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C. CHINTIROGLOU, C. ANTONIADOU, D. VAFIDIS, D. KOUTSOUBAS

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A review on the biodiversity of hard substrate invertebrate communities in the Aegean Sea

C. CHINTIROGLOU[1], C. ANTONIADOU[1], D. VAFIDIS[2] and D. KOUTSOUBAS[3]

[1]Aristotle University of Thessaloniki, School of Biology,
Department of Zoology, P.O. Box 134, Gr-540 06 Thessaloniki, Greece

[2]Fisheries Research Institute of Kavala,
Nea Peramos, 64007 Kavala, Greece

[3]Dept. Marine Science, University of the Aegean,
University Hill, 81100, Mytilini,
Lesvos island, Greece

e-mail: chintigl@bio.auth.gr

Abstract

This review attempts to estimate the biodiversity of the macrobenthic communities that develop on hard bottoms in the Aegean Sea. Literature analysis revealed that 1,171 species inhabit the hard substrate communities, constituting 20.9% of the total Mediterranean species. The hierarchical cluster analysis of the available data identified five major types: (1) the supralittoral communities, (2) the midlittoral communities, (3) the port communities, (4) the various facies of the photophilic algae community, and (5) the facies of the sciaphilic algae community. Thus, hard bottom communities in the Aegean seem to be separated mainly according to vertical zonation. A total of 68 hard-bottom species are under multiple exploitation, providing considerable economic profit. Taking into account the structural complexity of hard substrate benthic communities and their sensitivity to disturbances, it is essential to preserve the biodiversity of these biotopes.

Keywords: Biodiversity; Hard Substrate; Greek Seas; Eastern Mediterranean.

Intoduction

Biological diversity - or biodiversity is a cluster of concepts (CONTOLI, 1991), which encompasses many interrelated aspects, from genetics and molecular biology to community structure and habitat heterogeneity (BOERO, 1996). There is no single overall measure of biodiversity; rather there are multiple measures of different facets (GASTON & SPICER, 1996). Ecologists, for example, are used to measure diversity through a number of indices all of which relate, more or less directly, the number of species to their abundance (MAGURRAN, 1988). Despite its significant limitations, species richness, e.g. the number of species occurring in a site region or ecosystem, as it

'integrates' many different aspects (genetic, organismic, ecological) has to some extent become the common currency in studying biodiversity (GASTON & SPICER, 1996; BIANCHI & MORRI, 2000). Thus, in this paper, the term biodiversity will be used under the acceptation of species richness.

A review of the studies on Mediterranean benthic ecosystems revealed that the biodiversity of the macrobenthic fauna in the Aegean has received little attention, despite its cultural and economic importance. There are only few previous attempts that estimate the biodiversity of macrobenthos of this area. STERGIOU *et al*., (1997) gave a rough estimation of the macrobenthic species, which represents 47.4% of the total Mediterranean species, while KOUKOURAS *et al*., (2001) estimation, based on 15 taxa (bivalves and bryozoa not included), recorded 2,306 macrobenthic species.

Regarding the hard substrata communities, whose complexity can sometimes be compared with that of coral reefs (BELLAN-SANTINI *et al*., 1994), the relevant estimations are even scarcer. Studies on hard substratum are very limited compared with those conducted on soft substrata (ANTONIADOU & CHINTIROGLOU, 2005), mostly due to the difficulties involved in the approach to rocky bottoms (sampling with SCUBA diving). The first information on the bionomy of coastal hard bottom communities in the Aegean was derived from the cruises of Calypso in the southern part (PÉRÈS & PICARD, 1958) though their quantitative study started much later (CHINTIROGLOU & KOUKOURAS, 1992). This revision attempts to gather the available information from the Aegean Sea. Such a project, however, could only be on a small scale, due to paucity of relevant data from quantitative studies (ANTONIADOU, 2003; CHINTIROGLOU *et al*., 2004a).

Materials and Methods

A literature review on hard substrate of the Aegean Sea with links to species diversity, ecology and commercial interest was undertaken using electronic databases and references in published papers. All forms of literature, i.e. published works, Ph.D. dissertations and reports have been included. Abstracts from conferences have been partially included when no relative information was available. Literature with general references to hard substrate communities in the Aegean Sea or with detailed ones on specific species of these communities has been also cited in the bibliography.

