are encouraging for a future sustainable stock exploitation which could be combined with the development of sponge farming. Mariculture has been considered as one of the best, the most reliable, the least expensive and the most environmentally compatible method for the production of sponge biomass to provide bioactive metabolites (van Treeck et al. 2003). The Dodecanese, supporting wild populations of economically interesting sponge species, seems to be a suitable area for their cultivation, since environmental conditions are critical for the biosynthesis of the biologically active secondary metabolites (Page et al. 2005). Moreover, sponge culture in this area, could be an alternative activity in coastal areas where sponge fishing was traditionally carried out, helping in this way a natural repopulation of the area, and supporting the revival of the local traditional sponge fishing community. Of course, further research is needed in order to monitor the populations of bath sponges in the future and to assess stocks of other commercially important demosponge species.

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References

Antoniadou C, Voultsiadou E, Chintiroglou C. 2006. Sublittoral megabenthos along cliffs of different profile (Aegean Sea, Eastern Mediterranean). Belgian Journal of Zoology 136:69–79.

Bakus GJ. 1990. Quantitative ecology and marine biology. Rotterdam: Balkema.

Bell JJ, Barnes DKA. 2000. A sponge diversity center within a marine island. Hydrobiologia 440:55–64.

Bell JJ, Smith D. 2004. Ecology of sponge assemblages (Porifera) in the Wakatobi region, south-east Sulawesi, Indonesia: richness and abundance. Journal of the Marine Biological Association of the UK 84:581–591.

Ben Mustapha K, Vacelet J. 1991. Etat actuel des fonds spongifères de Tunisie. In: Boudouresque CF, Avon M, Graver V, editors. Les espèces Marines a protéger en Méditerranée. Marseille: GIS Posidonie Publications. p. 43–46.

Blunt JW, Copp BR, Munro MHG, Northcote PT, Princep MR. 2005. Marine natural products. Natural Product Report 22:15–61.

Boury-Esnault N. 1971. Spongiares de la zone rocheuse littorale de Banyuls-sur-Mer. I. ecologie et repartition. Vie Milieu 22:159–192.

Brümmer F, Nickel M. 2003. Sustainable use of marine resources: cultivation of sponges. In: Müller WEG, editor. Marine Molecular Biotechnology. Berlin/Heidelberg: Springer-Verlag. p. 143–161.

Castritsi-Catharios J, Miliou H, Pantelis J. 2005. Experimental sponge fishery in Egypt during recovery from sponge disease. Aquatic Conservation: Marine and Freshwater Ecosystems 15:109–116.

Chintiroglou C, Antoniadou C, Vafidis D, Koutsoubas D. 2005. Zoobenthos – Hard substrata communities. In: Papathanasiou E, Zenetos A, editors. State of the Hellenic Marine Environment. Athens: Hellenic Center for Marine Research Publications. p. 247–253.

Clarke KR, Warwick RM. 1994. Change in marine communities: an approach to statistical analysis and interpretation. UK: Natural Environment Research Council.

Corriero G, Longo C, Mercurio M, Marzano CN, Lembo MT. 2004. Rearing performance of *Spongia officinalis* on suspended ropes off the Southern Italian Coast (Central Mediterranean Sea). Aquaculture 238:195–206.

Elliot JM. 1971. Some methods for the statistical analysis of samples of benthic invertebrates. UK: Freshwater Biological Association, Scientific Publication.

Gaino E, Pronzato R. 1992. Epidemie e pesca intensive minacciano la sopravvienza delle spugne commerciali del bacino Mediterraneo. Bolletino dei Musei e degli Instituti Biologici dell' Universita di Genova 56/57:209–224.

Glasby TM. 1999. Effects of shading on subtidal epibiotic assemblages. Journal of the Experimental Marine Biology and Ecology 234:275–290.

Kefalas E, Tsirtsis G, Castritsi-Catharios J. 2003. Distribution and ecology of Demospongiae from the circalittoral of the islands of the Aegean Sea (Eastern Mediterranean). Hydrobiologia 499:125–134.

Kontoyiannis H, Krestenitis Y, Petihakis G, Tsirtsis G. 2005. Coastal areas: circulation and hydrological features. In: Papathanasiou E, Zenetos A, editors. State of the Hellenic Marine Environment. Athens: Hellenic Center for Marine Research Publications. p. 95–103.

Page MJ, Northcote PT, Webb VL, Mackey S, Handley SJ. 2005. Aquaculture trials for the production of biologically active metabolites in the New Zealand sponge *Mycale hentscheli* (Demospongiae: Poecilosclerida). Aquaculture 250:256–269.

