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Macrobenthic fauna associated with the invasive alien species *Brachidontes pharaonis* (Mollusca: Bivalvia) in the Levantine Sea (Turkey)

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The invasive alien mytilid species, Brachidontes pharaonis, *forms a biogenic habitat in the mediolittoral and upper-infralittoral zones of the Levantine Sea, hosting a number of alien and native species. Examinations of samples taken from dense, continuous mussel beds at seven stations along the coast of northern Levantine Sea yielded 187 macro-benthic invertebrate species belonging to 11 taxonomic groups. Polychaeta accounted for 46% and 37% of the total number of species and individuals, respectively. The top three dominant species in the mussel beds were* Stenothoe gallensis, Spirobranchus kraussi *and* Mytilaster minimus. *The species with the highest frequency values on the mussel beds were* Pseudonereis anomala, Phascolosoma stephensoni *and* Elasmopus pocillimanus. *The highest density and biomass of the associated fauna were estimated as 42,550 ind m^{-2} and 1503 wwt g m^{-2}, respectively. The species number in samples varied between 14 and 47 species. The environmental variables best explaining variations in zoobenthic community structures were salinity, dissolved oxygen and total inorganic nitrogen in the water column. The biotic indices, TUBI and ALEX, classified the ecological status of one or two stations as moderate or poor, based on the relative abundances of ecological and zoogeographic groups, respectively. A total of 21 alien species were found to be associated with the mussel bed, of which* Syllis ergeni *is being newly considered as a new established alien species for the Mediterranean Sea. The maximum density of associated alien species was calculated as 30,300 ind m^{-2}. The alien species assemblages were greatly affected by salinity and total inorganic nitrogen.*

Keywords: Community structures, species assemblages, zoobenthos, invasive species, spatial distribution, eastern Mediterranean

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INTRODUCTION

The alien mytilid species, *Brachidontes pharaonis*, which is a Lessepsian invader, is one of the pioneer species that were introduced from the Red Sea into the Mediterranean Sea via the Suez Canal, being reported near Port Said (Egypt) just 7 years after the opening of the Suez Canal in 1869 (Fuchs, 1878). This small species (max. 4 cm long) was successively reported from Lebanon (Gruvel & Moazzo, 1931), Israel (Haas, 1937), Sicily (Di Geronimo, 1971), and Syria, Greece and Turkey (Kinzelbach, 1985). It was also found in the northern Adriatic, on the Slovenian coast, where it built up a stable population (De Min & Vio, 1997).

It is one of the six species of the family Mytilidae that were considered as aliens for the Mediterranean Sea. The other species are *Musculista perfragilis* (Dunker, 1857), *M. senhousia* (Benson in Cantor, 1842), *Modiolus auriculatus* (Krauss, 1848), *Xenostrobus securis* (Lamarck, 1819) and *Septifer forskali* Dunker, 1855. Some of these species (*S. forskali, M. auriculatus* and *M. perfragilis*) could have been introduced to the Mediterranean via the Suez Canal; *X. securis* via aquaculture activities; and *M. senhousia* via multiple pathways (Suez Canal and aquaculture) (see Zenetos *et al.*, 2004). Among these species, *B. pharaonis* is the most successful one, abundantly and frequently occurring in the eastern and the western Mediterranean (Sicily) and having already expanded its distributional range even to the north Aegean Sea (Zenetos *et al.*, 2004; Doğan *et al.*, 2007). It settles preferably on the rocky mediolittoral zone and rarely on the upper infralittoral zones of the region, and formed dense populations in Israel (max. 30,000 ind m^{-2}) (Rilov *et al.*, 2004), Turkey (max. 40,000 ind m^{-2}) (Doğan *et al.*, 2008), Sicily (25,000 ind m^{-2}) (Sará *et al.*, 2006), and Malta (16,550 ind m^{-2}) (Bonnici *et al.*, 2012). This species totally or partly eliminated the native small mytilid species *Mytilaster minimus* (Poli, 1795) that was known to form continuous beds in the mediolittoral zone of the Levantine Sea (Gruvel & Moazzo, 1931).

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The faunal assemblages of this invasive species have not been investigated in detail in the Mediterranean Sea. However, some papers reported species of Serpulidae (Polychaeta) (Çinar, 2006), Decapoda (Crustacea) (Doğan *et al.*, 2008), Sipuncula (Açik, 2011), Amphipoda (Crustacea) (Bakir & Katağan, 2014), Eunicidae (Polychaeta) (Kurt-Sahin & Çinar, 2017) and Rissoidea (Gastropoda) (Bitlis-Bakir & Öztürk, 2016) associated with the *B. pharaonis* beds on the Levantine coast of Turkey. Ergen & Çinar (1997) gave a list of polychaetes along the Levantine coast of Turkey that were found on a variety of habitats including the *B. pharaonis* beds, but they did not specifically mention which polychaete species occurred on the mussel. Bonnici *et al.* (2012) studied the population of *B. pharaonis* and its associated fauna at one locality in the Maltese waters and reported a total of 48 zoobenthic and nine phytobenthic species on the habitat.

The present study mainly aims to investigate macrozoobenthic community structures of the alien mussel beds, to determine environmental variables mainly responsible for shaping the species assemblages of the habitat and to find out the importance of alien species associated with the mussel beds.

MATERIALS AND METHODS

Study area and sampling

Among 55 coastal stations selected for investigating macrozoobenthic community structures of the shallow-water benthic habitats along the Turkish Levantine coast within the framework of a TUBITAK project (104Y065), seven stations, which had large, continuous beds of the mussel *Brachidontes pharaonis*, were selected for the study of faunistic assemblages of the mussel beds (Figure 1). Three random replicates were taken at the lower mediolittoral zone at each station using a quadrate of 20 × 20 cm in dimension and all materials within each quadrate were carefully scraped by a spatula and immediately put in jars with 10% seawater-formalin solution. In the laboratory, material was first washed with tap water on a 0.5 mm mesh and then sorted under a stereomicroscope. Specimens belonging to each taxonomic group were put into separate vials and preserved with 70% alcohol. Specimens were then identified to species level and counted. Biomass (wet weights) of the mussel and associated fauna were determined by a balance after resting them on absorbent paper to remove water from their bodies.

At each station, seawater samples were taken at 0.5 mm depth to determine some main environmental variables. Temperature and the dissolved oxygen concentration were encountered in the field. Water samples for analysing salinity, pH, nitrite, nitrate, ammonium, phosphate phosphorus and silicate were poured into the bottles, frozen and then transferred to the laboratory immediately. Salinity, pH and nutrients were analysed by using the Mohr–Knudsen method, a pH meter and a spectrophotometer, respectively (Parsons *et al.*, 1984).

The specimens identified were deposited at the Museum of the Faculty of Fisheries of Ege University (ESFM), Izmir (Turkey).

Statistical analyses

A species and samples matrix (abundance) was created and then analysed to assess the structures of species assemblages of *B. pharaonis* beds. The dominance and frequency of each species were estimated. In all faunistic analyses, the abundances of *B. pharaonis* were omitted to find out the structures of associated faunal communities. The Shannon–Weaver Diversity (H') and Pielou's Evenness (J') Indices were used to find out the species diversity and equilibrium on the mussel beds. Cluster analysis based on the Bray–Curtis similarity index was used to delineate species assemblages in the region. Principal coordinate analysis (PCO) based on the Bray–Curtis similarity was performed to determine the environmental variables and species principally responsible for structuring species assemblages in the mussel beds. Raw data were transformed by using the transformation of log $(x + 1)$ before the multivariate analysis. SIMPROF analysis was used to assess significant species assemblages ($P < 0.05$) in the area. SIMPER analysis was applied to the species assemblages to assess which species contributed most to similarity and dissimilarity of species assemblages. One-way ANOVA was used to find out if there is a significant difference in community parameters (species numbers, diversity and evenness index) among stations. Before the analysis, the normality (Kolmogorov–Smirnov) and variance homogeneity (Cochran) tests were performed on the raw data. The Pearson correlation analysis was used to determine the correlation between the community parameters (diversity index, evenness index, species richness, number of species and number of individuals) and biotic indices, and environmental parameters. All analyses were performed using the PRIMER v7 and STATISTICA 7 packages.

The ecological status of each station was calculated using the biotic indices TUBI (Çinar *et al.*, 2015) and ALEX (Çinar & Bakir, 2014). In the calculation of TUBI scores, each species was assigned to one of the three ecological groups [sensitive/indifferent species (G1), tolerant species (G2) and opportunistic species (G3)], based on their sensitivity to an increasing stress gradient (see Table 1). The national database was used to determine ecological groups of each species presented by Çinar *et al.* (2015). The ecological

Fig. 1. Map of the investigated area with the location of sampling sites.

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Table 1. List of species found in association with the invasive Red Sea mussel *Brachidontes pharaonis*, and their maximum densities (ind m^{-2}) at stations.

