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Distribution, diversity, habitat preferences, and interactions with environmental variables of ostracod (Crustacean) species living in Gulf of Gemlik (The Sea of Marmara, Turkey)

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Abstract

The Gulf of Gemlik, located in the southeast of the Sea of Marmara, is facing a pollution threat due to intense of industrial facilities and urbanization with population growth. This study determined the living ostracod species in the Gulf of Gemlik and investigated their interactions with ecological parameters during a four-season period (August 2011, November 2011, February 2012, May 2012). Twenty-five ostracod species belonging to eight families were identified between at depths 1–96 m. The most abundant ostracod species in the gulf was *Loxoconcha rhomboidea*, *Xestoleberis communis*, *Xestoleberis aurantia*, and *Aurila convexa.* Positive correlations were observed between the individual numbers with dissolved oxygen, temperature, pH, and species numbers, according to Spearman correlations. Negative relationships were observed between individual numbers/depth and individual numbers/salinity.

Key words: Ostracoda, Gulf of Gemlik, ecology, distribution, Sea of Marmara

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Gemlik Körfezi'nde (Marmara Denizi, Türkiye) yaşayan ostrakod (Crustacea) türlerinin dağılımı, çeşitliliği, habitat tercihleri ve çevresel değişkenlerle etkileşimleri

Özet

Marmara Denizi'nin güneydoğusunda yer alan Gemlik Körfezi, sanayi tesislerinin yoğunluğu, nüfus artışı ve kentleşme nedeniyle kirlik tehdidi ile karşı karşıyadır. Bu çalışmada Gemlik Körfezi'nde yaşayan ostrakod türleri belirlenerek, dört mevsim boyunca ekolojik parametlerle ostrakod türlerinin etkileşimleri araştırılmıştır. (Ağustos 2011, Kasım 2011, Şubat 2012, Mayıs 2012). 1-96 m arasındaki derinliklerden sekiz familyaya ait 25 ostrakod türü tespit edilmiştir. Gemlik Körfezi'nde en yüksek bolluğa sahip ostrakod türleri olarak *Loxoconcha rhomboidea*, *Xestoleberis communis*, *Xestoleberis aurantia* ve *Aurila convexa* belirlenmiştir. Spearman korelasyonuna göre ostrakod birey sayısı ile çözünmüş oksijen, sıcaklık, pH ve tür sayısının pozitif ilişkili olduğu belirlenmiştir. Ostrakod birey sayısının, derinlik ve tuzluluk ile de negatif ilişkili olduğu gözlenmiştir.

Anahtar kelimeler: Ostracoda, Gemlik Körfezi, ekoloji, dağılım, Marmara Denizi

1. Introduction

The Gulf of Gemlik is an inlet of the Sea of Marmara in the Marmara region of Turkey. The gulf is located in the southeastern part of the Sea of Marmara. The presence of Turkey's fourth largest free-trade zone in Gemlik has caused a rapid development of the province, with both a population-density increase and industrial facilities on the coasts of the Gulf of Gemlik. The Sea of Marmara is an inner sea located between the Black Sea and the Aegean Sea, connecting to the Aegean Sea via the Dardanelles strait and to the Black sea via the Bosphorus strait [1]. The Sea of Marmara features

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the megacity of Istanbul and other industrial cities (Bursa, İzmit, Yalova, Tekirdağ, Balıkesir), and their major ports and industrial establishments are spread around the region. Accordingly, with the population density high around parts of this sea, it suffers from a pollution threat due to the intensity of industrial facilities, urbanization, and thus population growth. The Gulf of Gemlik is one of the regions featuring the highest levels of industrial, urbanization, and agricultural activities in the Sea of Marmara. Pollutants from the Black Sea, carried via the Bosphorus [2] Semi-closed coastal areas, such as gulfs and bays with restricted water circulation, might show the effects of the marine pollution more clearly [3] Biodiversity is an indicator of healty ecosystems and the environment [4]. Monitoring changes in the biodiversity can reflect the significant effects of the pollution of aquatic ecosystems [5].

Among benthic invertebrates, ostracods are an aquatic microcrustaceans that can inhabit in a variety of worldwide environments like oceans, seas, lagoons, lakes, streams, etc. and wide ranges of salinity from fresh to hypersaline environments. They have ornamented and calcareous bivalve shells (carapace), and the whole body and all appendages can be enclosed by these moving shells [6] The distribution of ostracods is related to several environmental factors, for example sediment type, salinity, temperature, pH, dissolved oxygen, water depth, predators, and anthropogenic pollution such as nutrient and metals-heavy content [7]. They are one of the major groups of marine benthos with high taxonomic diversity according to environmental conditions [8].

As the result of their sensitiveness to anthropogenic pollution [9], ostracods can be used as indicators in marine, brackish-water, and freshwater environments [10].

The list of ostracod species belong to the marine and coastal water of Turkey was reported by Perçin-Paçal et al. (2015) [11], with a total of 382 species (326 marine and 56 coastal brackish waters).

The present study's aims were threefold: (1) determining the actual ostracod species composition in the Gulf of Gemlik (The Sea of Marmara), (2) determining their habitat preferences according to environmental ecological factors (at depths 1–96 m), and (3) determining the effects of urbanization and anthropogenic impacts on ostracods.

2. Materials and methods

2.1 Study Area

The Gulf of Gemlik is located in the southeastern area of the Sea of Marmara (Figure 1).

