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ORIGINAL ARTICLE

Faunistic and ecological assessment of interstitial Harpacticoida (Crustacea, Copepoda) on a sandy beach in Balıkesir (Turkey)

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ABSTRACT

Interstitial harpacticoids along the mediolittoral zones of Sarımsaklı Beach, Turkey, were sampled monthly between April 2016 and March 2017 in order to reveal the effects of pH, water temperature, salinity, electrical conductivity, dissolved oxygen, and grain size on the occurrence and composition of the harpacticoids. Examination of the samples from nine stations revealed a total of 66 species. In terms of harpacticoid species abundance, *Ectinosoma soyeri* Apostolov, 1975 was ranked first followed by *Sarsamphiascus angustipes* (Gurney, 1927) and *Leptomesochra eulitoralis* Noodt, 1952. The variations in harpacticoid community were estimated by using some ecological indices (Species richness, Shannon's diversity and Pielou's evenness). Principal component analysis (PCA) based on the abiotic factors was applied for ordination of the stations. Relationships between environmental and temporal parameters as well as harpacticoid community structure were analyzed using distance-based Linear Models (DistLM). Relationships between environmental variables and most abundant species were determined with the Redundancy analysis (RDA). The abundance of *S. angustipes* and *Klieonychocamptus ponticus* (Serban and Plesa, 1957) were positively correlated with all tested variables except water temperature. The abundance of *Klieonychocamptus kliei* (Monard, 1935) was positively correlated with water temperature, grain size and salinity, while it was negatively correlated with dissolved oxygen and pH. The abundance of *Ameira* sp. and *Microsetella norvegica* (Boeck, 1865) were negatively correlated with all tested variables except water temperature. The abundance of *E. soyeri* and *Ameira parvula* (Claus, 1866) were negatively correlated with all tested variables except pH. The abundance of *Leptomesochra eulitoralis* was positively correlated with water temperature and salinity, while it was negatively correlated with grain size, dissolved oxygen and pH.

KEYWORDS

Biodiversity, meiofauna, new record, Sandy beach.

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Introduction

Sandy shores are highly dynamic and important biotopes having complex physical, chemical and biological processes. The structure of the marine habitat is shaped by the physical effects of waves and tides; and the sand and water in the region are always in motion. Large volumes of seawater are filtered through the porous sand bodies. Water filtration is of biological importance in providing oxygen and dissolved and particulate organic materials to the interstitial fauna of marine sand. Due to the high energy carried by the sea water, sandy shores have a rich and sensitive fauna (McLahlan *et al.*, 1985; Brown and McLachlan, 2006; Schlacher *et al.*, 2007; Sandulli *et al.*, 2010; Mantha *et al.*, 2012; Maria *et al.*, 2016). The relative abundance of various types of food (bacteria, fungi, unicellular algae, detritus, etc.) in pore water is much higher, therefore nematodes and harpacticoid copepods are found in higher density and diversity in interstitial habitats (Fenchel, 1978; Zaitsev, 2012). Harpacticoid copepods are one of the most important members of the benthic food chain, transferring carbon to higher trophic levels, consuming unicellular organisms and serving as prey for larger invertebrates (Schizas and Shirley, 1996; Drira *et al.*, 2018). They inhabit all available benthic habitats displaying considerable species diversity and represent the second most abundant meiofaunal group after nematodes in marine sediments (Huys *et. al.*, 1996).

Studies on marine harpacticoids in Turkey have concentrated mainly on taxonomic issues and more than 200 harpacticoid species have been reported from mediolittoral zones of Turkish seas so far (Bakır *et al.*, 2014; Alper *et al.*, 2015; Köroğlu *et al.*, 2015; Kuru and Karaytuğ, 2015; Sönmez *et al.*, 2015; Sönmez *et al.*, 2016; Alper *et al.*, 2018; Karaytuğ and Koçak, 2018; Yıldız and Karaytuğ, 2018; Sönmez *et al.*, 2018; Sönmez, 2019). But the actual harpacticoid diversity of sandy beaches of Turkey still remains to be revealed. Furthermore, a study on the effects of environmental factors on the abundance of mediolittoral harpacticoids has not been carried out in Turkey so far.