Thus, the bulk of information on hard substrate macrobenthic species in the Aegean derives from publications that deal with the most important macrobenthic groups, such as Porifera, Anthozoa, Polychaeta, Sipuncula, Mollusca, Crustacea, Bryozoa Echinodermata, Ascidiacea. However, none of these works deals exclusively with hard substrate communities. In addition to sporadic information on the benthic fauna of hard bottoms in the Aegean, which is found in a number of faunistic and ecological papers (e.g. KOUKOURAS *et al*., 1995, 1998; SIMBOURA *et al*., 1995; Morri *et al*., 1999; DAMIANIDIS & CHINTIROGLOU, 2000; KARALIS *et al*., 2003; CHINTIROGLOU *et al*., 2004a, 2004b), a comprehensive study of the hard substrate communities of the lower infralittoral zone in the northern part is recently presented by ANTONIADOU (2003).

For the quantitative analysis all the available data, derived from quantitative or semi-quantitative studies (KOCATAŞ, 1978; KOUKOURAS *et al*., 1985, 1996, 1998; VOULTSIADOU-KOUKOURA *et al*., 1987; CHINTIROGLOU & KOUKOURAS, 1992; TOPALOGLU & KIHARA, 1993; SIMBOURA *et al*., 1995; CHINTIROGLOU, 1996; ERGEN & ÇINAR, 1997; BAXEVANIS & CHINTIROGLOU, 2000; DAMIANIDIS & CHINTIROGLOU, 2000; ERGEN *et al*., 2000; ÇINAR & ERGEN, 2002; LOGAN *et al*., 2002; ANTONIADOU, 2003; ÇINAR, 2003; KARALIS *et al*., 2003; KITSOS & KOUKOURAS, 2003; CHINTIROGLOU *et*

Table 1
Number of species per taxon in the Mediterranean (M) and the Aegean Sea (AS). HS refers to species recorded from hard substrate biotopes.

Macrobenthic Taxa	Mediterranean	Aegean Sea				AS/M (%)	AS (HS)/M (%)
	Present work	Stergiou *et al.* (1997)	Koukouras *et al* (2001)	Zenetos *et al.* (2005) Present work	H.S.		
Porifera	589	117	170	200	188	34	31.9
Anthozoa	153	23	76	88	69	57.5	45.1
Polychaeta	1037	570	561	753	130	72.6	12.5
Sipuncula	28		9	17		60.7	
Caudofoveata	6			2		33.3	
Solenogastres	30			1		3.3	
Polyplacophora	30		19	19	19	63.3	63.3
Gastropoda	1320	637	622	756	222	57.3	16.8
Bivalvia	405	300		308	60	76	14.8
Scaphopoda	16			12		75	
Cephalopoda	59			29	1	49.2	1.7
Cirripedia	34		18	18	18	52.9	52.9
Amphipoda	449		260	260	69	57.9	15.4
Isopoda	165	370	74	74	14	44.8	8.5
Tanaidacea	43		18	18	10	41.9	23.3
Cumacea	91		52	52	1	57.1	1.1
Decapoda	374	231	252	252	73	67.4	19.5
Bryozoa	420*	200		200	200	47.6	47.6
Echinodermata	162	107	108	107	30	66	18.5
Ascidiacea	187		67	67	67	35.8	35.8
Miscelleana taxa		100					
TOTAL	5598	2655	2306	3233	1171	57.8	20.9

* rough estimation (Weinberg, personal communication)

al., 2004a, 2004b), were organized on species (rows) – community type (columns) tables. The performed multivariate techniques included a hierarchical cluster analysis (group average) based on presence – absence data and the Bray-Curtis semimetric distance (CLARKE & WARWICK, 1994).

Results

I. Qualitative Aspects

The previous attempts to estimate the macrobenthic biodiversity in the Aegean Sea are summarized in Table 1. According to these authors, the recorded species richness ranged from 2,306 to 2,655, representing 41.2% to 47.1% of the total Mediterranean species (MOJETTA, 1996; BIANCHI

Table 2

Species richness of the three dominant taxa, total number of species (T.N.Sp.) and Shannon-Wiener H' diversity index of hard substrate community types in the Aegean Sea. (SL = supralittoral, ML = midlittoral, L = ports, SAC = sciaphilic algae community, PAC = photophilic algae community)

COMMUNITY TYPE	T.N. Sp.	Polychaeta	Mollusca	Crustacea	H'
SL	5		3	2	
ML	36		9	24	
L	93	30	11	25	3.15
SAC	409	90	136	68	5.18
PAC	767	262	184	192	4.35
FACIES of PAC					
Clear-water Algae	388	130	88	88	5.24
Mussels, Sea anemone, Slightly polluted-water Algae	338	121	83	87	3.80
Polluted-water Algae	121	32	26	46	
Sponge assemblages	238	105	50	68	3.33
Coral *Cladocora*	223	113	75	47	

& MORRI, 2000; KOUKOURAS *et al.*, 2001; VOULTSIADOU, 2005, ZENETOS *et al.*, 2005). The biodiversity of this area significantly increases taking into account this review, as 3233 species were reported covering 57,8% of the Mediterranean fauna. From these species less than a half (1,171 species) has been reported from hard bottoms (Table 1). Thus, the Aegean Sea apparently harbours 3.3% to 76% of the Mediterranean marine species, with large differences depending on the group considered, whereas, for the species that live on the hard substrate, the percentage ranges between 1.1% and 63.3%.