		STATIONS						
	EG/ZG	K1	K5	K12	K19	K27	K28	K37
PORIFERA								
Sycon raphanus (Schmidt, 1862)	G1/GI	–	–	–	–	25	275	–
CNIDARIA								
Hydrozoa								
*_Macrorhynchia philippina_ (Kirchenpauer, 1872)	G1/GIV	–	–	–	–	–	25	–
Anthozoa								
Aiptasiogeton pellucidus (Hollard, 1848)	G2/GI	75	50	5075	25	50	75	–
Actinaria (sp. 1)	G2/GI	–	–	825	–	325	–	–
Actinaria (sp. 2)	G1/GI	125	–	–	–	–	–	–
Actinaria (sp. 3)	G1/GI	–	–	–	–	200	–	–
Actinaria (sp. 4)	G1/GI	100	–	–	–	–	–	–
TURBELLARIA								
Turbellaria (sp. 1)	G1/GI	50	–	–	–	–	–	–
Turbellaria (sp. 2)	G1/GI	–	–	–	–	25	50	–
Turbellaria (sp. 3)	G1/GI	50	200	–	25	125	25	–
Turbellaria (sp. 4)	G1/GI	–	50	–	–	100	50	75
NEMERTINI								
Emplectonema gracile (Johnston, 1837)	G2/GI	–	200	–	–	125	425	–
Lineus cf. _ruber_ (Müller, 1774)	G2/GI	–	–	25	–	225	175	–
Lineus sp.	G1/GI	–	–	–	–	25	–	–
Nemertopsis bivittata (Delle Chiaje, 1841)	G1/GI	200	175	–	–	–	–	–
Nemertini (sp. 1)	G2/GI	–	–	–	–	–	275	–
Nemertini (sp. 2)	G2/GI	375	975	125	50	50	–	125
NEMATODA								
Nematoda (sp.)	G2/GI	50	–	–	–	75	–	–
SIPUNCULA								
Onchnesoma steenstrupii steenstrupii (Koren & Danielssen, 1876)	G1/GI	–	–	25	–	–	–	–
Phascolosoma (_P._) _stephensoni_ (Stephen, 1942)	G1/GI	5150	475	–	975	1425	3225	525
Phascolosoma sp.	G1/GI	–	25	–	–	–	–	–
Aspidosiphon (_A._) _misakiensis_ (Ikeda, 1904)	G1/GI	25	–	–	–	50	50	325
OLIGOCHAETA								
Oligochaeta (sp.)	G3/GI	–	–	225	25	–	–	–
POLYCHAETA								
Polynoidae								
Harmothoe spinifera (Ehlers, 1864)	G1/GI	–	–	–	25	–	–	–
Lepidonotus clava (Montagu, 1808)	G1/GI	–	–	–	50	–	75	50
Phyllodocidae								
Eulalia clavigera (A. & Milne Edwards, 1833)	G1/GI	50	25	25	–	25	50	–
Eumida sanguinea (Örsted, 1843)	G1/GI	–	–	300	–	25	–	–
Pterocirrus macroceros (Grube, 1860)	G1/GI	–	–	–	–	–	–	125
Amphinomidae								
Hermodice carunculata (Pallas, 1766)	G2/GI	–	–	–	–	25	–	–
*_Linopherus canariensis_ (Langerhans, 1881)	G2/GIV	–	–	–	150	75	–	–
Chrysopetalidae								
Chrysopetalum debile (Grube, 1855)	G1/GI	–	–	–	125	125	250	300
Hesionidae								
Psamathe fusca (Johnston, 1836)	G2/GI	–	–	–	25	–	–	–
Oxydromus pallidus (Claparède, 1864)	G3/GI	25	–	–	–	–	–	–
Syllidia armata (Quatrefages, 1866)	G3/GI	–	25	–	25	–	–	–
Syllidae								
Branchiosyllis exilis (Gravier, 1900)	G1/GI	–	–	–	25	–	–	75
Eusyllis lamelligera (Marion & Bobretzky, 1875)	G1/GI	–	–	–	–	–	–	50
*_Exogone breviantennata_ (Hartmann-Schröder, 1959)	G1/GIII	–	–	–	–	–	–	25
Exogone dispar (Webster, 1879)	G1/GI	–	–	25	25	–	–	–
Haplosyllis spongicola (Grube, 1855)	G1/GI	–	–	–	–	–	–	100
Myrianida convoluta (Cognetti, 1953)	G1/GI	–	–	–	125	–	75	25
Myrianida quindecimdentata (Langerhans, 1884)	G1/GI	–	–	–	–	–	–	25
Odontosyllis fulgurans (A. & Milne Edwards, 1833)	G1/GI	–	25	–	25	–	50	–
Parapionosyllis minuta (Pierantoni, 1903)	G1/GI	–	–	25	–	–	–	–
Proceraea aurantiaca (Claparède, 1868)	G1/GI	–	–	–	–	–	25	–
Salvatoria clavata (Claparède, 1863)	G1/GI	–	–	–	25	75	75	–

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Table 1. Continued

	EG/ZG	STATIONS K1	K5	K12	K19	K27	K28	K37
Sphaerosyllis austriaca (Banse, 1959)	G1/GI	–	–	–	25	–	–	–
Sphaerosyllis pirifera (Claparède, 1868)	G1/GI	–	150	–	200	50	–	–
Sphaerosyllis taylori (Perkins, 1981)	G1/GI	–	–	–	–	–	75	–
Syllis amica (Quatrefages, 1866)	G1/GI	1625	1075	950	–	350	350	100
Syllis armillaris (O.F. Müller, 1776)	G2/GI		25	1275	–	–	800	–
Syllis beneliahuae (Campoy & Alquézar, 1982)	G1/GI	–	–	–	–	–	75	–
Syllis corallicola (Verrill, 1900)	G1/GI	–	–	–	–	–	–	75
**Syllis ergeni* (Çinar, 2005)	G2/GIII	150	50	1000	–	–	300	–
Syllis garciai (Campoy, 1982)	G2/GI	–	–	–	25	–	–	–
Syllis gerlachi (Hartmann-Schröder, 1960)	G1/GI	400	–	–	–	50	–	25
Syllis gracilis (Grube, 1840)	G1/GI	–	–	25	–	50	475	150
Syllis krohnii (Ehlers, 1864)	G1/GI	–	25		–	–	500	–
Syllis prolifera (Krohn, 1852)	G1/GI	–	25	1100	25	5275	225	–
Syllis pulvinata (Langerhans, 1881)	G1/GI	–	–	25	–	–	125	75
Syllis rosea (Langerhans, 1879)	G1/GI	–	25	–	–	–	–	225
Syllis vittata Grube, 1840	G1/GI	25	50	–	–	25	–	–
Syllis sp.	G1/GI	–	25	–	–	–	25	–
Nereididae								
**Ceratonereis mirabilis* (Kinberg, 1865)	G1/GIII	–	–	–	–	25	–	–
Composetia costae (Grube, 1840)	G2/GI	–	–	–	–	–	–	25
Composetia hircinicola (Eisig, 1870)	G1/GI	–	–	–	–	–	75	–
Nereis falsa (Quatrefages, 1866)	G2/GI	350	–	800	–	–	–	–
Nereis zonata (Malmgren, 1867)	G1/GI	25	25	25	–	25	100	25
Perinereis cultrifera (Grube, 1840)	G1/GI	1025	50	–	–	25	–	–
Platynereis dumerilii (Audouin & Milne Edwards, 1834)	G2/GI	700	50	–	–	–	–	–
**Pseudonereis anomala* (Gravier, 1900)	G2/GIV	775	2000	525	350	8925	800	650
Lumbrineridae								
Lumbrineris coccinea (Renier, 1804)	G1/GI	–	–	–	–	–	–	25
**Lumbrineris perkinsi* (Carrera-Parra, 2001)	G2/GIII	–	–	–	–	25	–	–
Scoletoma funchalensis (Kinberg, 1865)	G1/GI	–	–	–	25	–	–	–
Scoletoma impatiens (Claparède, 1868)	G1/GI	–	–	25	–	–	–	–
Eunicidae								
**Leodice antennata* Savigny in (Lamarck, 1818)	G1/GIV	–	25	–	–	–	350	25
Lysidice margaritacea (Claparède, 1868)	G1/GI	–	–	–	325	–	–	–
Lysidice unicornis (Grube, 1840)	G1/GI	–	–	–	–	25	–	25
Dorvillleidae								
**Dorvillea similis* (Crossland, 1924)	G1/GIII	–	–	–	25	–	–	250
Oenonidae								
Arabella iricolor (Montagu, 1804)	G1/GI	–	–	25	50	50	–	–
Orbiniidae								
Naineris laevigata (Grube, 1855)	G2/GI	–	–	–	–	–	50	–
Protoaricia oerstedii (Claparède, 1864)	G2/GI	–	25	25	–	75	125	25
Paraonidae								
Aricidea (*Acmira*) *cerrutii* (Laubier, 1966)	G1/GI	–	–	–	–	–	25	–
Spionidae								
Microspio mecznikowianus (Claparède, 1869)	G2/GI	–	25	–	–	–	–	–
Polydora agassizi (Claparède, 1869)	G3/GI	–	–	25	–	–	–	–
Dipolydora armata (Langerhans, 1880)	G2/GI	–	–		25	–	–	–
Polydora sp.	G2/GI	–	–	300	–	–	–	–
Pseudopolydora antennata (Claparède, 1869)	G1/GI	–	–	325	–	–	–	–
**Pseudopolydora paucibranchiata* (Okuda, 1937)	G3/GIV	–	–	–	–	–	–	25
Laubieriellus salzi (Laubier, 1970)	G1/GI	–	–	–	–	–	50	–
Prionospio fallax (Söderström, 1920)	G3/GI	25	–	–	–	–	–	–
Capitellidae								
Capitella teleta (Blake, Grassle & Eckelbarger, 2009)	G3/GI	–	–	1350	–	–	–	–
Capitellidae (sp.)	G2/GI	–	–	–	–	–	25	–
Mediomastus cirripes (Ben-Eliahu, 1976)	G3/GI	–	–	25	–	–	–	–
Cirratulidae								
Aphelochaeta sp.	G1/GI	–	–	–	–	50	–	–
Caulleriella sp.	G2/GI	–	–	100	–	–	–	50
Cirriformia sp.	G2/GI	–	–	–	–	–	–	50
Dasybranchus gajolae (Eisig, 1887)	G2/GI	–	–	25	–	–	–	–

