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Bioeroding (boring) polychaete species (Annelida: Polychaeta) from the Aegean Sea (eastern Mediterranean)

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Abstract

The present study reports polychaetes that bore into limestone rocks along the east coast of the Aegean Sea (eastern Mediterranean). Rock materials were collected at two depth intervals (0–5 and 5–10 m) at 15 stations in four localities of Ildırı Bay. A total of 276 specimens belonging to 12 species and four families (Eunicidae, Spionidae, Cirratulidae and Sabellidae) were recorded. Specimens belonging to *Dodecaceria* and *Pseudopotamilla* were identified at the genus level, because they differ from described species, were few in number or were in poor condition. *Dipolydora giardia* is a new species to the marine fauna of Turkey. The most dominant and frequent family in the area was Eunicidae, followed by Spionidae. *Lysidice ninetta* and *L. margaritacea* comprised 59% of the total number of individuals. The number of species and individuals, and the diversity index did not change with regard to depth or locality. Two species assemblages were found in the area, mainly formed by *Dipolydora* and *Lysidice* species. The Lessepsian species, *Palola valida*, which is a new record for the Aegean Sea, occurred abundantly at the study sites, posing a risk of damage to limestone rocks in the Mediterranean Sea. The morphological features of the species identified at the generic level and the burrow structure of these species are presented. The burrow shapes of *Palola siciliensis* and *P. valida* were described for the first time in the present study; they constructed complicated galleries, including more than four entrances.

Introduction

Polychaetes are one of the primary bioeroders of calcareous structures such as rocks, corals and bivalves (Scott *et al*., 1988; Peyrot-Clausade *et al*., 1992; Hutchings & Peyrot-Clausade, 2002). Bioerosion by polychaetes, where hard substratum is degraded into minute fragments, is a dynamic, destructive process that results in shaping of rocky bottoms and changes to the structural integrity of coral reefs (Hutchings, 1986; Tribollet & Golubic, 2011). Although there are three types of destruction (i.e. grazing, etching and boring; see Hutchings, 1986), polychaetes especially play important roles in the boring phenomenon, which is mediated by chemical and mechanical processes (Sato-Okoshi & Okoshi, 1993; Blake, 1996). They can secrete acid mucopolysaccharides from the ventral epithelium and segmental mucus glands to dissolve substrata, or they can utilize their jaws (i.e. Eunicidae) and specialized chaetae (i.e. Spionidae and Cirratulidae) to bore into substrata (Evans, 1969; Hutchings, 2008). Several polychaete families play roles in bioerosion, but many boring species have been reported in the families Eunicidae, Lumbrineridae, Dorvilleidae, Spionidae, Cirratulidae and Sabellidae (Hutchings, 1986; Fonseca *et al*., 2006). The majority of species construct circular, shallow burrows into the substrata, but eunicid worms form a sinuous, branched network (Glynn, 1997). However, young and adult worms can create different burrow shapes (Evans, 1969; Liu & Hsieh, 2000). Erosional losses of the Great Barrier Reef caused by polychaetes were estimated as 1.8 kg m^{-2} $year^{-1}$ (Davies & Hutchings, 1983). The mass infestation of boring spionid and sabellid species on bivalve beds can cause severe damage to mollusc shells, affecting the growth of their hosts and in turn resulting in financial loss to owners of aquaculture sites (Evans, 1969; Fitzhugh & Rouse, 1999; Simon *et al*., 2010).

Bioerosion created by polychaetes and their impacts on calcareous substrata have been studied at several localities world-wide, i.e. Atlantic Ocean (Bromley, 1978; Chughtai & Knight-Jones, 1988), Indian Ocean (Carreiro-Silva & McClanahan, 2012) and Pacific Ocean (Hutchings & Peyrot-Clausade, 2002; Fonseca *et al*., 2006). However, marine bioerosion has rarely been studied in the Mediterranean Sea. Sartoretto (1998) studied bioeroding species on coralligenous panels experimentally and determined that boring spionid species (*Polydora* spp.) occurred at the pioneering stage of colonization and their densities reached up to an average value of 1200 ind. m^{-2} after one year of submergence. Some studies emphasized the settlement of boring polychaetes on hard substrata (Laubier, 1958, 1959) and bivalves (i.e. Carazzi, 1893; Boscolo & Giovanardi, 2002) in the region. The distribution of boring eunicid species on scales of the endemic phanerogame *Posidonia oceanica* (Linnaeus) Delile, 1813 has been relatively well-studied in the region (Gambi, 2002; Gambi *et al*., 2005). However, there is only one study that specifically focused on the distribution of boring species on limestone rocks in the Mediterranean Sea (Casoli *et al*., 2019).

A few papers were specifically focused on boring polychaete species along the coast of Turkey. Çaglar (1954) reported the dense settlement of a polydorid species (identified as *Polydora ciliata*, whose presence is now questionable in the Mediterranean) on the mussel *Mytilus galloprovincialis* in the İstanbul Strait and studied its reproductive biology and larval development in the area. She also described galleries within shells constructed by the worm. Pinar (1974) and Sen *et al.* (2010) studied wood-boring bivalves and crustaceans at some ports in Turkey. Bioeroding sponges were specifically studied in Ildırı Bay, based on the material collected during the present study (Evcen & Çinar, 2015). However, boring sponges (see Evcen & Çinar, 2012), polychaetes (Demir, 1952–1954; Ergen, 1976; Kurt-Sahin & Çinar, 2009; Dagli *et al.*, 2011; Çinar *et al.*, 2014), phoronids (*Phoronis hippocrepia*, Çinar *et al.*, 2008), crustaceans (see Bakır *et al.*, 2014) and molluscs (see Öztürk *et al.*, 2014) were reported in general faunistic and ecological studies in the area.