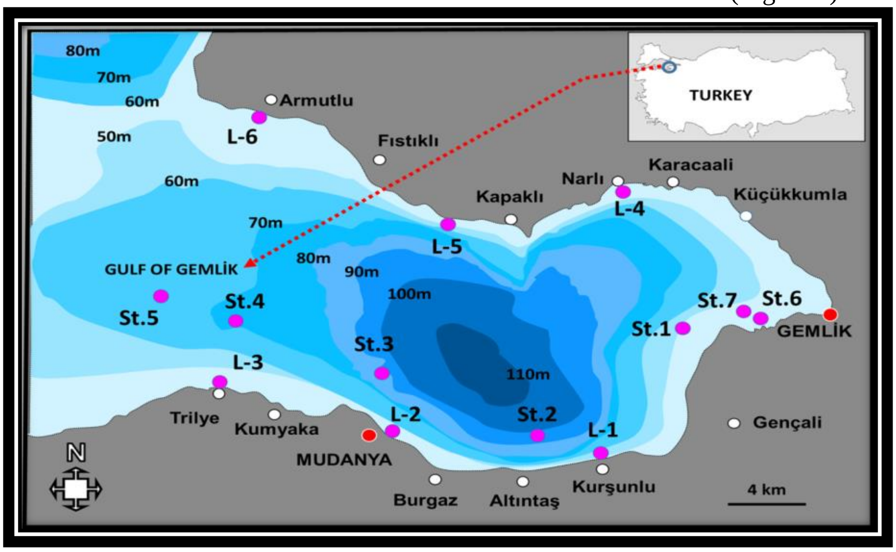

Figure 1. The locations of the sampling stations in the Gulf of Gemlik

The oceanographic characteristics of the coastlines of the Gulf of Gemlik are similar to the Sea of Marmara, and the water column has a two-layer structure. The surface water (brackish Black Sea water) of the Sea of Marmara has a salinity of 17.6‰ and flows through the Bosporus to the Sea of Marmara. The waters of the Mediterranean originate with a salinity of about 38‰ and flow through the Dardanelles to the Sea of Marmara in a lower layer. According to the density differences between the two water layers, there is an intermediate (halocline zone) salinity mass 25 m deep [12].

2.2 Sampling Procedure

A total of 13 stations, ranging in depths from 1 to 96 m, were sampled during the study period (August 2011, November 2011, February 2012, May 2012) (see Table 1).

A 0.1 m^2 Van Veen grab sampler was used to perform vertical cross-section sampling for each station at depths of 1 to 96 m. Only 200 g of all collected sediment by the Van Veen grab sampler was fixed in 70% ethanol in situ. The material was kept in polyethylene jars (250 ml bottles).

Table 1. Coordinates and depth ranges of the thirteen stations

Stations	Coordinates	Depth (m)
L-1	40°21'51.6"N, 29°02'04.1"E	1
L-2	40°22'12.8"N, 28°53'54.7"E	1
L-3	40°23'36.7"N, 28°47'53.7"E	1
L-4	40°28'47.5"N, 29°01'56.0"E	1
L-5	40°28'20.9"N, 28°54'13.3"E	1
L-6	40°30'33.0"N, 28°50'17.6"E	1
St.1	40°24'55.8"N, 29°03'33.8" E	50
St.2	40°23'47.7"N, 28°59'10.7"E	96
St.3	40°24'26.5"N, 28°53'04.9"E	90
St.4	40°26'43.0"N, 28°49'10.5"E	70
St.5	40°27'25.7"N, 28°45'45.2"E	60
St.6	40°25'15.4"N, 29°06'20.6"E	10
St.7	40°25'23.7"N, 29°06'8.6"D	30

The samples were brought to the laboratory, where the sediment was washed with pressurized tap water and separated into four grain-size fractions using standardized sieves (1.5, 0.5, 0.25, and 0.125 mm mesh size). Ostracods were sorted under a stereomicroscope and fixed again in 70% alcohol. Subsequently, specimens were preserved in 70% ethanol), and the retained material transferred to a Petri dish. Ostracod specimens were picked out of the sediment under a stereozoom microscope, and the soft body parts were dissected in lactophenol solution for taxonomic identification. The number of adult individuals belonging to each identified ostracod species was counted under a stereomicroscope. (The juvenile stages of each ostracod species were also observed at all sampling sites.) The ostracods were handpicked and identified using the keys developed by Mordukhai & Boltovskoi [13], Schornikov [14], Barbeito-Gonzales [15], Bonaduce et al. [16], Breman [17], Stambolidis [18], and Athersuch et al. [19]. The current taxonomy and classification of ostracod species were checked using the:WoRMS [20].

2.3 Analytical Procedure

The seawater samples were collected using a 3L Ruttner water sampler with marked rope at 5 m intervals at depths of 1–96 m for the physicochemical analyses of the seawater. The temperature (°C) of the sampling-depth water was measured by means of a thermometer fixed to the Ruttner water sampler, the Winkler method was used to measure dissolved oxygen (DO) (mg/L), and the Mohr-Knudsen method for the salinity (‰). YSI 556 MPS multi-parameter probes (Ohio, USA) connected to a YSI datalogger device were used to measure the pH values of the seawater.

2.4 Statistical Analyses

Jaccard's coefficient test of unweighted pair group mean averages (UPGMA) was used to show the similarity between the sampling stations and the clustering of ostracod species according to binary (presence–absence) data. The Multi-Variate Statistical Package (MVSP), version 3.22, was used to display the clustering of the 13 stations and 25 ostracod species for Jaccard's coefficient test [21].

The frequency of ostracod species was calculated by using the formula $F = N_a x100/N_n$, where F is the frequency of the species, N_a is the sampling number containing the species, and N_n is the total sampling number [22].

We used Biodiversity Pro software to examine seasonal distributional differences in ostracod species [23]. According to this program, we calculated the Shannon–Weaver diversity index (*H'*) evenness index (J') and Margalef's (D') index for each site over the period.

We used a two-tailed Spearman rank correlation test (with SPSS 21) to examine the relationships between environmental variables (temperature, salinity, pH, dissolved oxygen, and depth), and the abundance of 25 ostracod species collected during the study [24]. Canonical correspondence analysis (CCA) was also used to analyze species–environment relationships in order to identify environmental factors potentially influencing ostracod assemblages [25]. Data were analyzed using the MVSP, version 3.22 [21].

3. Results

In this study, 25 ostracod species belonging to 8 families were determined from 13 stations with 52 samples collected over the four seasons with depths varying from 1 to 96 m (Table 2). Ostracod samples were analyzed and, in total, 2611 individuals were determined.