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Table 1. Continued

		STATIONS						
	EG/ZG	K1	K5	K12	K19	K27	K28	K37
Dodecaceria sp.	G2/GI	–	–	–	–	–	–	25
Opheliidae								
Polyophthalmus pictus (Dujardin, 1839)	G1/GI	50	–	50	–	425	275	50
Terebellidae								
Neoamphitrite figulus (Dalyell, 1853)	G2/GI	–	–	–	–	–	175	–
Nicolea venustula (Montagu, 1819)	G2/GI	75	–	–	–	–	–	25
Polycirrus sp.	G1/GI	–	–	–	–	–	–	50
Terebella lapidaria (Linnaeus, 1767)	G3/GI	–	–	25	–	–	–	–
Timarete sp.	G2/GI	–	–	–	–	25	–	25
Sabellidae								
Amphiglena mediterranea (Leydig, 1851)	G1/GI	–	25	–	–	25	–	–
Dialychone collaris (Langerhans, 1881)	G1/GI	–	–	–	–	–	50	–
Megalomma sp.	G1/GI	–	–	–	–	–	25	–
Serpulidae								
**Hydroides elegans* (Haswell, 1883)	G3/GIV	–	–	25	–	–	–	–
**Hydroides operculata* (Treadwell, 1929)	G2/GIV	–	–	1625	–	–	–	–
**Spirobranchus kraussii* (Baird, 1865)	G2/GIV	75	–	27425	–	–	–	–
CRUSTACEA								
Cirripedia								–
Amphibalanus amphitrite (Darwin, 1854)	G1/GI	–	–	–	–	–	–	25
Chthamalus stellatus (Poli, 1791)	G2/GI	–	3675	–	–	–	–	150
Euraphia depressa (Poli, 1791)	G2/GI	450	–	–	–	–	–	–
Perforatus perforatus (Bruguière, 1789)	G2/GI	–	–	–	–	–	–	25
Tanaidacea								
Apseudes latreillii (Milne-Edwards, 1828)	G2/GI	–	25	–	–	3625	–	–
Chondrochelia savignyi (Kroyer, 1842)	G2/GI	–	–	–	–	225	–	75
Tanais dulongii (Audouin, 1826)	G2/GI	25	–	–	–	900	25	–
Amphipoda								
Ampithoe ramondi (Audouin, 1826)	G2/GI	1975	1375	–	75	1150	–	–
Caprella hirsuta (Mayer, 1890)	G1/GI	–	–	–	–	100	–	–
**Elasmopus pectenicrus* (Bate, 1862)	G2/GIII	1150	–	–	–	–	–	–
Elasmopus pocillimanus (Bate, 1862)	G1/GI	–	175	1200	525	6775	3900	975
Ericthonius punctatus (Bate, 1857)	G1/GI	–	–	–	–	175	150	–
**Gammaropsis togoensis* (Schellenberg, 1925)	G1/GIII	–	–	150	–	–	–	–
Hyale camptonyx (Heller, 1866)	G1/GI	–	–	–	–	350	–	–
Hyale crassipes (Heller, 1866)	G1/GI	175	750	600	–	925	650	125
Hyale schmidti (Heller, 1866)	G1/GI	150	–	–	–	–	–	–
Jassa marmorata (Holmes, 1905)	G3/GI	25	–	–	–	–	–	–
Jassa ocia (Bate, 1862)	G1/GI	–	–	–	–	–	100	–
Lembos websteri (Bate, 1857)	G1/GI	–	–	–	–	125	–	–
Quadrimaera inaequipes (A. Costa, 1857)	G1/GI	–	–	–	–	125	–	375
Ptilohyale plumicornis (Heller, 1866)	G1/GI	75	–	–	–	–	–	–
Podocerus variegatus (Leach, 1814)	G2/GI	–	–	–	25	–	900	–
**Stenothoe gallensis* (Walker, 1904)	G1/GIV	–	–	–	–	1025	28175	–
Isopoda					–			
Cyathura carinata (Kroyer, 1847)	G2/GI	–	–	75	–	–	–	–
Carpias stebbingi (Monod, 1933)	G1/GI	–	–	–	–	25	–	75
Natatolana neglecta (Hansen, 1890)	G1/GI	–	–	50	–	–	–	–
Cymodoce truncata (Leach, 1814)	G1/GI	–	–	25	–	–	–	–
Dynamene edwardsi (Lucas, 1849)	G1/GI	–	–	50	–	–	–	–
Dynamene bicolor (Rathke, 1837)	G1/GI	–	–	250	–	50	–	–
Dynamene magnitorata (Holdich, 1968)	G1/GI	–	–	50	–	–	–	–
Gnathia vorax (Lucas, 1849)	G1/GI	–	25	–	–	–	–	–
Gnathia maxillaris (Montagu, 1804)	G1/GI	–	–	–	–	–	–	75
Janiropris breviremis (G.O. Sars, 1883)	G1/GI	–	–	–		25	–	25
Janira maculosa (Leach, 1814)	G1/GI	–	50	–	125	400	–	125
**Paradella dianae* (Menzies, 1962)	G3/GIII	–	–	1175	–	–	–	–
Isopoda (sp.)	G1/GI	–	–	–	–	–	–	50
Decapoda								
Acanthonyx lunulatus (Risso, 1816)	G1/GI	–	–	–	–	125	–	25
Alpheus dentipes (Guérin, 1832)	G1/GI	–	–	–	–	–	–	25
Alpheus sp.	G1/GI	–	–	–	25	–	25	–

Continued

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Table 1. Continued

		STATIONS						
	EG/ZG	K1	K5	K12	K19	K27	K28	K37
Athanas nitescens (Leach, 1814)	G1/GI	–	–	–	–	–	25	100
Diogenes pugilator (Roux, 1829)	G1/GI	–	25	–	–	–	–	–
Hippolyte leptocerus (Heller, 1863)	G1/GI	–	–	–	–	–	–	50
Pachygrapsus marmoratus (Fabricius, 1787)	G1/GI	100	–	–	–	–	100	–
Pachygrapsus maurus (Lucas, 1846)	G1/GI	–	25	–	–	–	25	25
Pagurus sp.	G1/GI	–	–	–	–	–	–	75
**Pilumnopeus vauquelini* (Audouin, 1826)	G1/GII	–	–	–	–	–	50	–
Pilumnus hirtellus (Linnaeus, 1761)	G1/GI	25	–	–	25	–	25	25
Porcellana platycheles (Pennant, 1777)	G1/GI	–	–	–	25	–	–	–
PANTOPODA								
Tanystylum sp.	G2/GI	–	–	–	–	–	25	–
MOLLUSCA								
Polyplacophora								
Lepidochitona caprearum (Scacchi, 1836)	G1/GI	–	150	–	–	–	–	–
Chiton olivaceus Spengler, 1797	G1/GI	–	–	–	–	–	–	25
Acanthochitona crinita (Pennant, 1777)	G1/GI	–	–	–	–	–	–	50
Acanthochitona fascicularis (Linnaeus, 1767)	G1/GI	–	–	–	–	–	–	25
Gastropoda								
Patella caerulea Linnaeus, 1758	G1/GI	–	100	–	–	25	–	50
Patella rustica Linnaeus, 1758	G1/GI	–	100	–	–	–	–	–
Fissurella nubecula (Linnaeus, 1758)	G1/GI	–	–	725	–	–	25	–
**Cerithium scabridum* Philippi, 1848	G1/GIV	–	–	–	–	25	–	25
Bittium latreillii (Payraudeau, 1826)	G1/GI	–	–	–	–	–	–	25
Bittium reticulatum (da Costa, 1778)	G1/GI	–	–	–	–	–	–	25
Hydrobia acuta (Draparnaud, 1805)	G1/GI	–	–	–	–	–	–	25
**Conomurex persicus* (Swainson, 1821)	G1/GIV	–	–	–	–	25	–	–
Dendropoma cristatum (Biondi, 1859)	G1/GI	–	25	–	–	–	–	–
Hexaplex trunculus (Linnaeus, 1758)	G1/GI	–		–	–	–	–	50
**Ergalatax junionae* Houart, 2008	G1/GIV	–	–	–	–	–	–	25
Columbella rustica (Linnaeus, 1758)	G1/GI	–	–	–	–	–	–	100
Bivalvia								
**Brachidontes pharaonis* (Fischer P., 1870)	G2/GIV	12800	14700	12675	1975	15650	27525	5750
Mytilaster minimus (Poli, 1795)	G1/GI	125	–	17250	–	–	275	–
Mytilaster solidus Monterosato, 1883	G1/GI	–	–	–	–	–	25	75
Gregariella petagnae (Scacchi, 1832)	G1/GI	–	–	750	–	–	25	–
Musculus costulatus (Risso, 1826)	G1/GI	–	–	25	–	25	100	–
Petricola lithophaga (Retzius, 1788)	G1/GI	–	–	825	–	–	–	–
BRYOZOA								
Cradoscrupocellaria bertholletii (Audouin, 1826)	G1/GI	–	–	–	–	–	25	–
Schizoporella cf. *tetragona* (Reuss, 1848)	G1/GI	–	–	–	–	–	–	25
ECHINODERMATA							–	
Ophioderma longicauda (Bruzelius, 1805)	G1/GI	–	–	–	–	–	–	25
Ophiothrix fragilis (Abildgaard in O.F. Müller, 1789)	G1/GI	–	–	–	–	–	–	25
Paracentrotus lividus (Lamarck, 1816)	G2/GI	–	–	–	–	–	–	25
TUNICATA							–	
Tunicata (sp.)	G1/GI	–	–	–	–	–	50	–

The ecological (EG) and zoogeographic groups (ZG) to which each species was assigned is also given. Ecological Groups (EG) of TUBI: G1: sensitive and indifferent species, G2: tolerant species, G3: opportunistic species. Zoological Groups (ZG) of ALEX: GI: native species, GII: casual species, GIII: established species; GIV: invasive species. *denotes alien species.

groups of the species that are absent in the national database were assessed by the expert team for zoobenthos in the laboratory. The boundary of each ecological status for TUBI that was presented by Çinar *et al.* (2015) was used in the present study. The alien biotic index ALEX (Çinar & Bakir, 2014) was used to assess ecological status of stations based on the relative abundances of zoogeographic groups, which are native species (GI), casual alien species (GII), established alien species (GIII) and invasive alien species (GIV). The ecological status of stations was classified according to the ALEX scores from bad to high.