II. Quantitative Aspects

The repartition of the various species reported from hard substrate communities in the Aegean in higher taxonomic groups revealed that from the fourteen taxa three are dominant: Polychaeta, Mollusca and Crustacea, with percentages of 28.1%, 27.5% and 24.6%, respectively (Fig. 1). The species richness of the three dominant taxa, the total number of species and Shannon-Wiener (H') diversity index of hard substrate community types in the Aegean Sea are shown in Table 2.

The multivariate analysis of all the avail-

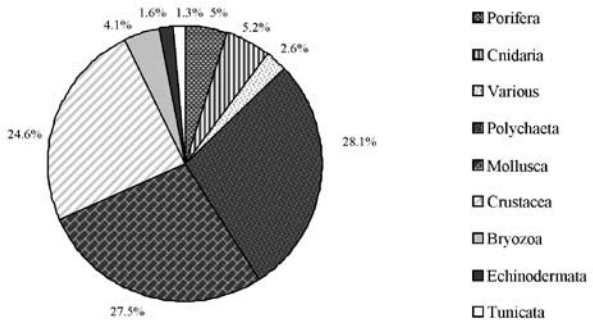

Fig. 1: Percentages of species on various taxa, recorded from hard substrate communities in the Greek Seas and the Turkish coasts of the Aegean.

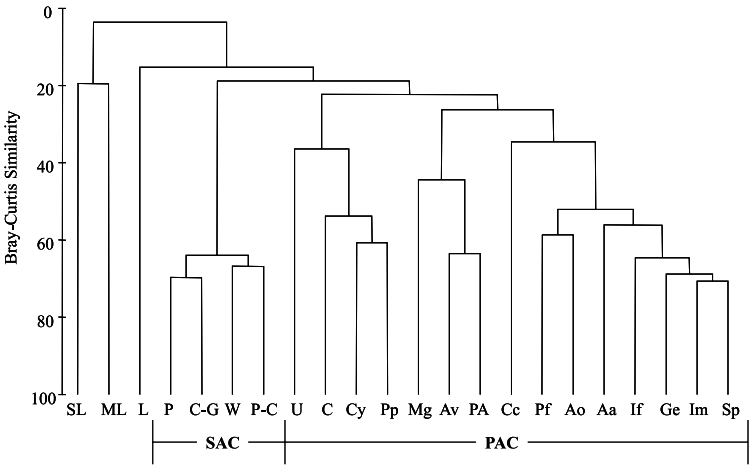

Fig. 2: Hierarchical cluster analysis of hard substrate communities based on presence – absence data of macrobenthic species. (SL = supralittoral, ML = midlittoral, L = ports, P = facies of the brown-algae *Padina* and *Zonaria*, C-G = facies of the algae *Gelidium* and *Cutleria*, W = facies of the red-alga *Womersleyella setacea*, P-C = facies of the encrusting red-algae Peyssoneliacea and Corallinacea, U = facies of the green-alga *Ulva*, Pp = facies of the brown-alga *Padina pavonica*, C = facies of the red-alga *Corallina*, Cy = facies of the brown-alga *Cystoseira*, Mg = facies of the mussel *Mytilus galloprovincialis*, Av = facies of the anthozoan *Anemonia viridis*, PA = facies of various algae, Cc = facies of the anthozoan *Cladocora caespitosa*, Pf = facies of the sponge *Petrosia ficiformis*, Ao = facies of the sponge *Agelas oroides*, Aa = facies of the sponge *Aplysina aerophoba*, If = facies of the sponge *Ircinia fascicularis*, Ge = facies of the sponge *Geodia cydonium*, Im = facies of the sponge *Ircinia muscarum*, Sp = facies of the sponge *Spongia officinalis*, SAC = sciaphilic algae community, PAC = photophilic algae community)