Materials and Methods

The study site and sampling

Sarımsaklı beach is located on the Aegean coast of Balıkesir province and is one of the longest (about 7 km) sandy beaches in Turkey (Tezsezer *et al.*, 2011; Doldur, 2016).

A total of nine stations were selected on the beach with 500 m intervals, from the west of the beach to Nikita Creek at the east (Fig. 1; Tab. 1). Monthly samplings were made between April 2016 and March 2017. Sediment samples were collected from the intertidal zone down to depth of 20 cm with the help of an aluminum tube corer having 3.1 cm inner diameter. Sediment samples were placed in 250 mL polypropylene containers and preserved with 70 % ethanol. Coordinates of the stations were taken with a Magellan eXplorist 610 GPS device. Water temperature (WT), pH, dissolved oxygen (DO), electrical conductivity (EC) and salinity (s) were measured in situ using a YSI 556MPS portable instrument.

Table 1. Coordinates and sampling dates of the stations.

Stations	Coordinates		Sampling dates
ST1	39.26699° N	26.64441° E	14.04.2016
ST2	39.26727° N	26.65177° E	13.05.2016
ST3	39.26738° N	26.65655° E	16.06.2016
ST4	39.26752° N	26.66169° E	14.07.2016
ST5	39.26741° N	26.66784° E	16.08.2016
ST6	39.26727° N	26.67305° E	23.09.2016
ST7	39.26716° N	26.67773° E	24.10.2016
ST8	39.26668° N	26.68519° E	16.11.2016
ST9	39.26628° N	26.68997° E	13.12.2016
			25.01.2017
			16.02.2017
			16.03.2017

Laboratory analysis

Extraction of Harpacticoida from the sediment was conducted following Ludox-TM density centrifugation method described by Burgess (2001). After centrifugation, the supernatant containing harpacticoids were washed in a sleeve of 50 µm of mesh and counted under Olympus SZX-12 stereo microscope. Identifications were made under an