This paper is aimed at assessing the distribution and diversity of bioeroding (boring) polychaete species in the Aegean Sea, and determining their morphological and ecological aspects.

Materials and methods

Sampling and material

The hard-bottom benthic samples were collected at 15 stations in four localities (southern part (SP), Eşek Islands (EI), eastern part (EP) and Gencelli Bay (GB)) at 0–10 m depths in Ildırı Bay (east Aegean Sea, Turkey) in August 2011 (Figure 1). Among the localities, Eşek Islands has no human settlements, but dense human settlements (especially in summer) exist in the southern part (near Çeşme). In Gerence Bay and the eastern part, mariculture (mainly sea-bass and sea-bream) activities take place. In the area, limestone rocks are generally present at 0–10 m depth; from 10 m depth downwards soft substrata with dense meadows of *Posidonia oceanica* together with *Caulerpa cylindracea* and *C. prolifera*, and *Halophila stipulacea* are present. Except for stations 5 and 6 where bottoms are covered with *P. oceanica* meadows at 0–5 m depth, hard bottom samples were taken at the depth intervals 0–5 and 5–10 m at all stations.

Samples were collected randomly at each depth interval of stations by snorkelling and scuba diving. Only one sample in a quadrat covering almost 0.5 m^2 area was taken in each depth interval of the stations. Rock samples were broken underwater using a hammer and chisel, and immediately covered with mesh and put in cloth bags. On board the pleasure vessel 'Çağan 2005', benthic samples collected in each depth interval were put in a large plastic washbasin and specimens among rock pieces were collected. Large rock pieces were carefully broken into small pieces to observe the placement and burrow structures of boring species. The material was put in separate jars and fixed with 4% formaldehyde. In the laboratory, benthic material was washed with tap water, sorted according to major taxonomic groups under a stereomicroscope (Olympus SZ-51) and preserved in 70% ethanol. Specimens were then identified and counted. In the identification of the specimens, papers including the original and subsequent descriptions of the species were used.

Specimens were deposited at the Museum of Faculty of Fisheries, Ege University (ESFM).

Photographs of specimens were taken with a digital camera (Olympus, Camedia, C-7070) attached to stereo (Olympus SZ-16) and compound (Olympus BX-51) microscopes. Total body length and width at chaetiger 10 (excluding parapodia and chaetae) were measured with an ocular micrometer.

Statistical analyses

Community descriptors such as the number of species and individuals, and the diversity ($\log_2$ base) and evenness index values were estimated for each sample and depth interval. The spatial patterns of species assemblages were assessed using the hierarchical cluster analysis in PRIMER (Clarke *et al.*, 2014). The pattern of species assemblages was explored and visualized using nMDS, applied on the Bray–Curtis resemblance matrix. Prior to analysis, the raw data were transformed by using the fourth-root transformation. The similarity profile test (SIMPROF) routine was run if groupings assessed are statistically significant at 0.05 (Clarke *et al.*, 2014). Similarity percentages analysis (SIMPER) was applied to the species-station matrices in order to identify the species which contributed most to the similarity of groups of stations. A two-way distance-based permutation multivariate analysis of variance (PERMANOVA) (Anderson, 2001) was used to test (1) if the community descriptors differ significantly in the depth intervals and localities, (2) if species assemblages differ significantly in the depth intervals and localities. The Euclidean distance matrix was used in the former analysis, and the Bray–Curtis similarity matrix was used in the latter. All analyses were performed by using the software PRIMER v7.

Results

Faunistic analysis

The shallow-water rocky bottom of Ildır Bay yielded 12 boring polychaete species belonging to four families (Eunicidae, Spionidae, Cirratulidae and Sabellidae) (Table 1). Spionidae were represented by the highest number of species (5 species), followed by Eunicidae (4 species) and Sabellidae (2 species). Among the species, the polydorid *Dipolydora giardia* is new to the marine fauna of Turkey, the Lessepsian species *Palola valida* new to the Aegean Sea, and one *Dococaceria* and two *Pseudopotamilla* species probably new to science – these are described below.

The dominant species in the area were *Lysidice ninetta* (39% of all specimens), *L. margaritacea* (20%) and *Dipolydora coeca* (13%). The species with the frequency value (occurrence) higher than 50% in all samples was *L. ninetta* (56%), but the scores changed according to the depth intervals. *Dipolydora coeca* (62%), *L. ninetta* (54%) and *L. margaritacea* (54%) had the highest frequency scores (>50%) in the 0–5 m depth interval, whereas only *L. ninetta* had the highest score (57%) in the 5–10 depth interval.

Almost similar numbers of species and individuals were found at the depth intervals, 0–5 and 5–10 m. Ten species and 141 individuals were encountered at 0–5 m depth, whereas 11 species and 135 individuals were found at 5–10 m depth. The mean scores of the community descriptors varied among localities and depths. The highest mean number of species (4 species) and individuals (23 individuals), and diversity score ($H' = 1.28$) were found at 0–5 m depth in Gencelli Bay (GB), whereas the highest evenness score ($J' = 0.92$) was estimated at 0–5 m depth in the eastern part of Ildırı Bay (EP) (Figure 2). The number of species, the number of individuals and the diversity index did not change significantly between the depth intervals and localities ($P > 0.05$), and the evenness index only differed significantly among localities (Pseudo-$F = 3.87$, $P < 0.05$) (Table 2).