Table 2. The names and name abbreviations of identified ostracod species with their abundance at each sampling at each sampling station from the Gulf of Gemlik. TNI: Total number of individuals.

	Ostracod species	Species Abbrev.	L Stations	St Stations	TNI	F % Frequency
1	*Acanthocythereis hystrix* (Reuss, 1850)	Ahis	1-2-3-4-5-6	1-4-5-6-7	112	84.6
2	*Aurila convexa* (Baird, 1850)	Acon	1-2-3-4-5-6	1-4-5-6-7	188	84.6
3	*Aurila speyeri* (Brady, 1868)	Aspe	1	4-5-6-7	32	32.7
4	*Callistocythere diffusa* (Mueller, 1894)	Cdif	1	4-5-6-7	50	38.5
5	*Carinocythereis carinata* (Roemer, 1838)	Ccar	1-2-3-4-5-6	1-4-5-6-7	111	84.6
6	*Costa batei* (Brady, 1866)	Cbat	-	2-3-4-5-6-7	39	46.2
7	*Costa edwardsii* (Roemer, 1838)	Cedw	-	2-3-4-5-6-7	35	46.2
8	*Cushmanidea elongata* (Brady, 1868).	Celo	1	4-5-6-7	56	38.5
9	*Cyprideis torosa* (Jones, 1850)	Ctor	-	6-7	24	15.4
10	*Cytheridea neapolitana* Kollmann, 1960	Cnea	-	4-5-6-7	44	38.5
11	*Hiltermannicythere (Falunia) rubra* (Mueller, 1894)	Hrub	-	2-3-4-5-6-7	42	46.2
12	*Loxoconcha gibberosa* Terquem, 1878.	Lgib	1-2-3-4-5-6	1-4-5-6-7	122	84.6
13	*Loxoconcha minima* Mueller, 1894	Lmin	1-2-3-4-5-6	1-4-5-6-7	126	84.6
14	*Loxoconcha rhomboidea* (Fischer, 1855)	Lrom	1-2-3-4-5-6	1-4-5-6-7	358	84.6
15	*Loxoconcha stellifera* Mueller, 1894	Lste	1-2-3-4-5-6	1-4-5-6-7	124	84.6
16	*Paracytheridea parallia* Barbeito-Gonzalez, 1971	Ppar	-	1-4-5-6-7	49	38.5
17	*Paradoxostoma fuscum* Mueller, 1894	Pfus	1-2-3-4-5-6	1-4-5-6-7	117	84.6
18	*Paradoxostoma simile* Mueller, 1894	Psim	1-2-3-4-5-6	1-4-5-6-7	109	84.6
19	*Paradoxostoma triste* Mueller, 1894	Ptri	1-2-3-4-5-6	1-4-5-6-7	63	84.6
20	*Pontocypris acuminata* (Mueller, 1894)	Pacu	1-2-3-4-5-6	1-4-5-6-7	98	84.6
21	*Pontocythere turbida* (Mueller, 1894)	Ptur	1-2-3-4-5-6	1-4-5-6-7	100	84.6
22	*Urocythereis britannica* Athersuch, 1977	Ubri	-	1-2-3-4-5-6-7	47	53.9
23	*Xestoleberis aurantia* (Baird, 1838)	Xaur	1-2-3-4-5-6	1-4-5-6-7	192	84.6
24	*Xestoleberis communis* Mueller, 1894	Xcom	1-2-3-4-5-6	1-4-5-6-7	221	84.6
25	*Xestoleberis dispar* Müller, 1894	Xdis	1-2-3-4-5-6	1-4-5-6-7	152	84.6

The highest numbers of individuals were observed to be *Loxoconcha rhomboidea* (358 individuals), *X. communis* (221 individuals), *X. aurantia* (192 individuals), and *A. convexa* (188 individuals) (Table 2). *Cyprideis torosa* (from 2 stations) and *Cytheridea neapolitana* (from 4 stations) showed the lowest diversity in the study area. *Loxoconcha rhomboidea* was the dominant species in all the seasons with the highest individual numbers (358)(Figure 2). Individual numbers of ostracod species according to season is shown in Figure 2.

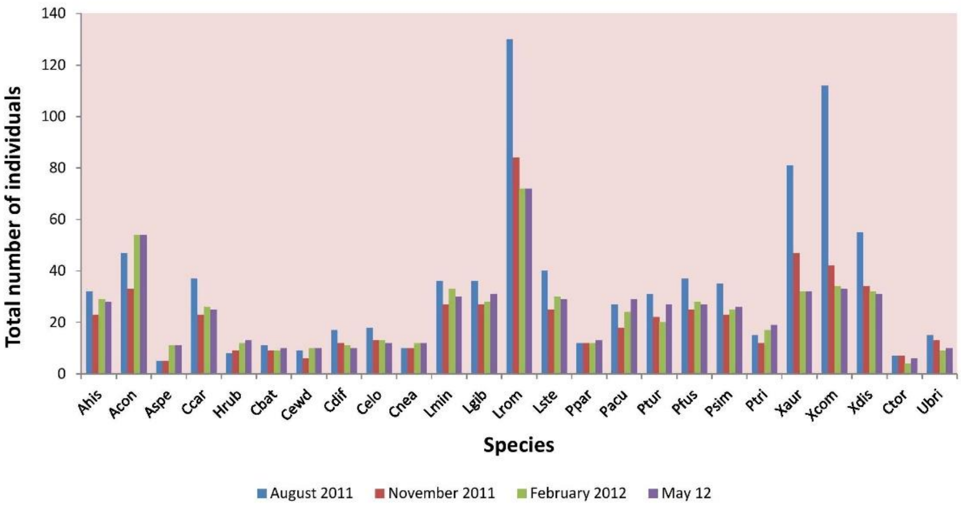

Figure 2. Composition of individual numbers of ostracoda species according to seasons

3.1 Water quality

Ecological parameters were seasonally measured in this study. During the study, temperature varied between 7 and 24.3 °C, while salinity varied from 18.45 to 35.81‰, the values of DO and pH ranged from 1.66 to 13.64 mg/L and 7.7 to 8.3, respectively, at the stations (Table 3). The determined maximum and minimum values for abiotic variables measured in the biotope of each ostracod species are shown in Table 4. Abundant and widely distributed ostracod species were observed as being species highly tolerant to various ecological parameters simultaneously (Table 4).