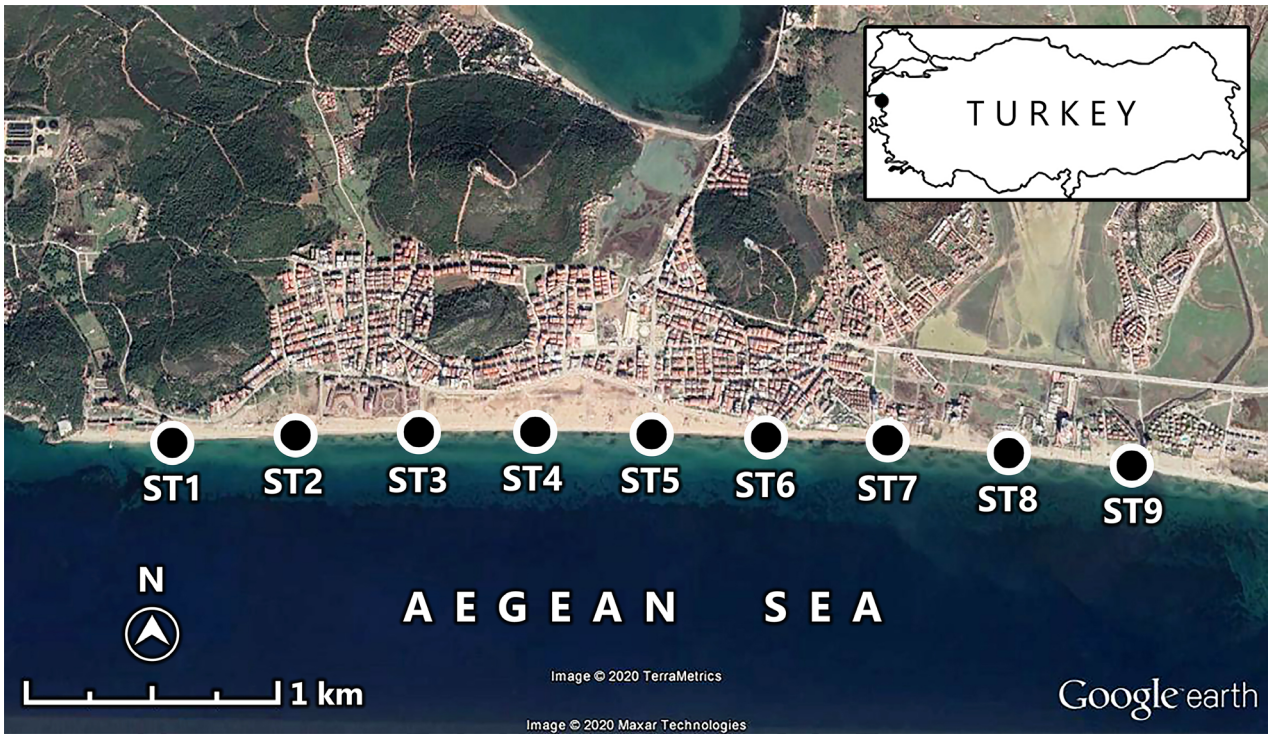

Figure 1. The study area and the sampling stations.

Olympus BX-50 microscope equipped with DIC according to Huys *et al*. (1996) and Wells (2007). Specimens were placed in 5 mL glass tubes with 70 % ethanol and deposited in the collection of the Department of Biology, Faculty of Science and Literature, Balıkesir University, Balıkesir, Turkey.

Grain size of the sediment (GS) was analyzed according to Buchanan (1984). Dried sediment samples were sieved through a series of sieves (mesh sizes: > 2000 µm, 1000 µm, 500 µm, 350 µm, 250 µm, 177 µm, 125 µm and 62 µm) representing intervals of the Wentworth scale. The weight of the sediment retained by each sieve was used to calculate the mean grain size. The results were processed using MS-Excel with Gradistat v4.

Data analysis

The species richness (S) was calculated according to the total number of different species for each station. Shannon's diversity (H') (Shannon and Weaver, 1949) and Pielou's evenness (J) (Pielou, 1975) were also calculated.

Prior to the statistical analysis, data sets were tested for normality. The Kruskal-Wallis test was chosen to analyze variations in environmental/biological parameters, as the data were not normally distributed (Kolmogorov-Smirnov, $P < 0.05$). The harpacticoid abundance data with many absences and rare species were transformed using the Hellinger transformation, which gives low weight to rare taxa (Legendre and Gallagher, 2001). Ordination analysis was used to investigate the environmental variables and the abundance of species. Before the analysis, the species with less than 1 % abundance were excluded from the data set. To avoid multicollinearity, the EC which strongly correlated with salinity (VIF > 20) was also removed. Kaiser-Meyer-Olkin and Bartlett's sphericity tests were conducted to determine the suitability of the data set, then the Principal Component Analysis (PCA) was carried out for ordination of the stations, based on the abiotic factors measured during the study period. The Detrended Correspondence Analysis (DCA) was applied to abundance data in order to determine the length of the ordination axes; as a result, the length was determined less than 4 SD. When the length of the coordination axes is less than 4 SD, it is appropriate to use linear coordination methods (Šmilauer and Lepš, 2014). Relationships between environmental and temporal parameters, as well as harpacticoid community structure, were analyzed using distance-based Linear Model (DistLM) (Legendre and

Anderson, 1999). A Bray-Curtis similarity matrix of Hellinger transformed harpacticoid abundance and a matrix of the normalized abiotic variables were used in the test. The abiotic variability was divided into 5 partitions in order to determine the proportion of total variation explained by each factor to the overall: (i) environmental variation (WT, DO, pH, GS and salinity), (ii) temporal variation (sampling date), (iii) spatial variation (latitude of the stations), (iv) spatio-temporal variability in environmental factors, and (v) unexplained variation. A stepwise selection of the environmental variables using the adjusted R^2 selection criterion and a permutation test of significance was used. A distance-based Redundancy Analysis (dbRDA) was performed to highlight the effect of temporal, spatial and environmental variables on harpacticoid abundance. The Redundancy Analysis (RDA) was performed to determine the relationships between environmental variables and the most abundant species.

Statistical analyses were performed using SPSS v26, PRIMER v7, MS-Excel with XLSTAT, and CANOCO v4.5.