Two main species assemblages (A and B) were determined in the area (SIMPROF test, $P < 0.05$) (Figure 3). Samples from the southern part (SP) and Eşek Islands were clustered in the MDS graphs (group B) and represented high similarity values. Locality and depth were not a significant factor affecting the assemblages (Table 3). The distribution and abundance of spionids and eunicids affected the species assemblages. The first assemblage (indicated as A in Figure 4), which is mainly

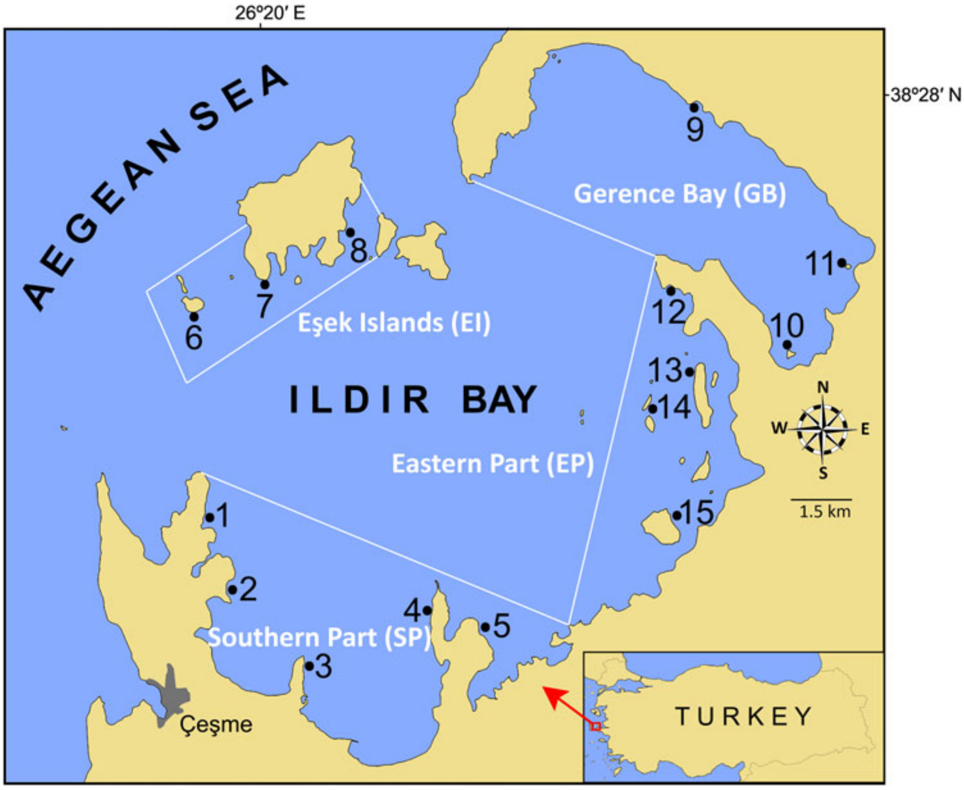

Fig. 1. Map of the investigated area indicating sampling stations within the localities.

Table 1. Abundance of boring polychaete species at stations (SP: Southern Part, EI: Eşek Islands, EP: Eastern Part, GB: Gencelli Bay)

Localities	SP					EI			GB			EP			
Stations	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Eunicidae															
Palola siciliensis (Grube, 1840)	1	2	–	–	–	–	–	–	–	–	1	–	–	–	–
Palola valida (Gravier, 1900)	2	1	–	–	–	1	3	1	1	1	–	2	–	2	2
Lysidice ninetta Audouin & M. Edwards, 1833	1	13	6	2	9	1	17	26	19	6	1	4	1	1	1
Lysidice margaritacea Claparède, 1868	1	3	9	2		4	13	3	10	2	1	–	7	–	–
Spionidae															
Dipolydora armata (Langerhans, 1880)	–	–	2	2	–	–	–	–	–	2	–	–	–	2	10
Dipolydora coeca (Örsted, 1843)	3	3	1	–	1		1	–	21	1	–	2	1	–	1
Dipolydora flava (Claparède, 1870)	–	–	–	2	–	–	–	1	4	2	–	–	3	1	–
Dipolydora giardi (Mesnil, 1896)	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
Polydora hoplura Claparède, 1868	–	–	–	–	–	–	–	–	10	2	2	2	1	–	–
Cirratulidae															
Dodecaceria sp.	1	1	–	–	–	–	1	1	–	–	–	1	–	–	1
Sabellidae															
Pseudopotamilla sp. 1	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
Pseudopotamilla sp. 2	–	1	–	–	1	–	–	–	–	–	–	–	–	–	–

dominated by the boring *Dipolydora* species, was formed at a few stations (2, 4, 10, 12, 14 and 15). The second assemblage (indicated as B in Figure 3), which is mainly dominated by the eunicids such as *Lysidice* species and *Palola valida*, was formed at the majority of stations. In this assemblage, there are two specific assemblages structured by different boring species (indicated as I and II in Figure 3). The species that showed strong or moderate correlations with the first and second nMDS axes were *Lysidice margaritacea* ($r = 0.76$, with MDS1), *Polydora hoplura* ($r = -0.45$, with MDS1), *L. ninetta* ($r = 0.57$, with MDS2) and *Palola valida* ($r = 0.51$, with MDS2).

According to the SIMPER analysis, the species most responsible for the similarity of the assemblage A was *D. armata* (contribution = 73%); and those most responsible for the assemblage