Table 3. Seasonal changes of environmental parameters determined at each station. . (Abbreviations: Sal= salinity, DO = dissolved oxygen; T = temperature)

	Stations	**T(°C)**	**Sal (‰)**	**DO (mg/L)**	**pH**	**Depth (m)**		**Stations**	**T(°C)**	**Sal (‰)**	**DO (mg/L)**	**pH**	**Depth (m)**
	L-1	24.3	20.67	9.53	8.2	1		**L-1**	12.5	24.43	9.27	8.1	1
	L-2	24.3	20.52	11.67	8.2	1		**L-2**	12.5	23.83	8.94	8.0	1
	L-3	22.9	20.25	9.56	8.1	1		**L-3**	11.8	20.46	12.21	7.9	1
	L-4	21.9	20.89	10.45	8.1	1		**L-4**	13.0	25.06	9.01	8.1	1
	L-5	24.4	20.25	8.79	8.2	1		**L-5**	12.3	24.23	6.13	8.0	1
	L-6	23.7	19.93	8.23	8.1	1		**L-6**	12.6	23.94	11.01	8.0	1
August 2011	**St.1**	16.4	34.86	3.19	7.8	50	**November 2011**	**St.1**	15.9	33.39	5.6	7.9	50
	St.2	16.2	34.98	2.26	7.7	96		**St.2**	15.1	33.98	2.82	7.8	96
	St.3	16.7	34.90	4.31	7.8	90		**St.3**	14.9	33.96	2.92	7.9	90
	St.4	16.8	34.79	4.48	7.8	70		**St.4**	14.4	33.99	4.54	7.8	70
	St.5	16.6	34.89	6.2	7.8	60		**St.5**	14.8	33.3	6.52	7.7	60
	St.6	20.0	21.19	7.05	8.2	10		**St.6**	13.3	25.71	13.64	8.1	10
	St.7	16.8	34.30	5.30	7.9	30		**St.7**	15.3	31.27	8.66	8.0	30
	L-1	7.1	18.66	9.34	8.2	1		**L-1**	16.4	21.83	7.31	8.0	1
	L-2	7.2	19.81	9.38	8.1	1		**L-2**	21.2	21.46	7.01	8.1	1
	L-3	8.0	18.75	10.09	8.2	1		**L-3**	23.3	20.49	8.13	8.2	1
	L-4	7.3	18.45	11.49	8.1	1		**L-4**	22.3	21.40	6.84	8.2	1
	L-5	7.6	18.93	11.28	8.0	1		**L-5**	20.1	22.05	8.82	8.2	1
	L-6	7.0	19.84	10.92	8.1	1		**L-6**	20.8	20.68	7.38	8.1	1
February 2012	**St.1**	14.5	26.05	4.42	8.0	50	**May 2012**	**St.1**	17.6	35.8	1.89	7.7	50
	St.2	14.0	25.74	3.2	8.0	96		**St.2**	14.6	35.81	3.33	7.9	96
	St.3	13.4	26.02	3.1	7.9	90		**St.3**	14.9	35.7	3.43	7.8	90
	St.4	13.0	26.44	3.81	8.0	70		**St.4**	16.9	35.07	1.89	7.7	70
	St.5	12.2	26.81	3.41	7.9	60		**St.5**	15.9	35.55	1.66	7.7	60
	St.6	8.6	20.47	9.47	8.3	10		**St.6**	19.6	23.81	6.08	8.1	10
	St.7	9.9	22.21	7.34	8.2	30		**St.7**	15.5	32.67	3.52	7.8	30

Table 4. The determined maximum and minimum values for abiotic variables measured in the biotope of the each ostracod species in the Gulf of Gemlik (Abbreviations are the same as Table 2,3)

Species	**Tw (°C)**	**Salinity (‰)**	**DO mg/L**	**pH**	**Depth (m)**	**TNI**
Ahis	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	112
Acon	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	188
Aspe	8.6-20	20.47-35.55	1.66-13.64	7.7-8.3	1-70	32
Cdif	7.1-24.3	18.66-35.55	1.66-13.64	7.7-8.3	1-70	50
Ccar	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	111
Cbat	8.6-20	20.47-35.81	1.66-13.64	7.7-8.3	10-96	39
Cedw	8.6-20	20.47-35.81	1.66-13.64	7.7-8.3	10-96	35
Celo	7.1-24.3	18.66-35.55	1.66-13.64	7.7-8.3	1-70	56
Ctor	8.6-20	20.47-34.30	5.30-13.64	7.8-8.3	10-30	24
Cnea	8.6-20	20.47-35.55	1.66-13.64	7.8-8.3	10-70	44
Hrub	8.6-20	20.47-35.81	1.66-13.64	7.7-8.3	10-96	42
Lgib	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	122
Lmin	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	126
Lrom	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	358
Lste	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	124
Ppar	8.6-20	20.47-35.55	1.66-13.64	7.7-8.3	10-70	49
Pfus	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	117
Psim	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	109
Ptri	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	63
Pacu	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	98
Ptur	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	100
Ubri	8.6-20	20.47-35.81	1.66-13.64	7.7-8.3	10-96	47
Xaur	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	192
Xcom	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	221
Xdis	7.1-24.3	18.45-35.8	7.7-8.3	7.7-8.3	1-70	152

The Shannon-Weaver diversity index (H') indicates that the highest diversity was determined at sampling station 6 for all the seasons. The lowest Shannon-Weaver values were determined in all seasons at stations 2 and 3. The highest Pielou’s index values were calculated at station 4 in February and the lowest at station L-2 in August. Margaleff’s index values were the highest at station 2 in February and May, the lowest at station L-1 in August (Table 5).