Results

Environmental parameters

Variations in the environmental parameters by station are presented in Tab. 2. Mean pH varied between 7.92 ± 0.07 and 8.02 ± 0.06 during the study period. Mean WT was lowest in ST1 with 16.08 ± 5.31 °C, while it was highest in ST9 with 19.73 ± 6.35 °C. Mean DO was lowest in ST9 and highest in ST1, 6.42 ± 1.32 mg/L and 8.74 ± 1.34 mg/L respectively. Mean EC varied between 47.59 ± 7.74 mS and 51.41 ± 8.85 mS. Mean salinity was lowest in ST3 with 37.49 ± 3.27 ‰, and highest in ST5 with 39.41 ± 1.98 ‰. Grain size of sediment varied between 906.99 ± 192.80 µm and 1234.08 ± 112.47 µm.

The Principal Components Analysis (PCA) of environmental variables showed that the first axis explained 44.48 % of the variance and the second axis explained 20.93 %. Axis 1 was related positively with pH (0.804), DO (0.756) and GS (0.507), and related negatively with WT (-0.861). Axis 2 was related positively with salinity (0.889). The irregular ordering of the stations reflected the temporal dissimilarity (Fig. 2).

Table 2. Measured environmental parameters at the stations (SD: standard deviation).

		ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9
pH	Min.	7.81	7.78	7.83	7.89	7.92	7.90	7.77	7.73	7.80
	Max.	8.11	8.13	8.11	8.10	8.09	8.08	8.13	8.09	8.03
	Mean ± SD	8.00 ± 0.08	7.95 ± 0.10	8.01 ± 0.07	8.02 ± 0.06	8.02 ± 0.06	8.00 ± 0.06	7.96 ± 0.10	7.95 ± 0.10	7.92 ± 0.07
WT (°C)	Min.	7.33	7.61	7.42	7.73	8.24	7.95	7.87	9.76	9.81
	Max.	23.58	25.55	24.27	24.90	25.66	26.56	26.84	27.39	28.62
	Mean ± SD	16.08 ± 5.31	16.54 ± 5.87	16.67 ± 5.85	17.05 ± 6.18	17.23 ± 6.07	18.08 ± 6.62	18.34 ± 6.57	18.88 ± 6.55	19.73 ± 6.35
DO (mg/L)	Min.	6.10	5.85	6.01	5.90	5.38	4.72	5.23	3.80	3.67
	Max.	10.56	10.85	11.65	11.30	10.45	9.84	10.38	9.76	8.90
	Mean ± SD	8.74 ± 1.34	8.03 ± 1.46	8.54 ± 1.78	8.13 ± 1.79	7.83 ± 1.72	7.53 ± 1.56	7.21 ± 1.37	7.28 ± 1.76	6.42 ± 1.32
EC (mS)	Min.	41.35	40.88	32.72	34.91	40.90	41.09	33.23	41.38	35.47
	Max.	57.10	57.96	58.55	60.23	59.94	62.08	62.86	63.34	64.92
	Mean ± SD	48.66 ± 5.20	48.88 ± 6.07	47.59 ± 7.74	49.33 ± 7.12	50.17 ± 6.08	50.85 ± 6.87	49.74 ± 9.31	51.74 ± 7.25	51.41 ± 8.85
Salinity (‰)	Min.	35.77	35.86	30.76	32.81	35.83	35.78	28.90	35.48	28.56
	Max.	42.49	41.89	40.99	42.53	42.46	42.63	42.57	42.64	42.39
	Mean ± SD	39.24 ± 2.09	39.03 ± 2.06	37.49 ± 3.27	38.78 ± 2.76	39.41 ± 1.98	39.18 ± 2.06	37.77 ± 4.25	39.14 ± 2.29	37.96 ± 3.92
Grain size (µm)	Min.	1043	616	869.3	588.2	739.1	723.2	855.5	589	460.3
	Max.	1407.3	1082	1311.4	1197.8	1284.1	1115.5	1107.2	1168.9	1124.6
	Mean ± SD	1234.08 ± 112.47	925.53 ± 151.76	1066.02 ± 143.45	958.2 ± 181.35	1040.88 ± 141.75	1000 ± 114.69	990.22 ± 77.85	938.97 ± 160.49	906.99 ± 192.80