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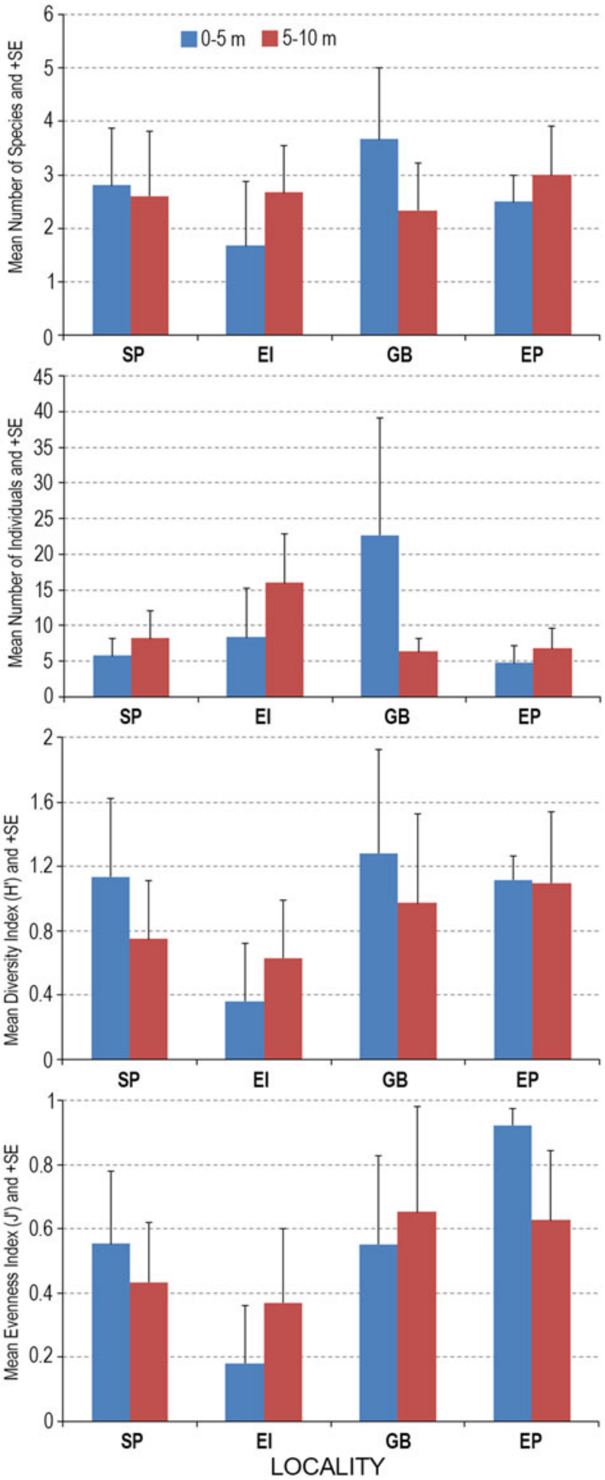

Fig. 2. The mean number of polychaete species and individuals, and the diversity and evenness index values at localities (SP: southern part, EI: Eşek Islands, EP: eastern part, GB: Gencelli Bay). SE: standard error.

B are *L. ninetta* (36%) and *L. margaritacea* (35%). The specific assemblages (BI and BII) within assemblage B are mainly structured with presence of the eunicids (*P. valida* and *L. ninetta*) and the polydorid (*Dipolydora coeca*) in the assemblage BII, and the difference in the abundance of *L. margaritacea*, which was three times higher in the assemblage BI.

The material included an alien species, *Palola valida*, which is a new record for the Aegean Sea. This Lessepsian species was found in 37% of all samples (F) and had an overall dominance score (D) of 5.8%. These scores did not change significantly in the depth intervals; 38% (F) and 6.38% (D) in the 0–5 m depth interval, *vs* 36% (F) and 5.18% (D) in the 5–10 m depth interval.

Burrow structures of species

The boring eunicids formed different burrow shapes. *Palola siciliensis* and *P. valida* constructed complicated galleries within limestone, including more than four entrances (Figure 4A). However, the whole shape of the burrow of *P. valida* could not be determined, due to damaged rocks. The *Lysidice* species, *L. ninetta* and *L. margaritacea* constructed a vertical, short burrow within limestone.

The bioeroding spionid polychaetes found in the study area generally constructed almost the same burrows within limestone. *Dipolydora armata*, *D. flava* and *D. giardia* and *Polydora hoplura* formed thin, long and straight grooves (Figure 4C–E), whereas *D. coeca* formed a characteristic L-shaped burrow within rocks (Figure 4B), sometimes in association with a *Lithophaga lithophaga* burrow. The burrow of this species was deeper than those of *Dipolydora giardi* and *D. armata.*

Pseudopotamilla species constructed irregular, short vertical burrows in limestone in the study area. *Dodecaceria* species bore into rocks, but its burrow type was not fully determined, due to damaged rocks.

Descriptions of the species identified at genus level

Phylum: Annelida Lamarck, 1802
Class: Polychaeta Grube, 1850
Order: Terebellida Rouse & Fauchald, 1997
Family: Cirratulidae Ryckholt, 1851

Dodecaceria sp.

Description. Largest specimen incomplete, with anterior fragment, 5 mm long, 0.8 mm wide, with 18 chaetigers. Body somewhat cylindrical, becoming enlarged in middle region, dark brownish in colour, with black speckles on palps, branchiae and body (Figure 5A). Prostomium rounded, expanded, with two slit-like nuchal organs placed on posterior margin. Peristomium multi-annulated, with 2–3 dorsal rings. Palps thick, laterally inserted, extending to 9–10 chaetiger. First segment achaetous, competely fused to peristomium. Branchiae dimorphic, from 'peristomium' to chaetiger 7, one pair per segment; those on chaetigers 1–3 with branchiae almost 2–3 times longer than posterior ones. Branchiae inserting more dorsally on anterior segments. Chaetigers annulated dorsally, 3–4 rings per chaetiger. Anterior chaetigers with serrated capillaries in notopodia and neuropodia; notopodial capillaries longer than neuropodial ones. Spoon-shaped hooks commencing on chaetiger 12; numbering three in both rami.

Remarks

As all specimens were incomplete, with anterior end, and most specimens were damaged, we did not determine if this species is distinct or not. More well-preserved specimens are required to name them. The specimens most probably belong to an undescribed species, as they showed morphological features different from described species, especially in terms of the branchial distributions and the shape of spoon chaetae when compared with species of *Dodecaceria* in the Mediterranean, namely *Dodecaceria sextentaculata* and *D. saxicola*.