According to Jaccard’s coefficient similarity dendrogram three clustering groups have been comprised. The First group occurred sampling stations L-1, L-2, L-3, L-4, L-5, and L-6, the second group St. 4, St. 5, St. 6, and St. 7, and the third group St. 2 St. 3. The stations were clustered according to similarities of depths values.

Table 5: The species diversity indices values calculated for four season (NS: number of species; NI: number of individuals, Shannon index (H'), Pielou’s evenness index (J’) Margaleff (D’).

Aug. 2011	L-1	L-2	L-3	L-4	L-5	L-6	St.1	St.2	St.3	St.4	St.5	St.6	St.7
NS	17	15	15	15	14	15	17	4	4	24	24	25	25
NI	138	83	88	83	72	70	64	9	7	50	53	74	72
Shannon H'	1,176	1,049	1,075	1,089	1,083	1,065	1,132	0,569	0,587	1,304	1,307	1,334	1,29
Pielou J'	0,956	0,892	0,914	0,926	0,92	0,905	0,92	0,946	0,975	0,945	0,947	0,954	0,923
Margaleff D’	11,216	12,506	12,343	12,506	12,922	13,007	13,288	25,151	28,399	14,126	13,919	12,839	12,922
Nov. 2011													
NS	17	15	15	15	15	15	17	4	4	24	24	25	25
NI	88	52	54	43	40	40	49	6	6	43	40	51	49
Shannon H'	1,179	1,097	1,077	1,112	1,121	1,067	1,146	0,577	0,577	1,332	1,344	1,35	1,342
Pielou J'	0,958	0,933	0,915	0,945	0,953	0,907	0,932	0,959	0,959	0,965	0,974	0,966	0,96
Margaleff D’	12,343	13,986	13,854	14,693	14,981	14,981	14,2	30,842	30,842	14,693	14,981	14,055	14,2
Feb. 2012													
NS	17	15	15	15	15	15	17	4	4	24	24	25	25
NI	67	55	53	48	49	34	48	5	6	47	45	65	65
Shannon H'	1,177	1,123	1,1	1,1	1,145	1,125	1,181	0,579	0,577	1,358	1,352	1,372	1,369
Pielou J'	0,956	0,955	0,935	0,935	0,973	0,957	0,96	0,961	0,959	0,984	0,98	0,982	0,979
Margaleff D’	13,143	13,79	13,919	14,275	14,2	15,671	14,275	34,336	30,842	14,353	14,517	13,238	13,238
May. 2012													
NS	18	15	15	15	15	15	17	4	4	24	24	25	25
NI	66	49	47	51	53	38	52	5	6	50	51	68	64
Shannon H'	1,2	1,125	1,111	1,102	1,124	1,119	1,198	0,579	0,54	1,351	1,338	1,365	1,362
Pielou J'	0,956	0,956	0,944	0,937	0,956	0,952	0,974	0,961	0,896	0,979	0,97	0,977	0,974
Margaleff D’	13,19	14,2	14,353	14,055	13,919	15,192	13,986	34,336	30,842	14,126	14,055	13,097	13,288

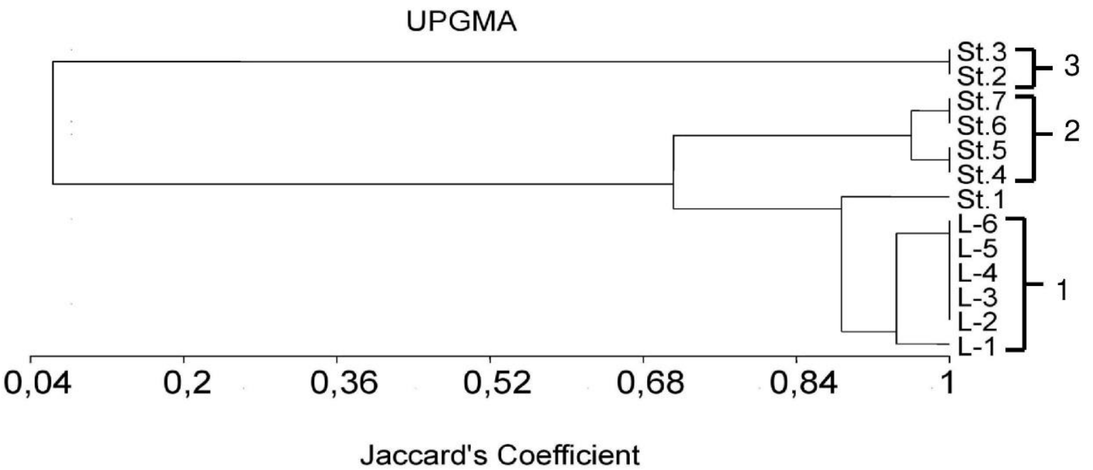

Figure 3. Jaccard’s coefficient similarity dendrograms showing faunal similarity among the 13 sampling sites (based on presence/absence of species)

A UPGMA diagram illustrates three clustering groups of the 25 ostracod species (Figure 4). These three groups were composed according to salinity levels (Figs. 4, 5).