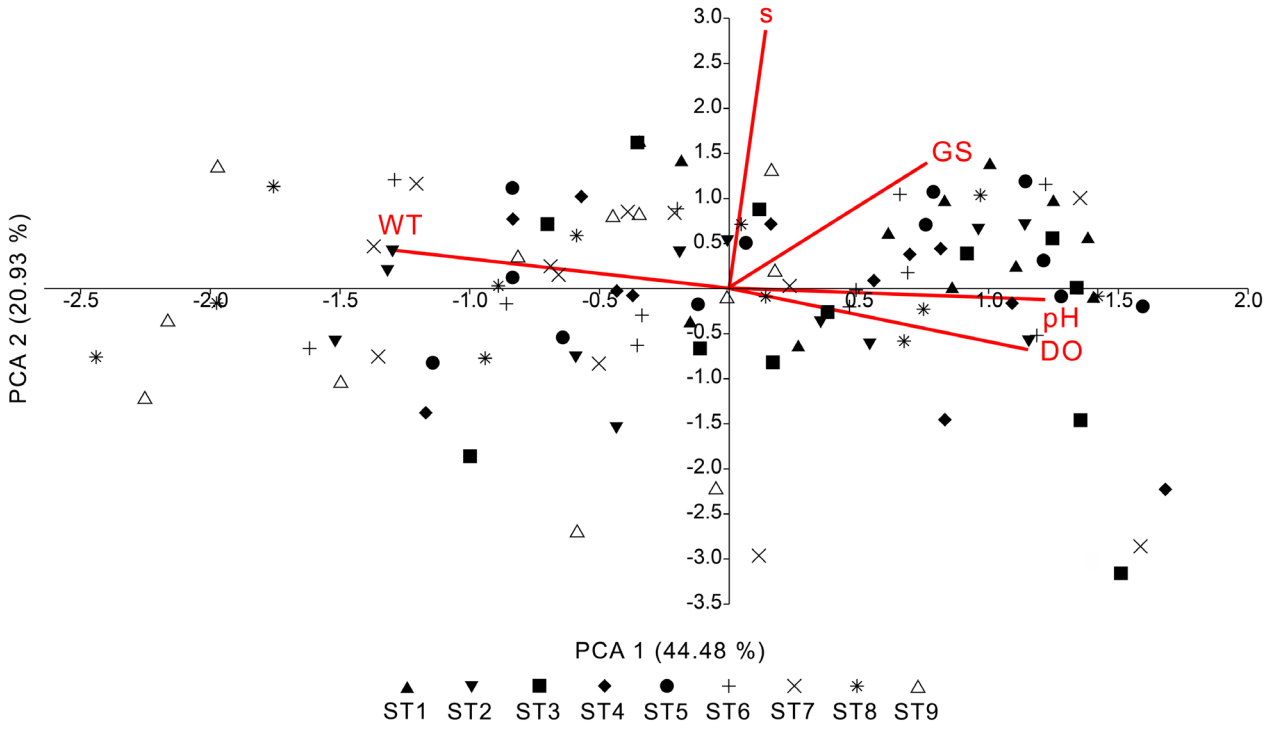

Figure 2. The Principal Components Analysis (PCA) ordination plot for environmental variables and stations.

Pearson correlation coefficients were calculated for the environmental parameters. As a result, some significant correlations were revealed: WT correlated negatively with DO ($P < 0.001$), pH ($P < 0.001$) and GS ($P < 0.05$). pH correlated positively with DO ($P < 0.001$) and GS ($P < 0.001$) (Tab. 3).