Phylum: Annelida Lamarck, 1802
Class: Polychaeta Grube, 1850
Order: Sabellida Levinsen, 1883
Family: Sabellidae Latreille, 1825

Pseudopotamilla sp. 1

Description. Specimen incomplete, 10.6 mm long (including branchial crown), 0.6 mm wide, with 38 chaetigers. Body pale

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Table 2. Overall PERMANOVA tests applied on the community descriptors (number of species, number of individuals, diversity index and evenness index) with regard to depth intervals (two levels: 0–5 and 5–10 m depths) and localities (four areas: southern part, Eşek Islands, eastern part and Gencelli Bay)

Source	Degree of freedom	Sum of square	Mean of square	Pseudo-F	P(perm)	Perms
Number of species						
Locality	3	2.42	0.81	0.22	0.89	9944
Depth	1	0.34	0.34	0.09	0.77	9833
Depth × Locality	3	3.07	1.02	0.27	0.84	9954
Residue	19	71.25	3.75			
Total	26	76.96				
Number of individuals						
Locality	3	365	122	0.90	0.46	9962
Depth	1	25	25	0.18	0.69	9832
Depth × Locality	3	425	142	1.05	0.39	9951
Residue	19	2563	135			
Total	26	3387				
Number of individuals						
Locality	3	365	122	0.90	0.46	9962
Depth	1	25	25	0.18	0.69	9832
Depth × Locality	3	425	142	1.05	0.39	9951
Residue	19	2563	135			
Total	26	3387				
Diversity index						
Locality	3	0.98	0.33	1.39	0.29	9958
Depths	1	0.21	0.21	0.90	0.36	9826
Depth × Locality	3	0.88	0.29	1.24	0.33	9960
Residue	12	2.82	0.23			
Total	19	5.01				
Evenness index						
Locality	3	0.25	0.08	3.87	**0.04**	9948
Depth	1	0.01	0.01	1.18	0.66	9827
Depth × Locality	3	0.08	0.03	1.23	0.33	9944
Residue	12	0.26	0.02			
Total	19	0.63				

Bold value is statistically significant ($P < 0.05$).

yellowish. Branchial crown 2 mm long, with seven pairs of radioles, with one compound eye near base, except for dorsal and ventral radioles (L, R = x111xxx) (Figure 5B1). Dorsal lips large, with pointed tip, associated with dorsal radiolar appendages. Ventral lips present; ventral sacs absent. Dorsal margin with narrow flanges, ventral margin with oblique flanges. Paired dorsal collar lappets low, truncated, not extending far beyond junction of crown and thorax; lateral collar margin deeply notched; ventral collar margin distinctly higher than dorsal margin, with a pair of broadly triangular lobes. Thorax with 10 chaetigers, abdomen with 28 chaetigers. Anterior margin of first ventral shield indented medially. Collar chaetae limbate. Thoracic notopodia with limbate and paleate chaetae; the latter with a small distal mucro (Figure 5B2). Abdominal neuropodia with limbate chaetae. Thoracic uncini with numerous teeth above main fang. Companion chaetae with flat tear-drop distal blades (Figure 5B3). Abdominal uncini relatively small, with short handle.

Remarks

This species differs from the previously reported species of *Pseudopotamilla* from the coasts of the Mediterranean Sea, namely *P. reniformis* and *P. saxicava*, in having deep, distinct notches on the lateral sides of collar; short paired dorsal collar lappets; and fewer eyes on the radioles. More undamaged specimens are needed to clarify its taxonomic entity.

Pseudopotamilla sp. 2

Description. Largest specimen incomplete, 6.6 mm long (including branchial crown), 0.8 mm wide, with 30 chaetigers. Body pale yellowish, with brownish speckles near tip of radioles (Figure 5C). Branchial crown 1.6 mm long, with seven pairs of radioles, with 1–3 compound eyes on two or three dorsal radioles (L = x221xxx, R = x32xxxx) (Figure 5C). Dorsal lips large, with pointed tip, associated with dorsal radiolar appendages. Ventral lips and ventral sacs present; ventral lips short, somewhat rectangular in shape; sacs located between crown and ventral crown flanges.

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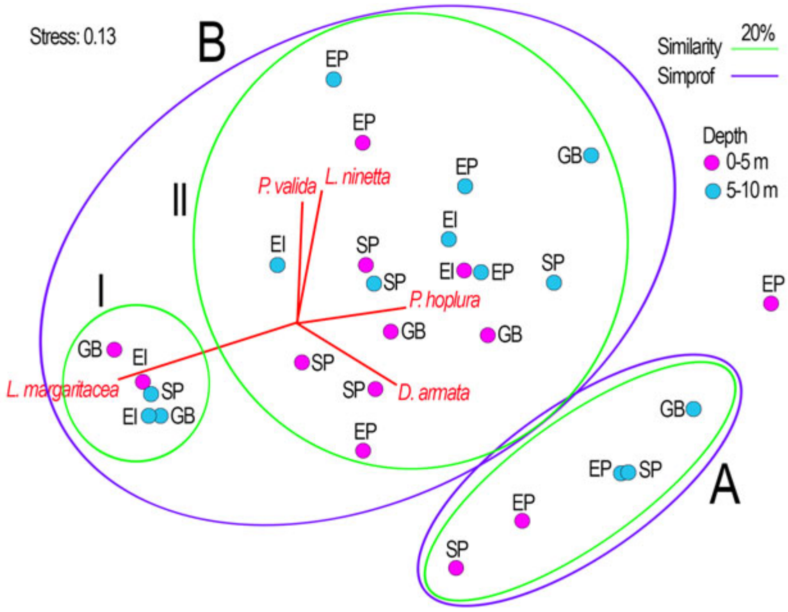

Fig. 3. nMDS analysis showing the similarity among stations, based on abundance data of all polychaete species. Vectors represent the species that relatively highly correlated with nMDS1 and nMDS2 (Pearson correlation, $r > 0.45$) (SP: southern part, EI: Eşek Islands, EP: eastern part, GB: Gencelli Bay).