RESULTS

Density and biomass of *Brachidontes pharaonis*

The density and biomass of the invasive mussel *Brachidontes pharaonis* significantly changed among stations (ANOVA, $P < 0.01$). The population density of the mussel ranged from 1575 ind m^{-2} (K19) to 27,525 ind m^{-2} (K28) in samples (Figure 2). The maximum mean density (22,250 ind m^{-2}) of the mussel was calculated at station K28, the minimum mean density (1775 ind m^{-2}) at station K19 (Figure 2). The mean

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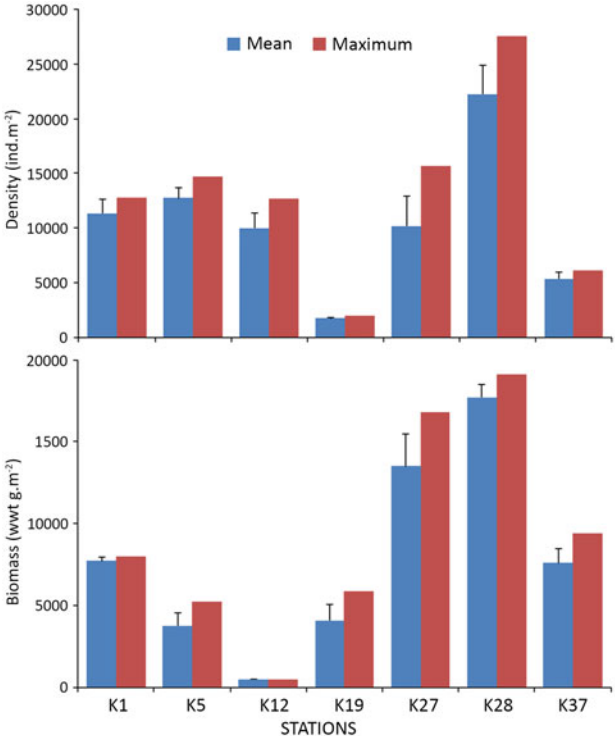

Fig. 2. Mean and maximum density and biomass of *Brachidontes pharaonis* at stations with + standard error (SE).

shell length of the mussel was ~16 mm at stations 1 and 5 (max. 28 mm). The biomass (wet weight) of the mussel varied among samples, with scores between 454 g m^{-2} (K12) and 19,088 g m^{-2} (K28). The mean biomass of the mussel at stations ranged from 468 g m^{-2} (K12) to 17,711 g m^{-2} (K28) (Figure 2). At station K12, specimens were mainly composed of juveniles, which is why, although the density of the mussel was relatively high (mean: almost 10,000 ind m^{-2}), the biomass of the mussel had the lowest score at this station. This could be mainly attributed to polluted freshwater discharges near the site.

Faunal assemblages of the *B. pharaonis* bed

A total of 187 macro-benthic species belonging to 11 taxonomic groups were identified in *B. pharaonis* samples collected at seven stations (Table 1). Among the groups, Polychaeta was the most dominant group in terms of the number of species (87 species, 46% of total number of species) and the number of individuals (37% of the total number of individuals) in the assemblages, followed by Crustacea and Mollusca (Figure 3). Five species, namely *Stenothoe gallensis, Spirobranchus kraussii, Mytilaster minimus, Elasmopus pocillimanus* and *Phascolosoma stephensoni*, comprised 67% of the total number of individuals encountered on the mussel beds, with *S. gallensis* being the most dominant one in the area (Figure 4). *Stenothoe gallensis* was found only at two stations (K27 and K28) and reached a maximum density of 28,175 ind m^{-2} (see Table 1). Similary, *P. kraussi* was only found at two stations and highly dominated the associated fauna of the mussel beds at station K12 (max. density: 27,425 ind m^{-2}). The species with the highest occurrence in samples were *Pseudonereis anomala* (100% of samples), *P. stephensoni* (81%), *E. pocillimanus* (76%), *Syllis amica* (76%) and *Hyale crassipes* (67%).

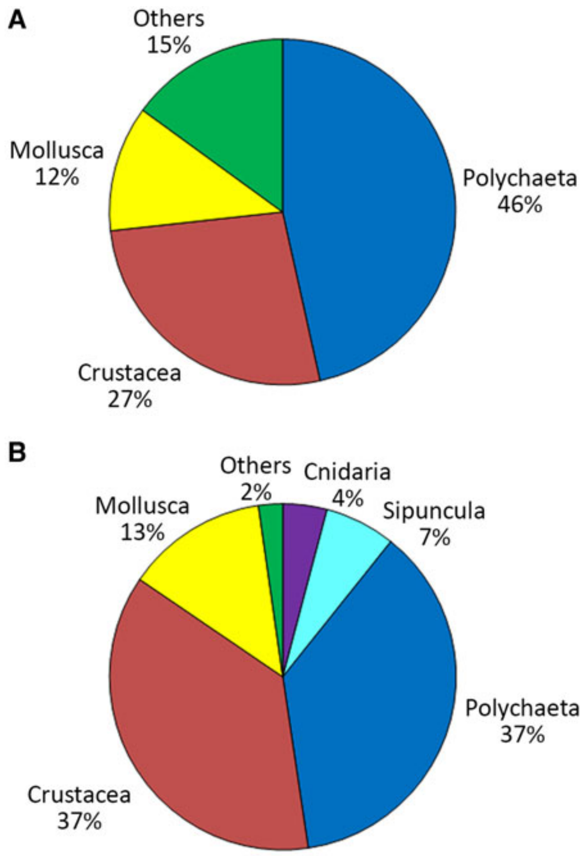

Fig. 3. A. Dominance of taxonomic groups in terms of the number of species, B. Dominance of taxonomic groups in terms of the number of individuals.

The mean number of species considerably varied among sampling stations, ranging from 17 (at station K19) to 39 (K28) (Figure 5). The macro-zoobenthos density ranked from 1800 ind m^{-2} (at station K19) to 42,550 ind m^{-2} (K12) among samples, with the highest mean density of 34,700 ind m^{-2}. The biomass (wet weight) of the associated fauna varied between 4.04 g m^{-2} (K19) and 1503 g m^{-2} (K12), with the highest mean biomass of 1395 g m^{-2}. The mean diversity index values (H') were lower than 3 at two

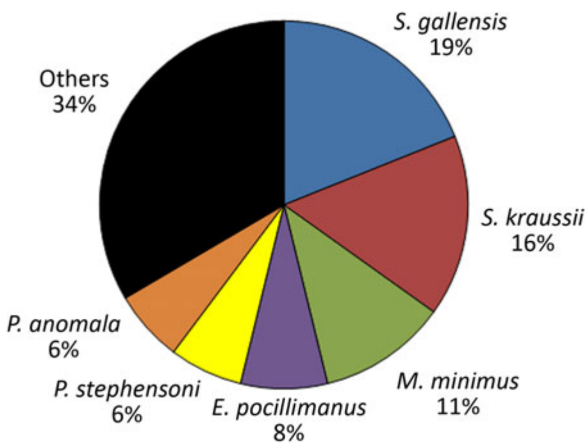

Fig. 4. Dominance of species associated with the *Brachidontes pharaonis* beds.

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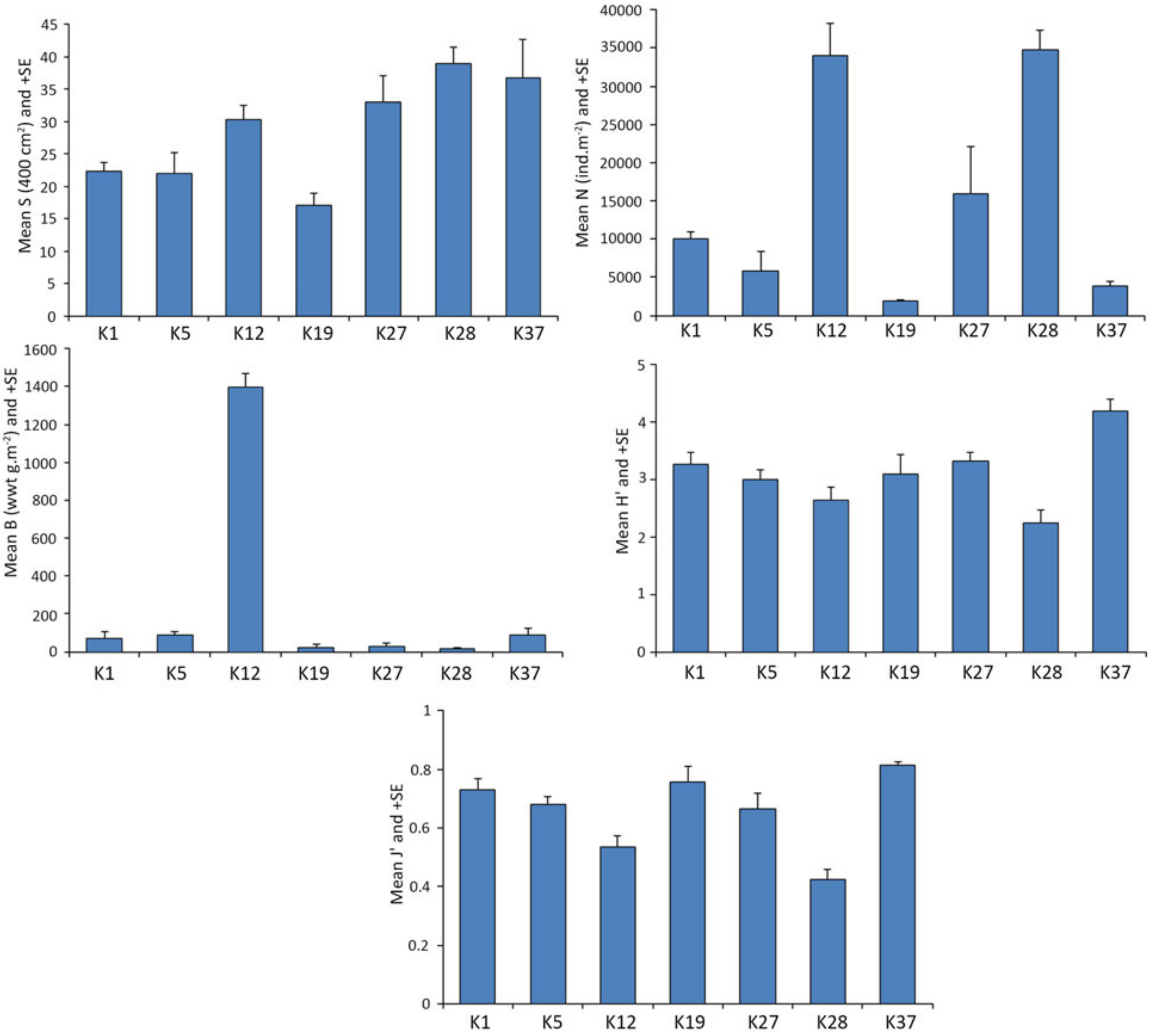

Fig. 5. Mean number of species (S), density (N), biomass (B) of the associated fauna, and mean values of diversity (H') and evenness (J') indices, with + standard error (SE).

stations (K12 and K28), where the two most dominant species (*S. kraussii* and *M. minimus* at station K12, and *S. gallensis* and *E. pocillimanus* at station K28) comprised almost 70–75% of total number of individuals that considerably diminished the score of H'. The lowest mean evenness index value ($J' = 0.42$) was calculated at station K28 and the highest ($J' = 0.82$) at station K37. The differences of these community parameters among stations were statistically significant ($P < 0.001$).