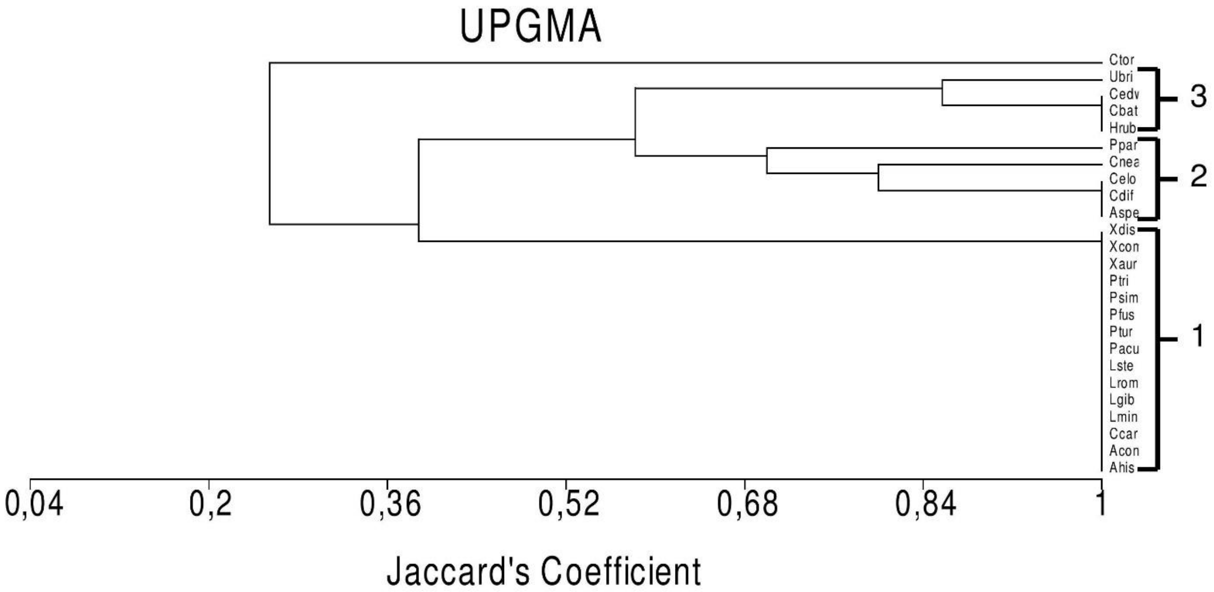

Figure 4. Jaccard's coefficient similarity dendrograms showing similarity among the 25 ostracod species (based on presence/absence of species)

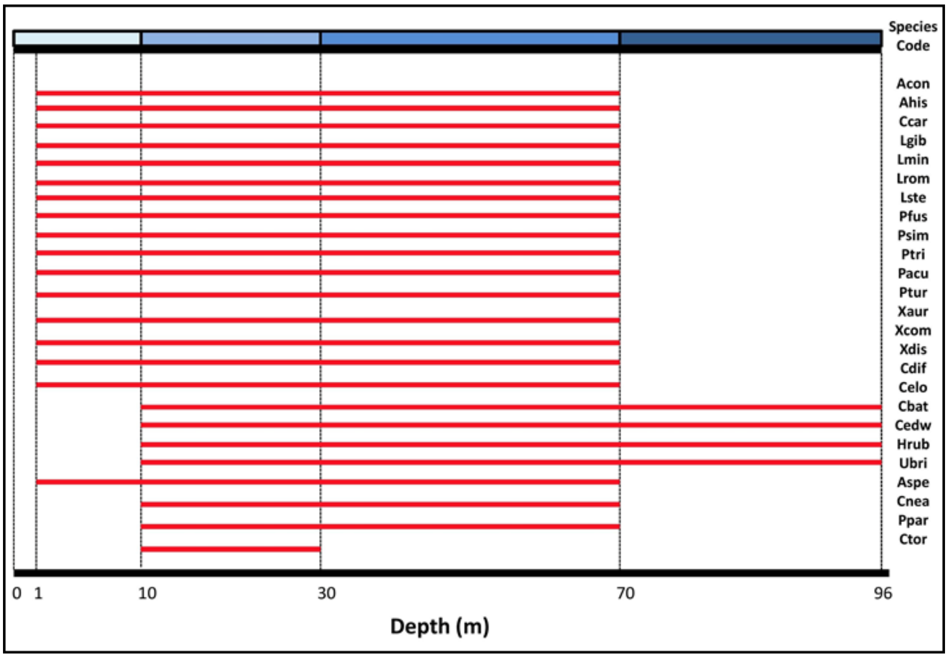

Figure 5. The diversity of the twenty-five ostracod species according the depth in Gemlik gulf

According to the Spearman correlation analyses, the *Loxoconcha* and *Paradoxostoma* species showed positive correlations with DO and pH and negative correlations with salinity and depth (Table 6). The same relationship was observed with *A. convexa*, *C. carinata*, *P. acuminata*, *X. communis*, and *X. dispar*. In contrast, *H. rubra*, *C. batei*, *C. edwardsii*, *P. parallia*, and *U. britannica*, which all showed positive correlations with salinity and depth and negative correlations with DO and pH. Like *L. rhomboidea* and *X. communis*, *A. convexa*, which had high individual numbers and was a widely distributed species, positively correlated with DO and pH and negatively with depth and salinity (Table 6).

Table 6. Spearman's rank correlation coefficient showing the correlation between the twenty-five ostracod species and five ecological variables. Bold numbers show significant correlations (levels of significance: **P<0.01, *P<0.05 (2-tailed) Abbreviations are the same as Table 2-3)