The seasonal variation in the environmental factors at the stations are presented in Fig. 3. Except for the grain size of the sediments, seasonal variations of all other environmental factors showed similar patterns in all stations. The higher values of mean WT (highest at ST9 with 26.9 °C) and the lower values of mean DO (lowest at ST9 with 5.23 mg/L) were observed in summer. The seasonal variation of WT was statistically significant at all stations; in summer it was higher than in winter (Kruskal-Wallis, $P < 0.01$). The higher values of mean DO were observed in colder seasons (highest at ST3 with 10.55 mg/L in winter) and the seasonal variation of DO was statistically significant at ST3–ST5 (Kruskal-Wallis, $P < 0.05$). Mean pH did not show a remarkable variation along the beach during the study period (highest at ST5 with 8.07 in winter; lowest at ST2 with 7.92 in spring). The higher values of mean salinity and mean EC were observed in winter and summer respectively (highest salinity at ST5 with 40.08 ‰, highest EC at ST9 with 58.11 mS). The seasonal variation of mean GS showed diverse patterns between stations. The lower values of mean GS were observed in both spring and summer at ST9 (870 µm and 851.3 µm respectively); in autumn at ST2 with 929.2 µm, and in winter at ST4 with 825.2 µm.

Table 3. Pearson correlation coefficients for environmental variables (boldface indicates significant correlations, **: $P < 0.01$, *: $P < 0.05$).

	pH	WT	s	DO	GS
pH	1	**-0.592****	0.013	**0.398****	**0.341****
WT		1	-0.045	**-0.600****	**-0.237***
s			1	0.011	0.115
DO				1	0.174
GS					1

Harpacticoid occurrence and composition

A total of 7677 harpacticoids were collected from 9 stations, comprising 5761 adults and 1916 copepodites. Identifications of the adult specimens revealed 66 species belonging to 42 genera in 17 families. The identified taxa, their distribution, relative abundance and relative frequency of occurrence are

given in Tab. 4. In terms of species richness, the family Ameiridae ranked first with 15 species followed by Ectinosomatidae with 12 species; Miraciidae with 9 species; Paramesochridae with 8 species; Leptastacidae with 5 species; Laophontidae with 4 species; Cylindropsyllidae and Darcythompsonidae with 2 species each; Arenopontiidae, Canthocamptidae, Cletodidae, Dactylopusiidae, Harpacticidae, Latiremidae, Parastenheliidae, Tachidiidae and Tisbidae with 1 species each.

Ectinosoma soyeri Apostolov, 1975 was the most common and widely distributed harpacticoid species with a total abundance of 2806 individuals/7.5 cm^2 (48.71 % of total adult abundance and a relative occurrence of 89.81 %). *Sarsamphiascus angustipes* (Gurney, 1927) was the second most abundant species with a total abundance of 1076 individuals/7.5 cm^2 (18.68 % of total adult abundance). *Leptomesochra eulitoralis* Noodt, 1952, *Microsetella norvegica* (Boeck, 1865), *Ameira parvula* (Claus, 1866), *Klieonychocamptus kliei* (Monard, 1935), *Klieonychocamptus ponticus* (Serban and Plesa, 1957) and *Ameira* sp. were the other abundant species. The contribution of the remaining 58 species to total adult harpacticoid abundance was 7.23 %.

Mean and SE of the biological indices (S, H' and J) at each station are presented in Tab. 5. Mean S varied between 4.33 ± 0.51 and 7.00 ± 1.02. Mean H' was lowest in ST9 with 0.64 ± 0.17, and highest in ST8 with 1.06 ± 0.19. Mean J was lowest in ST9 and highest in ST3, 0.50 ± 0.09 and 0.81 ± 0.03 respectively. Variation of Pielou's J for the stations was significant (Kruskal-Wallis, $P < 0.05$). Post-hoc tests revealed that Pielou's J at ST3 was significantly higher than in some other stations (ST1 and ST9, $P < 0.001$; ST7 and ST8, $P < 0.01$; ST4, $P < 0.05$).