The similarity among replicates at each station was higher than 45% and the highest scores (>70%) were estimated at stations K1, K12 and K28. Two main species associations (A and B) were encountered in the area at the level of 40% and the similarity among them was statistically significant (SIMPROF analysis, $P < 0.05$) (Figure 6). These associations occurred at the neighbouring stations K1 and K5 (group A), and K27 and K28 (group B), and relatively different species associations were found among distant stations, K12, K19 and K37. The species responsible for the similarity in the groups and the dissimilarity between groups were indicated in Table 2. Two amphipods, *Amphithoe ramondi* (contribution: 14%) and *Elasmopus pocillimanus* (11%) contributed much to the similarity in the groups A and B, respectively. High differences in the abundance of *A. ramondi, E. pocillimanus* and *Pseudonereis anomala* resulted in the dissimilarity (67%) between the groups (see Table 2). A very low similarity (around 22%) was estimated between station K12 and the others, due to exceptionally high densities of *Spirobranchus kraussii* (max. 27,425 ind m^{-2}) and *Mytilaster minimus* (17,250 ind m^{-2}) at the station.

The PCO analysis showed that the macro-zoobenthic assemblages of the mussel beds differed greatly among stations (Figure 7). The first two axes together explained almost 50% of the variability. The environmental variables which had the highest correlation with the axis PCO1 were salinity ($r = 0.90$), dissolved oxygen ($r = 0.72$) and total nitrogen ($r = -0.70$). Phosphate phosphorus ($r = 0.44$) and temperature ($r = 0.41$) showed high correlations with the axis PCO2.

Ecological status of stations

The importance of ecological groups (GI–GV) at stations is depicted in Figure 8. The sensitive (GI) and indifferent species

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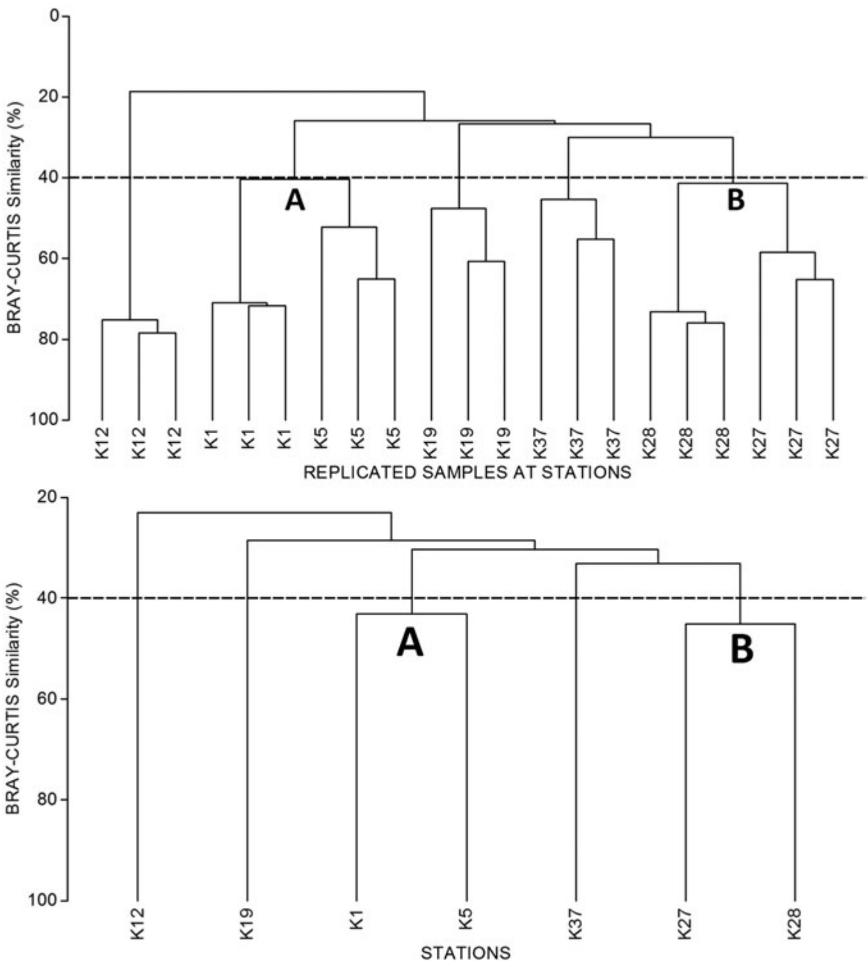

Fig. 6. Dendrogram indicating similarity and dissimilarity of replicated samples (upper graph) and stations (lower graph).

(GII) comprised more than 50% at most stations, except for stations K5 and K12 where tolerant species (GIII) accounted for more than 50% of total specimens. The opportunist species (GIV and GV) had lowest percentages (<1%) at stations, but these species possessed 3.2% of total abundances at station K12 where *Capitella teleta* (max. 1350 ind m^{-2}) and *Paradella dianae* (max. 1175 ind m^{-2}) occurred in abundance. The values of TUBI ranged from 2.69 (K12) to 4.45 (K37) in samples. According to the mean values of TUBI, only K12 had a value lower than 3, which is a threshold between good and moderate ecological status. The ecological status of other stations (water bodies) was classified as good or high (K37).

Table 2. The species (with per cent contributions) that contributed most to the species assemblages of the mussel *Brachidontes pharaonis* according to the SIMPER analysis.

Associations % similarity and dissimilarity	Similarity A 43%	 B 45%	Dissimilarity AXB 67%	 A AvA	 B AvA
Ampithoe ramondi	14	–	34	0	1378
Pseudonereis anomala	13	8	8	111	273
Syllis amica	12	–	–	–	–
Elasmopus pocillimanus	–	11	15	8	460
Phascolosoma (P.) stephensoni	– –	8	5	187	220
Stenothoe gallensis	–	7	–	–	–
Hyale crassipes	–	7	–	–	–
Syllis prolifera	–	–	6	1	144
Apseudes latreillii	–	–	3	1	73

AvA, Average Abundances.

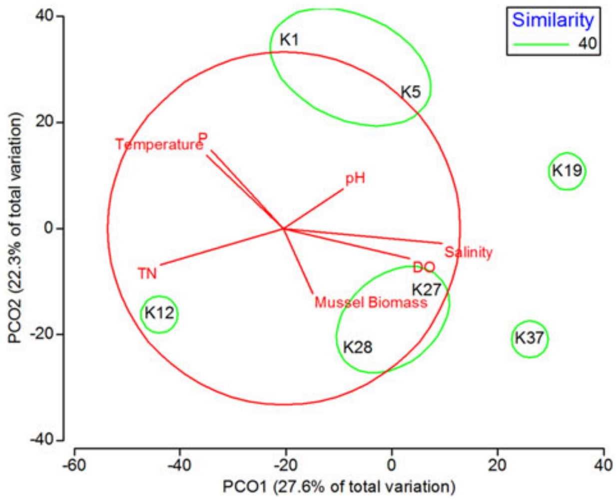

Fig. 7. Principal coordinate analysis (PCO) ordination graph of stations and the correlation of environmental/habitat variables with PCO axes, represented by superimposed vectors. The similarity among stations was encountered using the Bray–Curtis similarity index and secondarily superimposed on the PCO plot.

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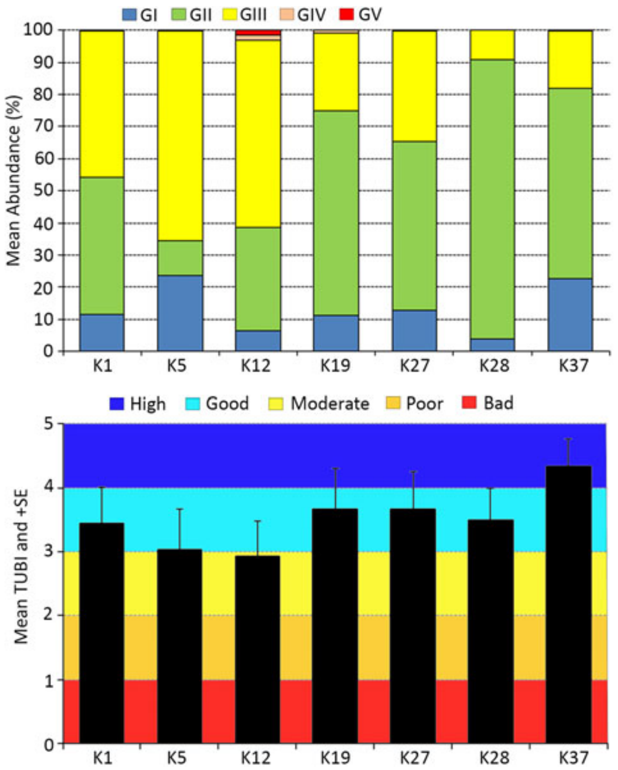

Fig. 8. The mean per cent abundances of ecological groups and the mean values of TUBI (with + standard error) at stations.

Relationships between biotic and abiotic data

The relationships between the environmental variables, and the community parameters of associated fauna and TUBI is depicted in Table 3. Three correlation values were found to be statistically significant; those between biomass, and salinity ($r = -0.84$) and total inorganic nitrogen ($r = 0.93$), and that ($r = -0.79$) between TUBI and phosphate phosphorus. The diversity index and TUBI values were negatively correlated with the concentrations of nutrients in ambient waters. Strong and negative correlations were estimated between TUBI, and the nitrogen and phosphate phosphorus. In contrast, correlations between TUBI, and salinity ($r = 0.73$) and dissolved oxygen ($r = 0.61$) were positive and relatively strong. The number of species was negatively correlated with silica ($r = -0.71$) and phosphate ($r = -0.49$), but was positively correlated with the mussel biomass ($r = 0.62$).