Table 3. Main tests of PERMANOVA based on fourth-root transformed species-abundance data

Source	Degree of freedom	Sum of square	Mean of square	Pseudo-F	P(perm)	Perms
Locality	3	8.34	2.78	0.83	0.66	9890
Depth	1	2.68	2.68	0.80	0.55	9943
Depth × Locality	3	6.43	2.14	0.64	0.86	9904
Residue	19	63.76	3.35			
Total	26	81.55				

Localities and the depth intervals were used as different fixed factors.

Dorsal margin with narrow flanges, ventral margin with oblique flanges. Paired dorsal collar lappets low, somewhat triangular, a little surpassing beyond the junction of crown and thorax; lateral collar margin deeply notched; ventral collar margin distinctly higher than dorsal margin, with a pair of broadly triangular lobes. Thorax with 8 chaetigers, abdomen with 22 chaetigers. Anterior margin of first ventral shield indented medially. Collar chaetae limbate. Thoracic notopodia with limbate and paleate chaetae; the latter with a small distal mucro. Abdominal neuropodia with limbate chaetae. Thoracic uncini with numerous teeth above main fang. Companion chaetae with flat tear-drop distal blades. Abdominal uncini relatively small, with short handle.

Remarks

This species differs from the previously reported species of *Pseudopotamilla* (*P. reniformis* and *P. saxicava*) from Mediterranean coasts and *Pseudopotamilla* sp. 1 in having deep, distinct notches on the lateral sides of collar; short paired dorsal collar lappets; and the distribution of eyes on radioles; ventral sacs. More undamaged specimens are needed to clarify its taxonomic entity.

Discussion

In the eastern Aegean Sea, limestone rocky substrata hosted 12 boring polychaete species belonging to four families. The most widespread and abundant species were eunicids (*Lysidice* species) and spionids (*Dipolydora* species). The present study is focused only on the species that bore into rocks, so other polychaete species effectively involved in bioeroding processes such as etching and grazing have not been considered.

In a previous experimental study performed on the Tyrrhenian coast of Italy by Casoli *et al.* (2019), two polychaete species, namely *Polydora ciliata* and *Dodecaceria concharum*, were reported as borers on limestone panels. However, the occurrence of these two species in the Mediterranean is highly questionable (see Çinar *et al.*, 2014) and previous records of *P. ciliata* in the Mediterranean and Black Sea were assigned to different species such as *P. cornuta* (Çinar *et al.*, 2005). It seems that they are Atlantic species and do not occur in the Mediterranean Sea. In our study, four *Diopolydora* species and one *Polydora* species were determined, among which *P. ciliata* was absent. Not only within limestone, but in other substrata, *P. ciliata* was never found in the Aegean Sea (Dagli *et al.*, 2011). *Dodecaceria concharum* was frequently reported in previous studies in the Mediterranean, but it seems not to occur in the region, but *D. sextentaculata* and *D. saxicola* do occur, which have different morphological features (e.g. shapes of branchiae, spoon chaetae, prostomium) when compared with *D. concharum* (MEÇ, pers. obs. on material in the Zoological Museum of Copenhagen). In this study, the *Dodecaceria* species found did not resemble previously described species and they require further examination with additional intact material.

Lysidice ninetta and *L. margaritacea* were embedded tightly into rocks, and observed to construct vertical, short burrows, suggesting that they are active borers of rocks rather than being nestlers (i.e. species living inside burrows shaped by other boring species *sensu* Hutchings, 2008). They are known to be active

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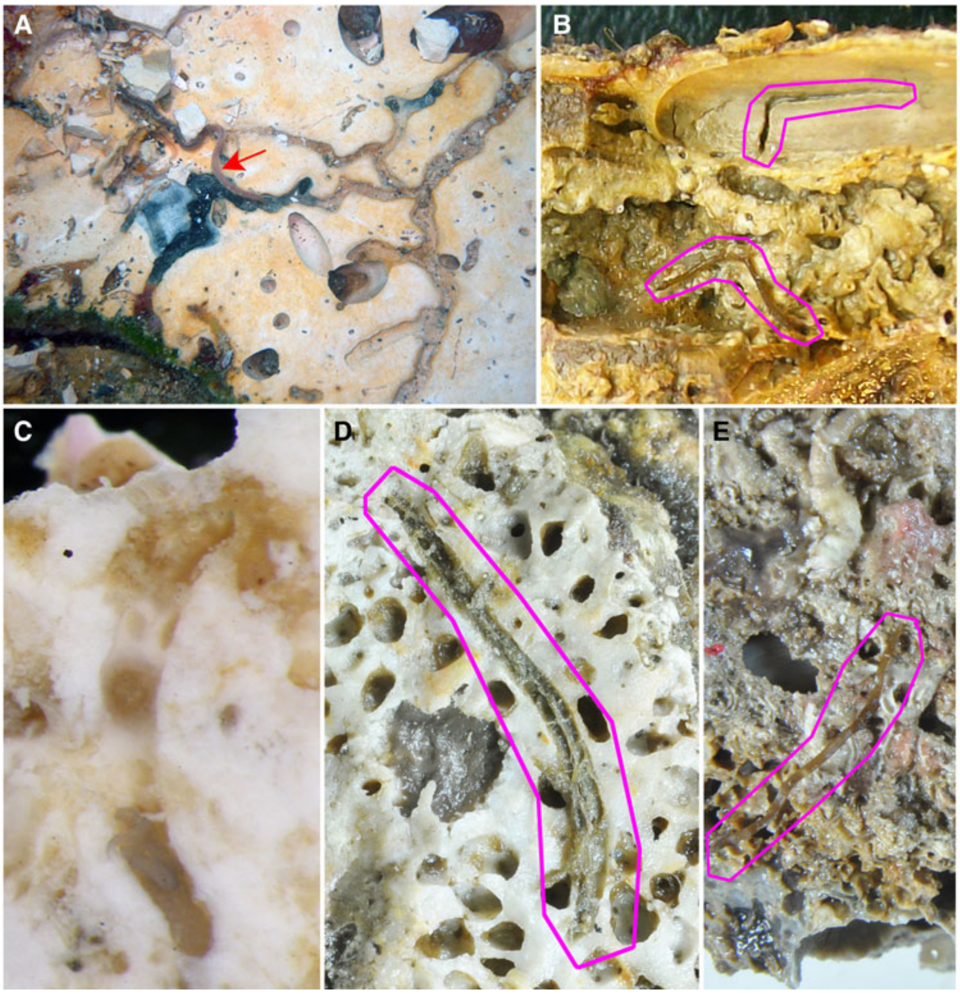