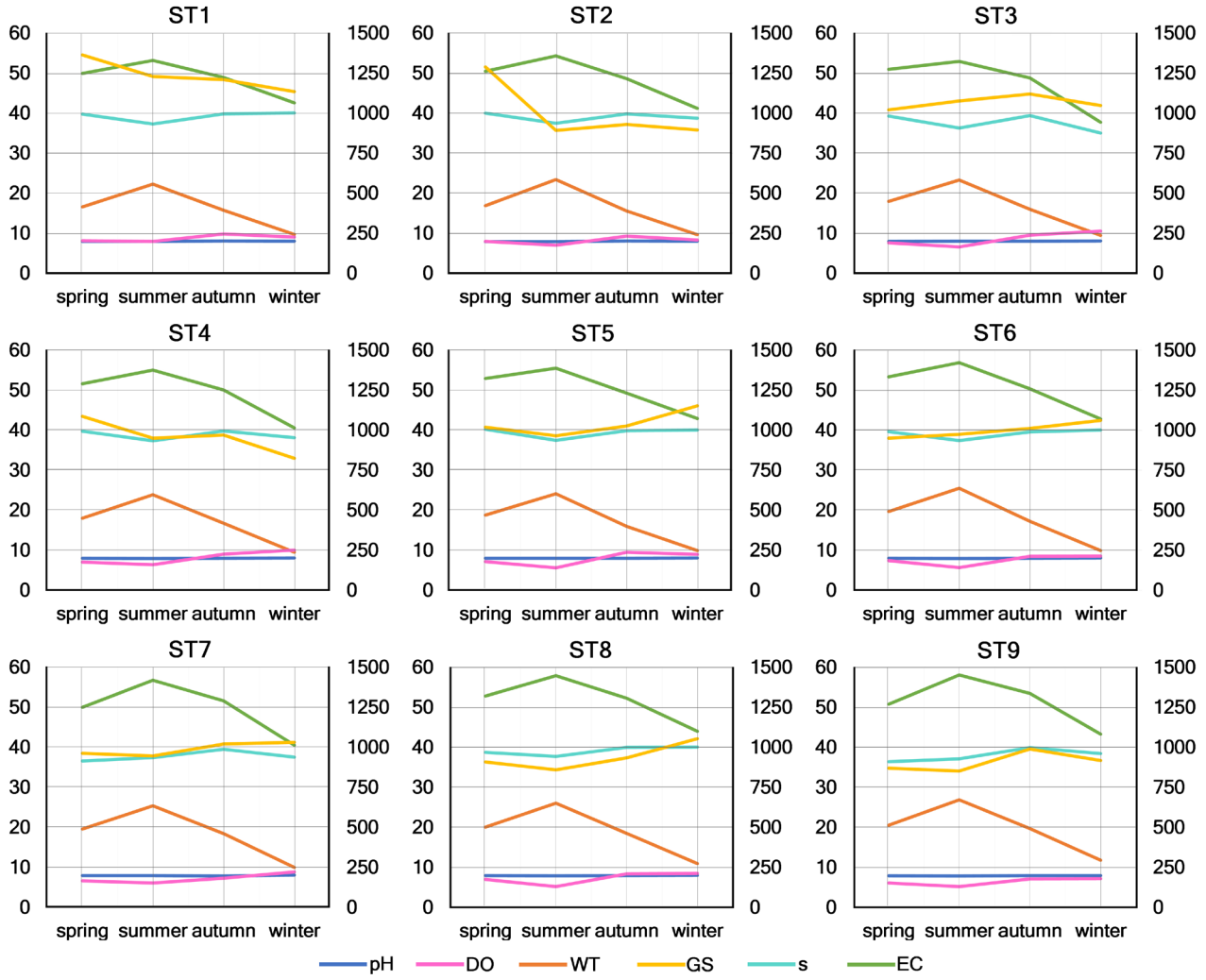

Figure 3. The seasonal variations in the environmental factors according to the stations (scale on the right axes for GS).

Table 4. Distribution, relative abundance [%] (Abun.) and relative frequency of occurrence [%] (Occ.) (N = 108) of adult harpacticoid species (boldface indicates new records for Turkish fauna).