Table 3. Relationships between environmental variables, and the community parameters of associated fauna and TUBI.

	S	*N*	*B*	*H'*	*J'*	TUBI
Salinity	−0.02	−0.53	**−0.84**	0.37	0.41	0.73
Temperature	−0.57	0.08	0.26	−0.23	0.03	−0.47
Dissolved oxygen	−0.19	−0.39	−0.49	0.27	0.39	0.61
pH	−0.04	−0.54	−0.08	0.56	0.52	0.38
Total inorganic nitrogen	0.06	0.55	**0.93**	−0.27	−0.32	−0.51
Phosphate	−0.49	0.01	0.37	−0.28	−0.08	**−0.79**
Silica	−0.71	−0.34	−0.04	0.00	0.34	−0.07
Mussel biomass	0.62	0.30	−0.46	−0.17	−0.39	0.37

S, Number of species; N, Number of individuals; B, Biomass; H', Shannon-Weaver's diversity index; J', Pielou's evenness index.
Bold values were statistically significant ($P < 0.05$).

Alien species

A total of 21 species belonging to four taxonomic groups (Hydrozoa, Polychaeta, Crustacea and Mollusca) were determined on the invasive alien mussel. The ratio between the number of alien species and native species is 0.13 and that between the number of individuals of alien species and native species is 0.77. The alien species comprised 43% of the total number of individuals of the associated fauna. The ratio between the number of native and alien species was almost the same at stations (almost 10%), but that between the number of individuals of natives and aliens considerably varied among stations, with the highest ratio (almost 70%) being estimated at K28 (Figure 9). The correlation between the abundances of alien species and native species in samples was positive ($r = 0.74$) and significant ($P < 0.05$). The total abundances of alien species in samples were positively and significantly correlated with the density of *B. pharaonis* ($r = 0.67$, $P < 0.05$). A weak and insignificant positive correlation ($r = 0.35$, $P > 0.05$) was estimated between abundances of native species and the density of *B. pharaonis* in samples.

The number of alien species varied from 1 to 6 (K12 and 27) at stations, with the highest mean value being calculated at K12 (Figure 10). The density of alien species reached up to 30,300 ind m^{-2} in the area. The mean density of alien species ranged from 342 ind m^{-2} (station K19) to 23,600 ind m^{-2} (K28); the mean diversity index from 0.33 (station K5) to

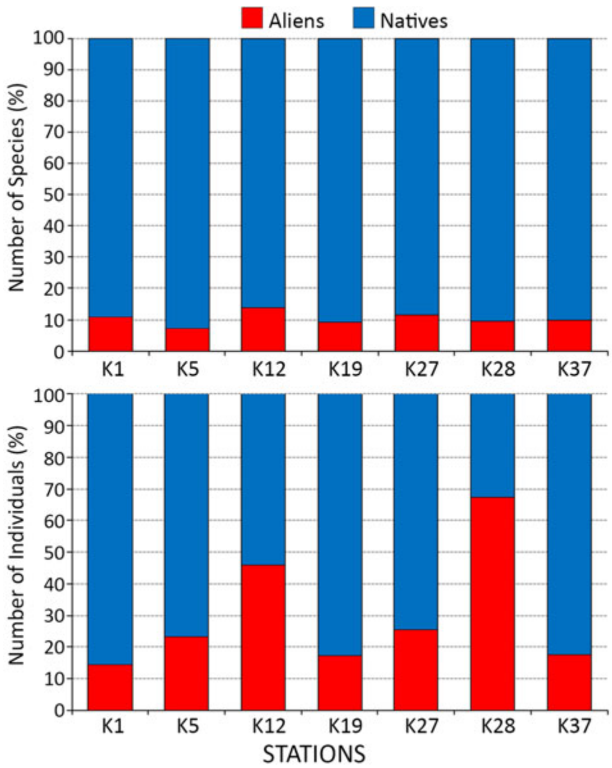

Fig. 9. The ratios between the number of alien and native species (upper graph), and between the number of individuals of alien and native species (lower graph) at stations.

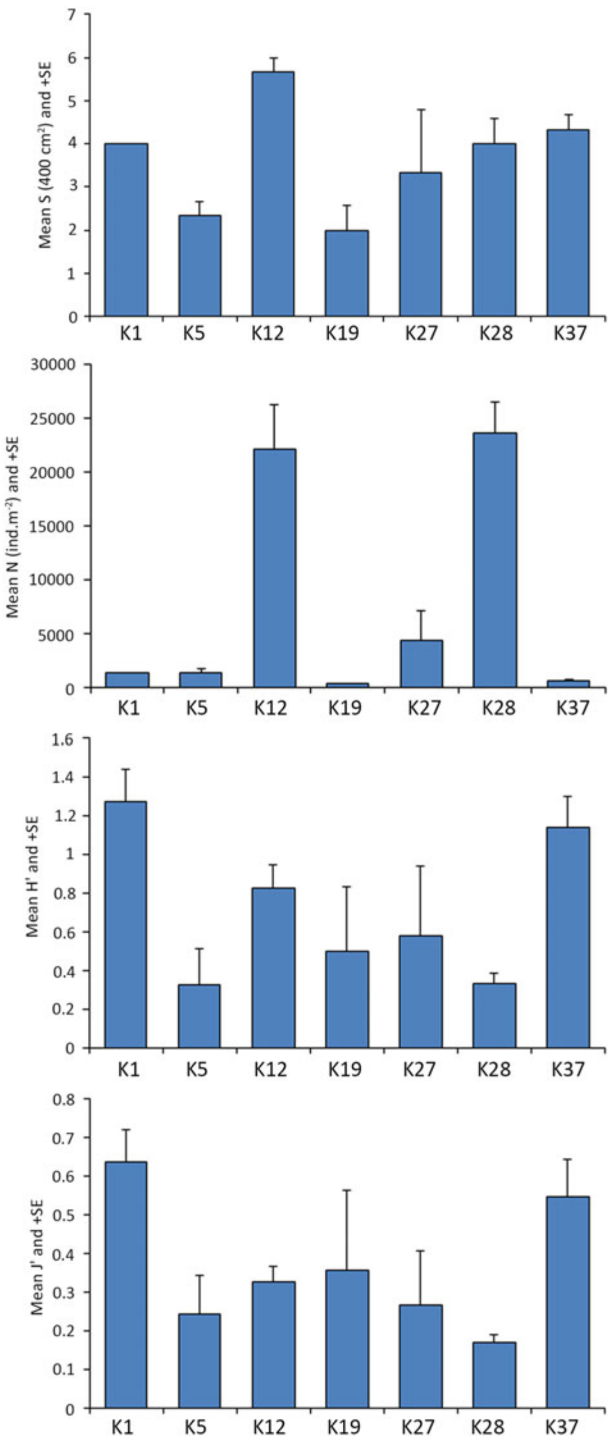

Fig. 10. Mean number of alien species (S) and the density of alien species (N), and the mean diversity (H') and evenness (J') indices based on solely alien species, with + standard error (SE).

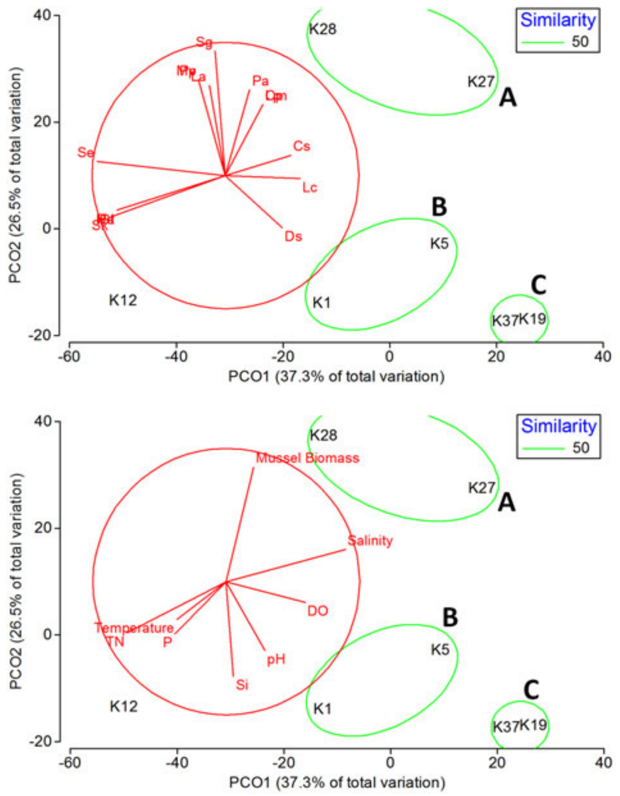

Fig. 11. Principal coordinate analysis (PCO) ordination graph of stations and the correlation of species (upper graph) and environmental/habitat variables (lower graph) with PCO axes, represented by superimposed vectors. The similarity among stations was encountered using the Bray–Curtis similarity index and secondarily superimposed on the PCO plot. Cs: *C. scabridum*, Ds: *D. similis*, Gt: *G. togoensis*, Ho: *H. operculata*, La: *L. antennata*, Lc: *L. canariensis*, Lp: *L. perkinsi*, Pa: *P. anomala*, Pp: *P. paucibranchiata*, Pd: *P. dianae*, Se: *S. ergeni*, Sg: *S. gallensis*, Sk: *S. kraussii.*

1.28 (K1); the mean evenness index from 0.17 (station K28) to 0.64 (K1).

Three species assemblages (groups A, B and C) were found in the area based on the abundance data of alien species (Figure 11). Station K12 showed a low similarity (25%) with the groups, mainly because of the high abundances of *Spirobranchus kraussi, Hydroides operculatus* and *Paradella dianae* at this station. The species mainly responsible for the formation of these assemblages were *Pseudonereis anomala* (contributions: 76, 83 and 53% in groups A, B and C, respectively) and *Stenothoe gallensis* (contribution: 47% only in group C). The dissimilarity among the groups were mainly due to the differences in abundances of the amphipods *S. gallensis* and *Elasmopus pectenicrus*, and the polychaetes *Syllis ergeni, Spirobranchus kraussii* and *P. anomala*.