	Tw	Sal	DO	pH	Depth	SN	IN
Ahis	,128	**-,560****	**,548****	**,429****	**-,728****	,071	**,577****
Acon	,081	**-,664****	**,542****	**,550****	**-,753****	,202	**,682****
Aspe	-,052	,261	-,187	-,166	,301*	**,828****	,196
Ccar	,188	**-,512****	**,490****	**,448****	**-,645****	,322*	,829**
Hrub	-,069	**,528****	**-,507****	**-,389****	**,704****	**,455****	-,188
Cbat	-,038	**,649****	**-,635****	**-,506****	**,865****	,088	**-,419****
Cedw	-,076	**,587****	**-,554****	**-,443****	**,785****	,310*	-,277*
Cdif	-,025	,117	-,039	,042	,116	**,815****	**,425****
Celo	-,038	,130	-,034	,041	,124	**,828****	**,421****
Lmin	,083	**-,484****	**,424****	**,466****	**-,630****	,276*	**,693****
Lgib	,143	**-,631****	**,595****	**,561****	**-,762****	,233	**,731****
Cnea	-,045	,309*	-,209	-,167	,349*	**,832****	,167
Lrom	,263	**-,582****	**,631****	**,543****	**-,789****	,061	**,727****
Lste	,092	**-,554****	**,568****	**,489****	**-,709****	,244	**,702****
Ppar	,019	**,496****	**-,384****	**-,359****	**,419****	**,800****	,159
Pacu	,238	**-,447****	**,392****	**,534****	**-,554****	**,495****	**,757****
Ptur	,295*	-,264	,279*	,270	**-,445****	**,362****	**,553****
Pfus	,113	**-,533****	**,606****	**,530****	**-,719****	,246	**,722****
Psim	,273	**-,604****	**,591****	**,537****	**-,774****	,111	**,624****
Ptri	,094	**-,470****	**,413****	**,458****	**-,570****	**,477****	**,691****
Xaur	,250	-,246	**,375****	,239	**-,447****	**,414****	**,652****
Xcom	,278*	**-,539****	**,618****	**,545****	**-,689****	,216	**,760****
Xdis	,121	**-,483****	**,480****	**,475****	**-,666****	,247	**,667****
Ctor	-,016	,025	,083	,185	,060	**,645****	,317*
Ubri	,060	**,762****	**-,691****	**-,599****	**,831****	,352*	-,245

Species numbers did not correlate with other ecological parameters when we evaluated species numbers and individual numbers with the ecological parameters according to the Spearman correlations (Table 7). However, individual numbers showed positive correlations with temperature, DO, and pH and negative correlations with salinity and depth.

Table 7. Spearman's rank correlation coefficient showing the correlation between the species numbers and invidual numbers with ecological parameters. Bold numbers show significant correlations (levels of significance: **P<0.01, *P<0.05 (2-tailed) Abbreviations are the same as Table: 3)

	Tw	Sal	DO	pH	Depth	SN	IN
Tw	1						
Sal	0,127	1					
DO	-0,182	**-,810****	1				
pH	0,047	**-,822****	**,698****	1			
Depth	-0,031	**,827****	**-,820****	**-,716****	1		
SN	0,003	0,102	0,031	0,021	0,005	1	
IN	**,314***	**-,418****	**,445****	**,467****	**-,538****	**,491****	1

The relationship between the physicochemical variables and species composition in the Gulf of Gemlik is illustrated by the CCA biplot in Figure. 6**.** The lengths of the arrows on the CCA graph show the strong effect of environmental variables on the distribution of ostracods**.** The results of the CCA showed that pH and DO have positive effects, similar to the Spearman correlations, on most of the ostracod species, as shown in the diagram (Figure 6).

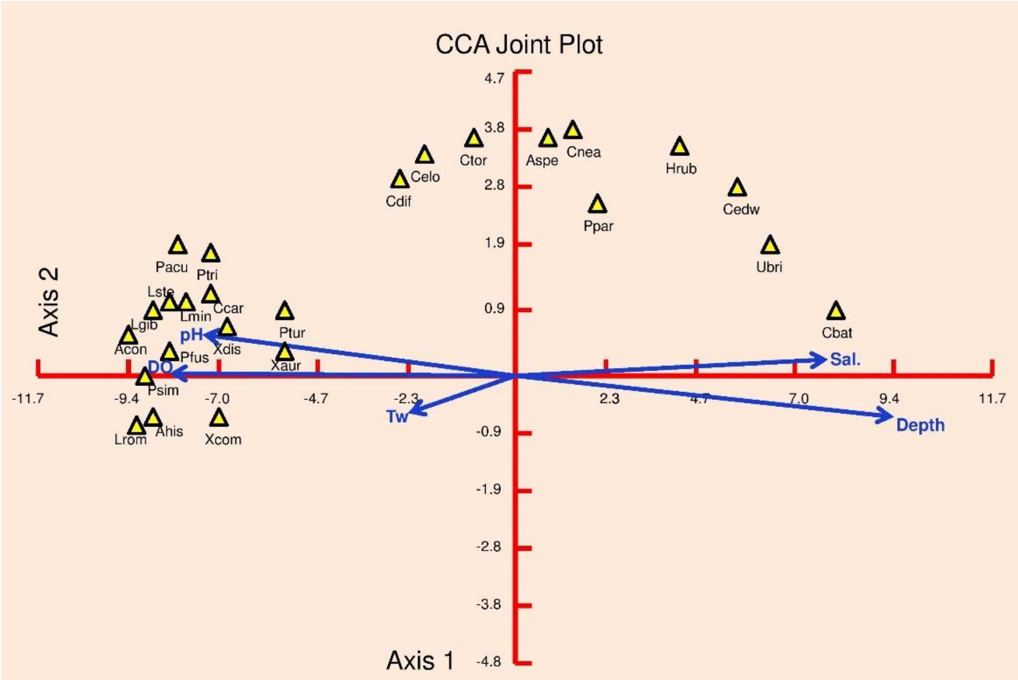

Figure 6. CCA showing the relationship between twenty-five species (yellow triangle) and five environmental variables (arrows) in the thirteen sampling sites. For explanation of abbreviations and variables, see Table 2-3

4. Conclusions and discussion

According to the results over the four-seasonal period, *L. rhomboidea* was the most dominant species from the 13 sampling stations at the Gulf of Gemlik with the highest number of inidividuals (358) and frequency of 84.6%. *Xestoleberis communis*, *X. aurantia*, and *A. convexa* were other dominant species, at a frequency of 84.6% (see Figure 2).

Loxoconcha rhomboidea is a very common species found in Turkish coastal waters (the Mediterranean Sea, the Aegean Sea, the Turkish strait system, and the Black Sea) and in sublittoral zones [11]. This species was reported from depths range of about 1 m down to 57 m [15,18], from wide ranges of variation of the salinity and in muddy and phytal biotopes [18] of the Mediterranean Sea. In the present study, this species showed positive correlations with DO and pH and negative correlations with salinity and depth, according to the Spearman correlations and CCA (see Table 6, Figure 6). *Loxoconcha rhomboidea* is a species tolerant of and resistant to changes in environmental conditions [26] , and seems well adapted to the environment of the Gulf of Gemlik.