Fig. 4. Burrow structures of boring polychaete species. (A) *Palola siciliensis*, arrow indicates a specimen of *P. siciliensis* within the gallery; (B) *Dipolydora coeca*; (C) *Dipolydora armata*; (D) *Polydora hoplura*; (E) *Dipolydora flava*.

borers of *Posidonia oceanica*, using their chitinous, strong jaws to bore into the scales of *P. oceanica* and create distinct traces (Gambi *et al.*, 1995; Çinar, 2013a). *Lysidice ninetta* has previously been reported as a borer of rocks (Bromley, 1978; Castriota *et al.*, 2003), but *L. margaritacea* was found as a borer within limestone for the first time in the present study.

Different shapes of burrows constructed by boring polychaetes were determined in the present study. The most complicated, branched burrow with several entrances was formed by two *Palola* species, *P. valida* and *P. siciliensis*. Such a burrow type has not previously been described for these species. The other boring species have almost short, straight/vertical or L-shaped (*Dipolydora coeca*) burrows. However, polydorids are known to construct various types of burrows, such as surface fouling burrows, U shaped burrows, complex burrows, and mudblisters (Blake & Evans, 1973). The boring mechanisms of the species have not been observed in the present study. However, it is known that the boring strategy changes according to families; eunicid species use their strong jaws or secrete acids (Hutchings, 2008); *Dodecaceria* species utilize their spoon-shaped chaetae and secrete acid-like substances (Evans, 1969); *Pseudopotamilla* species usually perform boring by secreting acid, but the peristatic movements by specimens within burrows are believed to accelerate the process (Chughtai & Knight-Jones, 1988); *Polydora*/*Dipolydora* species utilize three mechanisms (Blake & Evans, 1973): a chemical mechanism (secreting acid); a mechanical mechanism (using enlarged modified chaetae on chaetiger 5); and a combined mechanism (both chemical and mechanical). Further investigation is required to determine the exact mechanism of burrow formation in these *Palola* species.

Multivariate analysis indicated that two distinct species assemblages occurred in Ildırı Bay; spionid and eunicid assemblages. The reason(s) why spionid and eunicid species were clustered at some certain stations is unknown at this stage, but spatial and temporal distributions of boring polychaetes are known to be shaped by some biotic and abiotic factors. Hutchings & Peyrot-Clausade (2002) reported that water quality had a great impact on the abundance of borers indirectly; it stimulated the development of epilithic and endolithic algae that changed the periphery of substrata where initial borers lived. Sedimentation also affects the composition of bioeroders (Hutchings *et al.*, 2005; Osnorno *et al.*, 2005). Under heavy sedimentation, endolithic algae do not develop due to light availability, decreasing the levels of grazing, whereas in clean waters, high rates of bioerosion occur due to grazing and boring activities by bivalves and polychaetes. Anthropogenic nitrogen enrichment of waters was proved to enhance the settlement of boring spionid polychaetes on corals in the Red Sea, causing coral skeleton aberrations (Wielgus *et al.*, 2006). Casoli *et al.* (2019) proved that boring activities of polychaetes increased with the increase in the abundance of ascidians, barnacles and bryozoans on limestone panels in the Mediterranean Sea. In Ildırı Bay, where intense fish farming and tourism activities take place at some locations, anthropogenic disturbance affected the composition of the benthic fauna (Ergen