The PCO analysis indicated that the first two axes explained a total of 64% variation. The species strongly correlated ($r > \pm 0.80$) with the first axis (PCO1) were *S. ergeni* ($r = -0.97$), *S. kraussi* ($r = -0.86$), *Gammaropsis togoensis* ($r = -0.82$), *Hydroides elegans* ($r = -0.82$) and *H. operculatus* ($r = -0.82$). *Stenothoe gallensis* was only species that showed a strong correlation ($r = 0.93$) with the axis PCO2. The most important environmental variables affecting the community structures of alien species in the area are depicted in Figure 11. Salinity ($r = 0.90$) and total inorganic nitrogen ($r = -0.74$) showed strong correlations ($r > \pm 0.70$) with the first axis PCO1, and the mussel biomass ($r = 0.86$) and silica ($r = -0.71$) with the second axis PCO2. The main reasons for the unique species assemblage occurring at station K12 might be lower salinity and higher nutrients values (especially TIN). Higher wet weights of the mussel estimated at stations K28 and K27 where *S. gallensis* only occurred resulted in the discrimination of the group A in the PCO graph.

Among the zoogeographic groups, GI (native species) comprised more than 80% of the mean abundances at stations K1, K19, K27 and K37, which therefore had high ecological

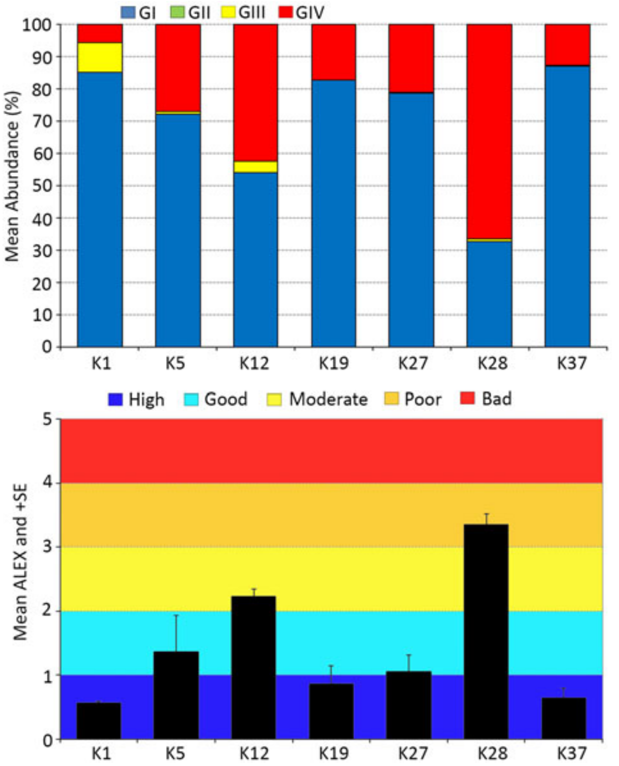

Fig. 12. The mean per cent abundances of zoogeographic groups and the mean values of ALEX (with + standard error) at stations.

Table 4. Relationships between environmental variables, and the community parameters of associated alien fauna and ALEX.

	S_{alien}	N_{alien}	H'_{alien}	J'_{alien}	ALEX
Salinity	−0.66	−0.51	−0.22	−0.04	−0.33
Temperature	0.08	−0.01	0.22	0.21	−0.23
Dissolved oxygen	−0.40	−0.31	−0.05	0.10	−0.30
pH	−0.07	−0.44	0.37	0.51	−0.35
Total inorganic nitrogen	0.72	0.55	0.23	0.00	0.25
Phosphate	−0.06	0.04	−0.23	−0.20	0.07
Silica	−0.25	−0.21	0.08	0.26	−0.28
Mussel biomass	−0.04	0.23	−0.23	−0.29	0.37

S, Number of species; N, Number of individuals; B, Biomass; H', Shannon–Weaver's diversity index; J', Pielou's evenness index.

status according to the ALEX values (Figure 12). The invasive species accounted for more than 40% of total abundances of associated fauna at two stations (K12 and K28). These scores eventually increased the ALEX values that classified the ecological status of these stations as moderate or poor.

The number of alien species and individuals, and diversity index and ALEX were negatively correlated with salinity but positively correlated with total inorganic nitrogen (TIN) (Table 4). The mussel biomass were positively correlated with total number of individuals of alien species and ALEX.

DISCUSSION

The invasive mussel *Brachidontes pharaonis* formed a dense population along the mediolittoral zone and upper infralittoral zone of the north Levantine Sea. The maximum density and biomass of the species were estimated as 22,250 ind m^{-2} and 19,088 wwt g m^{-2}, respectively. Such high densities of this species were previously estimated in Israel (Rilov *et al.*, 2004) and Sicily (Sará *et al.*, 2006). Doğan *et al.* (2008) reported an exceptionally high density (40,000 ind m^{-2}) of this species along the Levantine coast of Turkey, but the specimens of this species in the area were generally juveniles and densely attached themselves to thalli of *Jania rubens* (Linnaeus) J.V. Lamouroux, 1816 (pers. observation). The density of the mussel reached a maximum of 7000 ind m^{-2} in the Red Sea, a possible donor area of the species (Safriel *et al.*, 1980). It was observed in the field that this species mainly preferred horizontal rocky substrate and built up beds alone or together with other sessile species like *Spirobranchus kraussi* or *Mytilaster minimus*. Rilov *et al.* (2004) also found extensive beds of *B. pharaonis* on horizontal and relatively narrow rocky habitats where the *Dendropoma* rim was absent and algal coverage was low. The biomass (dry-weight) of *B. pharaonis* was previously estimated maximally as 50 g m^{-2} in Israel (Rilov *et al.*, 2004).

The invasive mussel was known to be in competition with the native mussel *M. minimus*. They were mixed together in a random spatial pattern, but in different abundances, depending on wave exposure (Safriel & Sasson-Frosting, 1988). Safriel & Sasson-Frosting (1988) concluded that *B. pharaonis* was a typical species in sheltered areas, whereas *M. minimus* was common in wave-exposed sites. However, Rilov *et al.* (2004) proved this argument false and found dense settlements of *B. pharaonis* on wave-exposed rocks. This is true for our cases, in that continuous, large mussel beds were found at stations where strong hydro-dynamism occurred. A considerable increase was observed in the dominance of *B. pharaonis* along the coast of Israel (Rilov *et al.*, 2004). The ratio between the density of *B. pharaonis* and *M. minimus* on beach rocks changed 12-fold over a period of 25 years. The decline of *M. minimus* was thought to be due to the interference effect imposed by the larger *B. pharaonis* on *M. minimus* recruits (Safriel & Sasson-Frosting, 1988). In the present study, only six samples out of 21 included specimens of *M. minimus*, with a relatively high dominance at station K12 where the ratio between the density of *B. pharaonis* and *M. minimus* was estimated as 0.74. In other samples, densities of *M. minimus* can be negligible when compared with those of *B. pharaonis*. Why did *M. minimus* form dense populations at K12 and was almost absent at other stations? This question cannot be well explained by the present sampling design and the number of samples taken. However, the features that made station K12 unique among other stations were to have higher total inorganic nitrogen concentration (7.92 µg l^{-1}, almost 10 times higher than those at other stations) and lower salinity value (38.4 PSU) due to domestic waste-water discharge near the site. It might indicate that polluted waters can act as a refuge for *M. minimus* and a barrier for the spread of *B. pharaonis* in the area. The salinity value measured at station K12 was at a manageable level both for *M. minimus* and *B. pharaonis*. However, the former species was observed to represent signs of stress only at salinities slightly above 37 PSU, whereas the latter species become stressed only at salinities over 45 PSU, which enables it to invade rocky shores even in hyper-saline environments (Sará & de Pirro, 2011). The biomass of *B. pharaonis* was almost 20 times lower than the mean of biomass of the species in the

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area at the polluted station K12, where two sessile species *S. kraussi* and *M. minimus* were also dominant. It seems that *B. pharaonis* is not only in competition with *M. minimus*, but also the serpulid worm, *S. kraussi* in the Levantine Sea. In the SW Atlantic, it was proved in a sewage-impacted site that the massive settlement of a spionid polychaete *Boccardia proboscidea* Hartman, 1940 caused a drastic decline in the density of *Brachidontes rodriguezii* (d'Orbigny, 1842) due to the biogenic reef that suffocated the mytilid (Jaubet *et al*., 2013).

The macro-zoobenthic fauna associated with the *B. pharaonis* mussel beds proved to be diversified, with a total of 187 species belonging to 11 higher taxa. Most of them belonged to polychaetes and crustaceans. Several papers (Çinar, 2006; Doğan *et al*., 2008; Açik, 2011; Bakir & Katağan, 2014; Bitlis-Bakir & Öztürk, 2016; Kurt-Sahin & Çinar, 2017) indicated the species of some taxonomic groups associated with this mussel along the coasts of Turkey, but all of these papers were produced completely or partly based on the dataset presented in the present study. The associated fauna of *B. pharaonis* were previously mentioned in the Mediterranean Sea by Bonnici *et al*. (2012) on the coast of Malta, who identified 48 invertebrate species on the mussel bed. The species richness of the mussel beds on the Turkish coast is almost four times higher than that found on the Maltese coast. The mean species number at stations ranged from 17 to 30 species in the present study, whereas Bonnici *et al*. (2012) reported it between four and 15 in the Maltese waters. This big difference in the species richness between distant mussel beds might be complicated, but the structures of the beds, the sampling placement in the littoral zone, the hydrographic features of ambient waters, species interactions in beds, the differences in quadrate sizes (4 times larger in the present study) might lead to this difference. However, Bonnici *et al*. (2012) stated that the faunal assemblages of the mussel beds were considerably affected by the age of the mussel bed. They also suggested that the *B. pharaonis* beds in Malta, which had intermediate-sized individuals, was recently settled and possessed a low proportion of dead mussel shells, resulting in lower abundance and richness of the associated fauna. Mohammed (1997) carried out a faunistic study on the *B. pharaonis* beds in the Great Bitter Lake in Suez Canal and reported a total of 47 species belonging to eight taxonomic groups, of which Crustacea and Mollusca comprised 46% and 41% of total abundances, respectively. He postulated that the age of mussel beds was the main factor affecting the species assemblages of the mussel. In older mussel beds, the complexity of the habitat increases as a result of larger shell lengths of the mussel that could provide more available spaces for the associated fauna and accumulate more sediments and detritus from ambient waters (Tsuchiya & Nishihira, 1986; Tsuchiya & Bellan-Santini, 1989). The difference in the diversity of faunal assemblages of mussel beds in different areas could also be linked to the availability of taxonomic expertise on different taxonomic groups, the number of samples, the geomorphology of shores and structural complexity of the bed (Hammond & Griffiths, 2004).