Xestoleberis communis is another common species in Turkish coastal marine waters [11]. According to observations in Turkish marines, it is able to survive despite a wide range of changes in environmental conditions [27,28]. This species has been identified as a dominant species and is widely distributed in the Mediterranean Sea [15,29,30,31], as well as in the Adriatic Sea, **w**ith sandy-bottom substrata and at depths of 27–80 m [16,18]**.** In this study, it showed positive correlations with DO and pH and negative correlations with salinity and depth, according to the Spearman correlations and CCA, similar to *L. rhomboidea* (see Table 6, Figure 6). Opportunistic ostracod species *X. communis* was reported from as a dominant species in the polluted waters in the Nador Lagoon (Morocco) together with to other ostracod species members of Loxoconchidae family [31,32] .

Xestoleberis aurantia is a species widespread in the Sea of Marmara [11]. Although, until now, there has been no record of it in the Dardanelles strait, it has been recorded in the Black Sea, the Aegean, and the Mediterranean, as well as on the coastlines of Turkish marine environments [11]. *Xestoleberis aurantia* has been identified as being a euryhaline species in northeast England [33] and, while known as a marine brackish littoral species, it has also been reported in freshwater and oligohaline shallow-water environments [34]. It showed a positive correlation with DO and a negative correlation with pH according to the Spearman correlations and CCA in this study, with a frequency across the sampling stations of 84.6% (see Table 2, Table 6, Figure 6).

Aurila convexa is common and widely distributed in the littoral and sublittoral zones of most Turkish coastlines and lagoonal waters [11]. It is known to be a cosmopolitan Mediterranean species [16], is also common in the Sea of Marmara, and has been recorded in northern parts of the Aegean Sea[18], as well as in the Black Sea in brackish water systems since it is a polyhaline species [14]. We observed that a frequency of this species at the sampling stations of 84.6%, and it showed positive correlations with DO and pH and negative correlations with salinity and depth, according to the Spearman correlations and CCA (see Table 2 & 6, Figure 6)**.**

Most of the species showed positive correlations with DO and pH and negative correlations with salinity and depth (Table 7, Figure 6.), while five species (*H. rubra*, *C. batei*, *C. edwardsii*, *P. parallia*, and *U. britannica*) showed positive correlations with salinity and depth and negative correlations with DO and pH, according to the Spearman correlations and CCA (Table 7). The latter's frequency at the sampling stations was between 38.5% and 53.9%, with individual numbers and diversity lower than other species (Table 2). *Cytheridea neapolitana*, *C. elongate*, *C. diffusa*, *A. speyeri*, and *C. torosa* did not show significant correlations with any of the ecological parameters (Table 6, Fig 6). The frequency of these species was between 15.4% and 38.5%, and their individual numbers and diversity were also lower than other species (Table 2).

It has generally been observed that DO significantly decreases at depth. Previous studies have measured DO decrease at depth in the Bandırma and Erdek gulfs [27,28], similar to the Gulf of Gemlik. It is well known that DO values of surface waters are higher than deep waters due to photosynthetic activities and wave actions; in contrast, at depth, with excessive bacterial and animal activity, the numbers of phytoplankton increase and higher organic loads in eutrophic systems lead to a decrease in DO levels [35]. When the DO level falls below 5 mg/L, oxygen-sensitive invertebrate and fish species are negatively affected [36]. Although the measured average values of DO were generally appropriate for the survival of the species in this study, levels decreased to less than 5 mg L-1 at St. 2 and St. 3 at points during the seasons (see Table 3). Results of this study show that some ostracod species were negatively affected from the lack of DO (see Table 4&6).

Discharges of industrial and domestic waste into the Gölayağı and Karsak creeks negatively affect the water quality of the Gulf of Gemlik [37]. According to Integrated Coastal Area Plan of Bursa Province, (2015) [37] while the Sea of Marmara is less polluted, the Gulf of Bandırma and the Gulf of Gemlik are at a mid-level stage of pollution; yet, both gulfs have been found to be prone to intense pollution. In 2008, an environmental problem occurred as a result of the formation of mucilage from the proliferation of diatoms together with bacteria throughout the Sea of Marmara. Previous studies have reported that living organisms and the water quality of the Sea of Marmara are affected by longstanding pollution [38]. To date, 210 benthic ostracod species have been determined from the Sea of Marmara[39]. When we compare the ostracod species numbers in the Gulf of Gemlik (25 species) with other gulfs in the Sea of Marmara, we see a very low ostracod density: Bandırma gulf, 75 species; Erdek gulf, 92 species [27,28] . The absence of most taxa, and the almost total dominance in the Gulf of Gemlik of tolerant ones (especially *L. rhomboidea* and *X. communis*), shows that the general effect of pollution on ostracods is the decreasing of abundance and diversity. Some taxa are more sensitive to pollution, with the subsequent changes in ecological parameters, than others, thereby strengthening the role of ostracods as indicators and biomonitors of environmental hazards and anthropogenic pollution [40]. Indeed, supporting our findings, several authors have mentioned that *Loxochonca spp.* and *X. communis* can be environmental indicator species in polluted environments [41,42]. As can be inferred from the results of the current study, the low number of species and individuals together with low DO levels determined at some of the stations show that pollution is the reason for negative changes in the quality of water in the Gulf of Gemlik. These polluted environments allow for the progress of cosmopolitan species with wide ecological tolerance through the elimination of low-tolerance species. The existence of environmentally tolerant species *L. rhomboidea* [26], *X. communis* [31,32], *X. aurantia* [26], and *A. convexa* [26] and the increases in the number of ostracod-tolerant species support our findings. Although the results of this study have not been thoroughly evaluated in terms of pollutants on the surface waters, these results show that the coastline ecosystem of the Gulf of Gemlik should be periodically monitored due to extant pollutants.

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