able data revealed obvious differences among biotopes and ecological zones. As hierarchical cluster analysis shows, five main groups are formed (Fig. 2). The first (group A) includes the communities of the supralittoral zone (SL), the second (group B) those of the midlittoral (ML), while the third (group C) contains the port communities (L). The fourth group (group D) consists of the facies of the sciaphilic algae community (SAC) and the fifth (group E) includes various facies of the photophilic algae community (PAC). This last group, in particular, is divided into five subgroups. The first subgroup (E1) contains the seven sponge assemblages, the second (E2) the facies of the coral *Cladocora*, and the third (E3) the communities of mussels, of the sea anemone *Anemonia viridis* and of various algae under the influence of increased organic load. The subgroup E4 contains the facies of clear water algae, while E5 the facies of the green alga *Ulva* in polluted areas. Frequently found species per community type (e.g. main group) are shown in Table 3.

III. Commercial Species

From the 135 invertebrate species that are under exploitation in the Aegean, 68 populate hard bottom communities (Table 4). These species are exploited in different ways, as most of them do present multiple exploitation (e.g. human food, fishing bait, household utility, jewellery, industry, collections/museums). However, at a species lev-

Table 3
Frequently found species (or taxa) per hard substrate community type in the Aegean Sea. (For abbreviations see Table 2).

SL	ML	L	PAC	SAC
Chthamalus depressus	*Actinia equina*	*Bowerbankia* sp.	*Arca noae*	*Agelas oroides*
Littorina punctata	*Amphithoe helleri*	*Balanus trigonus*	*Anemonia viridis*	*Axinella* sp.
Melaraphe neritoides	*Apanthura corsica*	*Ciona intestinalis*	*Aplysina aerophoba*	*Alvania mamillata*
Patella lusitanica	*Chthamalus stellatus*	*Clavelina lepadiformis*	*Bittium reticulatum*	*Bittium latreilli*
		Hydroides elegans	Caprellidae	*Halocynthia papillosa*
		Leptochelia savignyi	*Elasmopus rapax*	*Leptopsammia pruvoti*
		Nemertea	*Ircinia*	*Megathiris detruncata*
		Ophiodromus pallidus	*Modiolus barbatus*	*Microcosmus sabatieri*
		Sphaeroma serratum	*Platynereis dumerilii*	*Modiolus adriaticus*
		Styela canopus	*Scoletoma funchalensis*	*Spondylus gaederopus*

el, 45% of the total number of commercial value species (37 species) are edible organisms, thus collected mainly as food resource (Table 4).

Discussion

The basic concept of biodiversity focuses on species richness, e.g. composition that is the important indicator of diversity across spatial scales and habitats (GASTON & SPICER, 1996). As regards the biodiversity of the invertebrates inhabiting benthic communities in the Aegean, a total of 3,161 species were recorded, according to literature review, whereas 1,171 species populate the rocky bottoms. These results significantly change our view on the biodiversity of the Mediterranean, as the Aegean Sea is ranked as second among the other areas. Thus, the reported faunistic impoverishment of the eastern Mediterranean, in comparison with the western basin, seems to be an artefact, mainly due to limited sampling efforts at this area (BELLAN-SANTINI, 1985). The gap between the two Mediterranean sub-areas has severely reduced as revealed by the results provided during the last years, showing that the total number of species recorded in the eastern basin continually increases in relation to the increment in sampling efforts in this area (ANTONIADOU, 2003).

In the middle of the last century, PÉRÈS & PICARD (1958) postulated that the NE Mediterranean consists of a homogenous region. Rather recently, BIANCHI & MORRI (1983) described the physiognomy of benthic communities in the sea surrounding a South Aegean island (Kos) and argued that a distinction should be made between the north and the south sub-areas. This seems to be true at least in the Aegean Sea, where benthic communities are rather differently distributed (CHINTIROGLOU, VAFIDIS &

Table 4
Benthic organisms with commercial interest in the Aegean Sea and different ways of their exploitation.

TAXA	MED	AS	HS	Food Source	Fishing Bet	Household utility	Jewellery	Industry (Drugs, cosmetics etc)	Collection Museums
PORIFERA	7	7	7			*		*	*
CNIDARIA	11	7	7	*			*	*	*
SIPUNCULA	1	1							
POLYCHAETA	5	5	1		*				
MOLLUSCA	200	74	36	*	*		*	*	*
CRUSTACEA	79	36	12	*					*
ECHINODERMATA	6	2	2	*					*
TUNICATA	6	3	3	*					
TOTAL	315	135	68						

ANTONIADOU, unpublished data). Most of the quantitative information on benthic communities derives from the sublittoral zone, where two major types where described in the Aegean: (1) the photophilic algae community and (2) the sciaphilic algae community. The former seems to expand mainly in the north, whereas the later develops in deeper sites in the south.