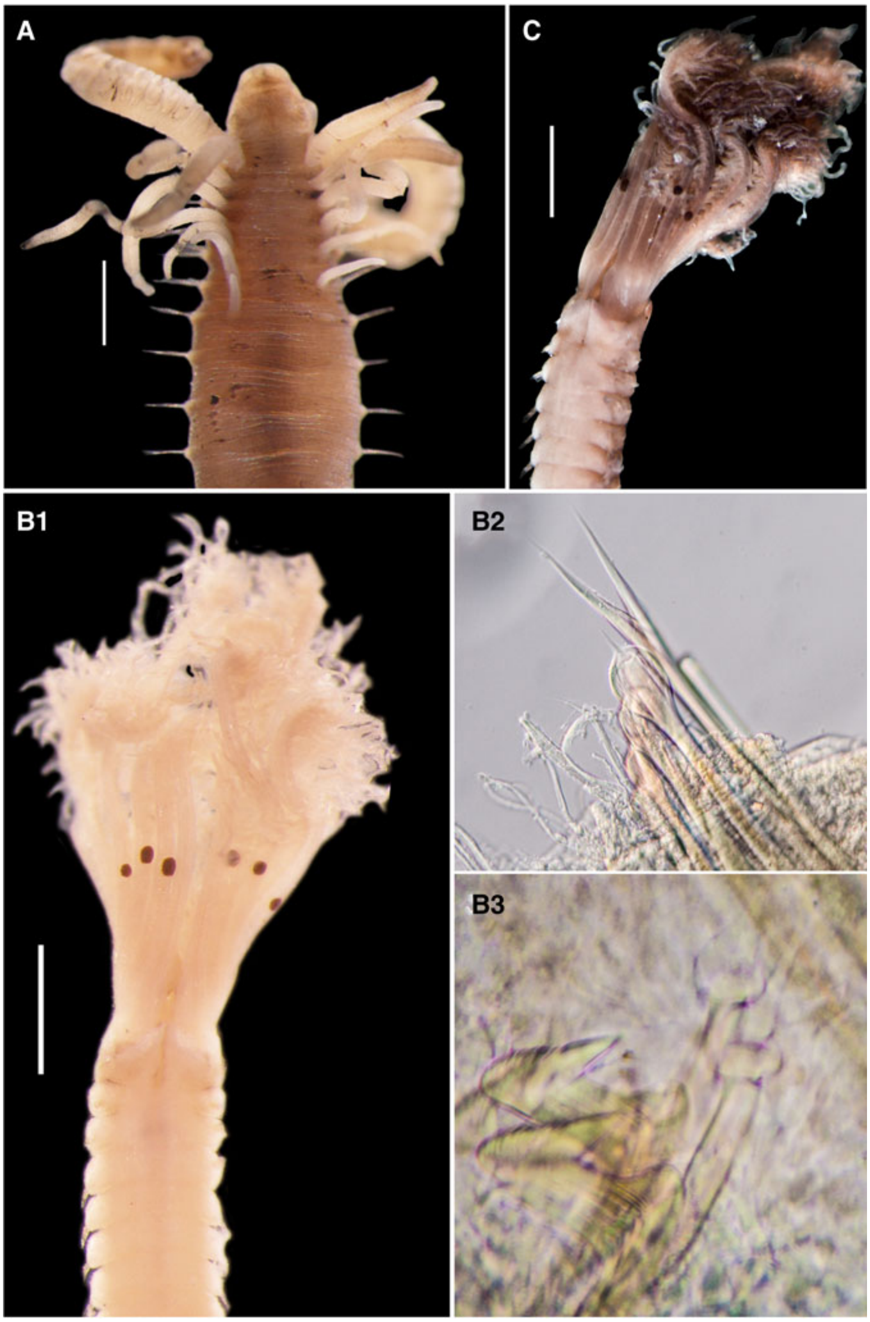

Fig. 5. (A) Anterior end of *Dodecaceria* sp., dorsal view (ESFM–POL/2011–335); (B1) Anterior end of *Pseudopotamilla* sp.1, dorsal view (ESFM–POL/2011–338); (B2) Thoracic chaetigers of *Pseudopotamilla* sp.1; (B3) Uncini and companion chaetae of *Pseudopotamilla* sp.1; (C) Anterior end of *Pseudopotamilla* sp.2 (ESFM–POL/2011–338), dorsal view. Scale bars: A = 0.5 mm; B1, 0.6 mm; B2, 75 µm; B3, 25 µm; C, 0.7 mm.

et al., 2004). It is unknown at this stage as to how these factors might affect the distribution and abundance of polychaete borers. In the western Mediterranean, some boring sponges (*Cliona* spp.) adapt well and grow larger in areas with high sedimentation rates (Carballo *et al*., 1994).

Depth was not a factor significantly affecting the distribution of borers in Ildırı Bay. However, we only investigated shallow depth intervals (0–5 and 5–10 m), because the presence of rocks generally ended at 10 m depth in the area and from that depth downwards a soft bottom with phanerogames commenced. In the Mediterranean Sea, scale borers of *Posidonia oceanica* (*Lysidice* spp.) showed a clear depth preference; *L. collaris* was abundant in shallow waters (10 m) and *L. ninetta* in deep waters (28 m) (Gambi *et al*., 1995; Gambi, 2002). No clear depth zonation was assessed for the boring species examined in the study area, except for the sabellids (*Pseudopotamilla* spp.) that occurred only in 5–10 m depths.

Among the borers, *Palola valida* is an alien species of Red Sea origin, previously reported only on the Levantine coast of Turkey (Kurt-Şahin & Çinar, 2009, 2017; Çinar *et al*., 2019). It was reported on a variety of habitats such as rocks, algae and sponges, but its abundance and frequency were estimated to be far higher on rocks (Kurt-Şahin & Çinar, 2017). This species was also found in coralligenous constructions in Fethiye Bay (MEÇ, unpublished data). Boring alien species belonging to families Spionidae, Cirratulidae and Sabellidae were previously reported worldwide and commonly infested shells of cultured mollusc species (Çinar, 2013b). In the Mediterranean Sea, no boring alien polychaete species has been reported to date, but a sipunculan, *Aspidosiphon elegans*, was reported to bore into rocks in the Levantine Sea, causing bioerosion (Açik, 2018). In addition, boring alien bivalve species (*Petricola hemprichi*, *Gastrochaena symbium* and *Sphenia rueppelli*) infested large bivalve species such as *Spondylus* spp. in the Levantine Sea (Zenetos *et al*., 2010). Increasing densities and distributional ranges of these species within the Mediterranean Sea could create a nuisance, causing physical damage of rocks as well as biogenic habitats like coralligenous habitats. The interactions between native and alien boring species in such habitats would be an interesting subject to study further.

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Conclusions

The present study sheds more light on the diversity and distribution of boring polychaete species in the Mediterranean where no detailed study has been carried out so far. Two different species assemblages were identified in the region which might have been structured due to specific environmental conditions, a matter which merits further investigation. Examination of species shows the likelihood of previously undescribed species present in the area, which also merits further investigation. New burrow constructions of *P. valida* and *P. siciliensis* have been found. The importance of alien invasive species in shallow-water benthic environments of the eastern Mediterranean is increasing and habitat-forming or -destructive alien species, such as the eunicid *Palola valida*, might irreversibly modify benthic habitats of the Mediterranean, causing detrimental effects to native biodiversity.

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