Pansini M. 1997. Effeti della luce sulla morfologia, distribuzione ed ecologia di alcune demosponge mediterranee. Biologia Marina Mediterranea 4:74–80.

Pansini M, Morri C, Bianchi CN. 2000. The sponge community of a subtidal area with hydrothermal vents: Milos Island, Aegean Sea. Estuarine Coastal and Shelf Science 51:627–635.

Perez T, Capo S. 2001. Eponges commerciales du Park National de Port-Cros: estimation de la densité de deux populations de *Spongia officinalis* (Linné, 1759). Scientific Reports of the Port-Cros National Park, France 18:143–148.

Perez T, Garrabou J, Sartoretto S, Harmelin JG, Francour P, Vacelet J. 2000. Mortalité massive d'invertébrés marins: un événement sans précédent en Méditerranée nord-occidentale. Les Comptes rendus de l'Académie des sciences, Paris, Life Sciences 323:853–865.

Preciado I, Maldonado M. 2005. Reassessing the spatial relationship between sponges and macroalgae in sublittoral rocky bottoms: a descriptive approach. Helgoland Marine Research 59:141–150.

Pronzato R. 1999. Sponge-fishing, disease and farming in the Mediterranean Sea. Aquatic Conservation: Marine and Freshwater Ecosystems 9:485–493.

Pronzato R, Bavestrello G, Cerrano C. 1998. Morpho-functional adaptations of three species of *Spongia* (Porifera, Demospongiae) from a Mediterranean vertical cliff. Bulletin of Marine Science 63:317–328.

Pronzato R, Bavestrello C, Cerrano C, Magnito G, Manconi R, Pantelis J, Sara A, Sidri M. 1999. Sponge farming in the Mediterranean Sea: New perspectives. Memoirs of the Queensland Museum 44:485–491.

Shen YC, Lu CH, Chakraborty R, Kuo YH. 2003. Isolation of sesquiterpenoids from sponge *Dysidea avara* and chemical modification of avarol as potential antitumor agents. Natural Products Research 17:83–89.

Sipkema D, Franssen MCR, Osinga R, Tramper J, Wijffels RH. 2005a. Marine sponges as pharmacy. Marine Biotechnology 7:142–162.

Sipkema D, Osinga R, Schatton W, Mendola D, Tramper J, Wijffels RH. 2005b. Large-scale production of pharmaceuticals by marine sponges: sea, cell, or synthesis? Biotechnology and Bioengineering 90:201–222.

Takur NL, Müller WEG. 2004. Biotechnological potential of marine sponges. Current Science 86:1506–1512.

Treeck van P, Eisinger M, Müller J, Paster M, Schumacher H. 2003. Mariculture trials with Mediterranean sponge species. The exploitation of an old natural resource with sustainable and novel methods. Aquaculture 218:439–455.

Uriz M, Rosell D, Martin D. 1992. The sponge population of the Cabrera Archipelago (Balearic Islands): characteristics, distribution and abundance of the most representative species. P.S.Z.N.I. Marine Ecology 13:101–117.
Vacelet J. 1959. Répartition générale des éponges et systématique des éponges cornées de la région de Marseille et de quelques stations méditerranéennes. Recueil de travaux de la Station Marine d' Endoume 16:39–101.
Vacelet J. 1969. Eponges de la roche du large et de l'étage bathyale de Méditerranée. Mémoires du Muséum National d'Histoire Naturelle Série A 29:1–219.
Vacelet J. 1991. Statut des éponges commerciales en Méditerranée. In: Boudouresque CF, Avon M, Graver V, editors. Les espèces Marines a protéger en Méditerranée. Marseille: GIS Posidonie Publications. p. 35–42.
Verdenal B, Verdenal M. 1987. Evaluation de l'intérêt économique de la culture d'éponges commerciales sur les cotes Méditerranéennes Françaises. Aquaculture 64:9–29.
Voultsiadou E. 2005a. Demosponge distribution in the eastern Mediterranean: a NW-SE gradient. Helgoland Marine Research 59:237–251.
Voultsiadou E. 2005b. Sponge diversity in the Aegean Sea: check list and new information. Italian Journal of Zoology 71:53–64.
Voultsiadou-Koukoura E. 1987. Some remarks on the Mediterraneanan species of the genus *Aplysina* (Demospongiae, Porifera). In: Vacelet J, Boury-Esnault N, editors. Taxonomy of Porifera. NATO ASI Series G13:275–279.
Zervakis V, Theocharis A, Georgopoulos D. 2005. Circulation and hydrography of the open seas. In: Papathanasiou E, Zenetos A, editors. State of the Hellenic Marine Environment. Athens: Hellenic Center for Marine Research Publications. p. 104–110.