There are about 1,000 species recorded from quantitative or semi-quantitative researches on hard substrate communities in the Greek Seas and the Turkish coasts of the Aegean. The grouping of these species in higher taxa showed that, apart from the numerous taxa, there are three dominant groups, which are Polychaeta, Mollusca and Crustacea. These results are similar to those reported from other geographical regions of the Mediterranean, since the sum equals almost 80% of the total fauna (BELLAN-SANTINI, 1969). The diversity indices (H') also show significant similarities, especially when they refer to specific communities, e.g, *Mytilus galloprovincialis*, *Anemonia viridis*, *Aplysina aerophoba* etc. In contrast, the values are higher in the communities of photophilic and sciaphilic algae.

The main environmental factors that determine the community structure are humidity, light, hydrodynamics, salinity and sedimentation, according to the depth zone (PÉRÈS, 1982; MARGALEF, 1984; MARINOPOULOS, 1988). This is supported by the multivariate analysis results, as the hard substrate communities were clearly separated on the basis of vertical zonation (supralittoral, midlittoral, upper- and lower sublittoral zone) and of the water condition (ports, *Ulva* facies). Moreover, the substrates' architecture influences the separation of the various facies, either as an abiotic feature (artificial: concrete, natural: granite, limestone) or as a biotic factor of microhabitat formation (e.g. the assemblages of symbiotic fauna in sponges and *Cladocora*).

The review of the relative literature has revealed that 135 invertebrate species are under exploitation in the Aegean Sea (FISHER *et al*., 1987). All these species are benthic, except the cephalopod mollusk *Argonauta argo*, which is a pelagic species. As regards their ecological distribution, there are almost equally dispersed among soft and hard bottom communities. Thus, 68 species are distributed in hard substrate (Table 4). The production of each hard substrate species collected from the Aegean is rather dif-

ficult to estimate. The official facts on the commercial species, as published by the National Statistical Service and the ETANAL (a company associated with the Greek Ministry of Agriculture recording production from 12 different fish markets in Greece) are available for only 12 invertebrate species, and these are also limited. Thirty of the exploited species, belonging to different taxonomic groups (Mollusks, Crustaceans, Echinoderms, Ascidians), have a mean annual production of 7.000tns (less than 10% of the total fisheries' production), whereas 12 of them are distributed in hard bottoms. Despite the small number of the hard substrate invertebrates exploited in the Aegean, and the fact that their total production/year is rather small (3.000 tns/year), their economic value is considerable (over 17million EURO/year).

The hard substrate communities are very sensitive due to their structural and functional complexity, their high productivity, and also their position on the trophic web (primary and secondary consumers). Certain processes and activities have a negative impact on rocky bottoms, such as eutrophication, species' introduction and invasion, effluents - liquid or solid wastes (terrigenous waters, domestic and industrial discharge, toxic substances, etc.), coastal engineering (breakwaters, seawalls, docks, harbours, dredging, etc.) species' collection (for both commercial and aesthetic reasons), sports and recreation (SCUBA diving, spearfishing, anchoring) etc. (BELLAN-SANTINI *et al*., 1994).

Increased organic load is the greatest menace for hard substrate communities, leading to decreased water clarity and phytoplankton blooms. The community structure is strongly modified, as only tolerant species can survive (most of the filter-feeder species suffer from silt blocking their branchial apparatus). As a result, biodiversity is severely reduced and the biotopes become monotonous. Thus, several biotopes are heavily modified (e.g. Thermaikos Gulf, Saronikos Gulf), while the majority still maintains a good ecological status (e.g. Chalkidiki peninsula, most of the islands). Integrated management plans and actions to preserve benthic communities, in accordance with international directives, are essential before an irreversible degradation of these diverse biotopes occurs (BELLAN-SANTINI *et al*., 1994; SALA *et al*., 1996; GARRABOU *et al*., 1997; CERRANO *et al*., 2000; PEREZ *et al*., 2000; CHEVALDONNE & LEJEUSNE, 2003).

Conclusions

Concluding, we should note the augmented biodiversity of the Aegean Sea, which is ranked as second among the other Mediterranean areas. This stands also for hard bottoms, in which polychaetes, mollusks and crustaceans dominate the community structure. The hard substrate communities, which are distributed mainly according to vertical zonation and water condition, host an important number of commercially exploited invertebrates and thus their conservation seems to be a high priority.

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