The dominant species of the *B. pharaonis* beds on the Turkish coast were *Stenothoe gallensis*, *Spirobranchus kraussii, Mytilaster minimus, Elasmopus pocillimanus* and *Phascolosoma stephensoni* that accounted for 67% of total abundances of the associated fauna. The top two dominant species (comprising 35% of total abundances), namely *S. gallensis* and *S. kraussii*, were alien species possibly introduced to the Mediterranean from the Red Sea via the Suez Canal (Çinar *et al*., 2011). *Stenothoe gallensis* is a small amphipod (~3 mm) that mainly occurred in the shallow-water benthic habitats (1–25 m) of the western and eastern Mediterranean Sea such as algae beds (Krapp-Schickel, 1976; Kocatas & Katağan, 1978), mussel beds (Çinar *et al*., 2008) and *Posidonia oceanica* meadows (Kocatas & Katağan, 1978; Zakhama-Sraieb & Charfi-Cheikhrouha, 2010). The maximum density of these species was previously estimated as 463 ind m^{-2} on a *P. oceanica* bed in Tunisian waters (Zakhama-Sraieb & Charfi-Cheikhrouha, 2010) and as 400 ind m^{-2} on *Mytilus galloprovincialis* in the harbour environment of the Aegean Sea (Çinar *et al*., 2008), whereas it reached up to 28,175 ind m^{-2} on the *B. pharaonis* bed (this study). This species comprised almost 30% of total amphipod abundances found on *Cystoseira* spp. on the coast of Sicily (Krapp-Schickel, 1976). The density of the invasive serpulid polychaete species *S. kraussi* reached 27,425 ind m^{-2} on the mussel bed. It occurred both on mussel shells and spaces among mussels as an erect form. This species was previously known from the area and reported to build up a belt like biogenic habitat in the low mediolittoral zone where its density and biomass was calculated as 31,375 ind m^{-2} and 80 wwt g m^{-2}, respectively (Çinar, 2006). Its distribution within the Mediterranean is confined to the eastern Levantine Sea (Mersin and İskenderun Bays, and Israeli coast). This species was also known to be a component of fouling communities and built up a dense aggregation in the Suez Canal (35,000 ind m^{-2}) (Emara & Belal, 2004) and Hong Kong (30,000 ind m^{-2}) (Jianjun & Zongguo, 1993). In the *B. pharaonis* beds on the coast of Malta, *Bittium* spp. were the most abundant species, followed by Tanaidacea (sp.) and *Rissoa* sp (Bonnici *et al*., 2012). However, their population densities on the mussel beds from the Levantine Sea were too low (i.e. 40 ind m^{-2} for *Bittium* spp.). The most dominant species on the *B. pharaonis* beds in the Suez Canal were *Pirenella conica* (Blainville, 1829), *Gammarus* sp. and *Amphibalanus amphitrite* (Darwin, 1854), all comprising 63% of total abundance (Mohammed, 1997). The similarity between these two studies performed in different regions was that the dominant species belonged to the superfamily of Gastropoda Cerithoidea. However, abundances of this superfamily that were represented by three species (*Cerithidium scabridium* and *Bittium* spp.) were negligible (<0.1%) in the present study.

The PCO analysis indicated two main species associations in the area. The environmental variables mainly responsible for these groupings were dissolved oxygen, total inorganic nitrogen and salinity. Çinar *et al*. (2008) found a similar finding that nutrient concentrations in ambient waters were main drivers in structuring faunal assemblages of *M. galloprovincialis* in the Aegean Sea. The species contributed most to the similarity of assemblages were *Amphithoe ramondi* and *Elasmopus pocillimanus*. However, abundances of *Pseudonereis anomala, Syllis amica* and *Phascolosoma stephensoni* enabled stations to be grouped together at relatively high similarity levels. Çinar *et al*. (2008) also indicated the importance of amphipods and syllids in forming different assemblages on the Mediterranean mussel. Bonnici *et al*. (2012) determined three different species assemblages on the *B. pharaonis* beds in Malta and encountered the importance of *Bittium* spp., Tanaidae (sp.), *Rissoa* sp. in constituting these assemblages. In the present study, no *Rissoa* species was found on the *B. pharaonis* beds, but three tanaid species (*Apseudes latreilli, Chondrochelia savignyi* and *Tanais dulongii*) were encountered in the area. Among these species, *A. latreilli* formed a relatively high population (3625 ind m^{-2}) at station K27 and was one of the main species responsible for the dissimilarity between the species assemblages of the *B. pharaonis* beds.

According to TUBI scores, the ecological status of stations was good or high, except for K12 whose ecological status was found to be moderate. As pointed out earlier, this station is located near a waste-water outfall and was mainly characterized by higher nitrogen concentration. The nutrients (especially phosphate and nitrogen) and TUBI were negatively and significantly correlated, indicating that TUBI enabled detection of deterioration in ecological functioning. This index was newly developed, based on macro-zoobenthos data from soft sediments along the Aegean and Levantine coasts of Turkey and has proved to be more effective in assessing the ecological status of water bodies than other biotic indices widely used in the Mediterranean Sea such as AMBI, M-AMBI, BENTIX and MEDOCC (Çinar *et al.*, 2015). The present study indicated that it is also a useful tool in classifying benthic quality status of hard bottom substrates.

The invasive alien mussel *B. pharaonis* hosted a number of alien species (a total of 21 species) with high abundances. Most of these alien species were the Lessepsian invaders, but five species, namely, *Linopherus canariensis, Hydroides elegans, Pseudopolydora paucibranchiata, Paradella dianae* and *Conomurex persicus* could have been introduced to the eastern Mediterranean by shipping. The alien species reported in the present study were known from the Turkish coasts (Çinar *et al.*, 2011). However, it is the first time *Syllis ergeni* has been classified as alien species in the Mediterranean Sea. This species was originally described from the Aegean Sea (Çinar, 2005) and then subsequently reported from the Mediterranean coast of Egypt (Abd-Elnaby & San Martín, 2011) and the Red Sea (Faiza Abd-Elnaby, pers. comm.). As its distribution is only confined to the Levantine and its neighbouring sea (Aegean Sea), and it dominated shallow-water benthic habitats in the areas, this species could be an alien species introduced to the Mediterranean from the Red Sea via the Suez Canal. The alien species occurring in all samples with relatively high abundance was the nereidid polychaete worm *Pseudonereis anomala*. This species is known to be an invasive species dominating shallow-water benthic habitats of the Levantine (Çinar & Altun, 2007) as well as Aegean Seas (Çinar & Ergen, 2005). This species greatly expanded its distributional range to the coast of Sicily (D'Alessandro *et al.*, 2016). Limited information regarding the population density and biomass of *P. anomala* is available. This species was reported to attain a highest density on the coast of Turkey [2475 ind m^{-2} (on the alga *Jania rubens*), 7.95 g m^{-2} (on *B. pharaonis*)] (Çinar & Altun, 2007). In the present study, the maximum density of it was estimated as 8925 ind m^{-2}. This species is known to be in competition with the native nereidid species such as *Perinereis cultrifera* and *Platynereis dumerilii* (Ben-Eliahu, 1989).

Does high alien diversity (=xenodiversity) found on the invasive mussel bed support the invasion meltdown hypothesis? This hypothesis points out that the successful establishment of one invasive species in a new environment facilitates other alien species to invade (Simberloff & Von Holle, 1999). The alien species found in the mussel beds were also found in different coastal habitats, but the habitat selectivity of alien species should be investigated if the mussel bed habitat favours or facilitates the establishment of any alien species in the area. Almost half of the individuals of the associated fauna belonged to alien species, indicating the importance of alien species in the benthic habitats of the Levantine Sea. In Mersin Bay, alien species comprised 31% of the total number of individuals in soft substrata (Çinar *et al.*, 2012b). However, in polluted soft substrata in İzmir Bay, alien species comprised more than 75% of total individuals (Çinar *et al.*, 2012a). On the Mediterranean mussel beds in the Aegean Sea, Çinar *et al.* (2008) reported 10 alien species, of which *Hydroides elegans* and *H. dianthus* (Verrill, 1873) were the most dominant ones. These species accounted for up to 80% of total individuals at some stations. Three different alien species assemblages were developed in the area, mainly based on the presence/absence and abundances of *Pseudonereis anomala, Spirobranchus kraussi, Paradella dianae, Syllis ergeni* and *Stenothoe gallensis*. The nutrient concentrations, salinity and mussel biomass were the factors mainly controlling the structures of these assemblages. High dominance of alien species at samples increased the ALEX values which classified two stations as moderate (K12) or poor (K28). This index also showed a positive correlation with total inorganic nitrogen in ambient waters. Çinar *et al.* (2012a, b) also indicated the importance of nutrient concentrations in ambient waters, depth and sediment structure in the distribution of alien species in the eastern Mediterranean Sea. The abundances of alien species increased with increasing abundance of native species. The present study did not detect any competition between native and alien species. Such a tendency was also noted by Çinar *et al.* (2012a, b). However, some alien species were reported to eliminate some common opportunistic species in the polluted environments (Çinar *et al.*, 2006).

The present study indicated that the invasive mytilid species, *B. pharaonis* provided shelter and food for a diversified faunal assemblage in the region. The interactions between the structures, orientations of the mussel beds and the associated fauna still remain largely unexplored. In addition, spatio-temporal variations of the faunal assemblages of the beds in larger areas merit detailed investigations to shed more light on the assessment of community structures of the invasive mussel beds.

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