Taxon	Distribution	Abun.	Occ.	Taxon	Distribution	Abun.	Occ.
Ameira parvula	ST1-ST9	2.85	22.22	*Harpacticus* sp.	ST4	<1	<1
Ameira* aff. *spinipes	ST6, ST9	<1	1.85	*Afrolaophonte pori*	ST2-ST9	<1	13.89
Ameira sp.	ST1, ST3-ST9	1.39	11.11	*Klieonychocamptus kliei*	ST1-ST9	2.50	33.33
Filexilia brevipes	ST1	<1	<1	*Klieonychocamptus ponticus*	ST1-ST9	1.77	26.85
Filexilia marinovi	ST1, ST4, ST7	<1	3.70	*Paralaophonte* sp.	ST3	<1	<1
Filexilia sp.	ST4	<1	1.85	*Delamarella obscura*	ST1, ST4, ST6-ST8	<1	4.63
Leptomesochra eulitoralis	ST1-ST9	11.43	50	***Leptastacus uncinatus***	ST8	<1	3.70
Leptomesochra sp. sensu Bodin 1964	ST1, ST7, ST9	<1	2.78	*Leptastacus* sp.	ST8	<1	<1
Nitocra cari	ST1, ST9	<1	1.85	***Minervella* aff. *baccettii***	ST8	<1	<1
Nitocra typica	ST9	<1	<1	***Schizothrix pontica***	ST2	<1	<1
Parevansula sp.	ST6, ST8	<1	1.85	*Schizothrix* sp.	ST8	<1	<1
Proameira* aff. *psammophila	ST7	<1	1.85	*Amonardia perturbata*	ST5, ST8, ST9	<1	2.78
Pseudoleptomesochrella halophila	ST1, ST4	<1	1.85	*Amonardia* sp.	ST6	<1	<1
Sicameira leptoderma	ST8	<1	<1	***Protopsammotopa*** sp.	ST8	<1	<1
Sicameira sp.	ST8	<1	<1	*Pseudamphiascopsis attenuatus orientalis*	ST3, ST7	<1	1.85
Arenopontia nesaie	ST9	<1	1.85	*Robertgurneya* sp. 1	ST6, ST8	<1	3.70
Taurocletodes tumenae	ST7, ST9	<1	2.78	*Robertgurneya* sp. 2	ST9	<1	2.78
Cletodes longicaudatus	ST8	<1	<1	*Sarsamphiascus angustipes*	ST1-ST9	18.68	61.11
Stenocaris gracilis	ST6	<1	<1	*Schizopera gligici*	ST9	<1	<1
Stenocaris minor	ST8	<1	<1	*Schizopera* sp.	ST4	<1	<1
Dactylopusia sp.	ST6	<1	<1	*Apodopsyllus* sp.	ST9	<1	<1
Leptocaris biscayensis	ST2, ST5, ST7-ST9	<1	10.19	***Diarthrodella secunda***	ST8	<1	<1
Leptocaris sp.	ST8	<1	<1	***Diarthrodella orbiculata***	ST8	<1	<1
Arenosetella germanica	ST8, ST9	<1	2.78	*Diarthrodella* sp.	ST9	<1	<1
Arenosetella lanceorostrata	ST1, ST2, ST8	<1	3.70	*Emertonia constricta*	ST1, ST4-ST8	<1	8.33
Arenosetella sp.	ST7	<1	1.85	*Leptopsyllus punctatus*	ST4, ST5	<1	1.85
Ectinosoma melaniceps	ST1-ST4, ST6, ST8, ST9	<1	12.04	***Wellsopsyllus*** sp. 1	ST8	<1	1.85
Ectinosoma soyeri	ST1-ST9	48.71	89.81	***Wellsopsyllus*** sp. 2	ST8	<1	<1
Glabrotelson bozici	ST6, ST8, ST9	<1	2.78	***Karllangia ornatissima***	ST8	<1	1.85
Glabrotelson leptoderma	ST2	<1	<1	*Euterpina acutifrons*	ST7	<1	<1
Halectinosoma sp.	ST6	<1	<1	*Scutellidium longicaudum*	ST1	<1	<1
Microsetella norvegica	ST1, ST3-ST8	5.35	13.89				
Noodtiella sp.	ST1-ST9	<1	15.74				
Sigmatidium* aff. *kunzi	ST6, ST8, ST9	<1	1.85				
Sigmatidium sp.	ST8, ST9	<1	1.85				

The seasonal variation of the harpacticoid abundance among the stations is presented in Fig. 4. A similar variation pattern was observed at most of the stations. Abundances in spring and summer were generally higher than those in autumn and winter. In spring, mean abundance was highest in ST7 with 166 ± 90 ind./7.5 cm² and lowest in ST3 with 26 ± 8 ind./7.5 cm². In summer, it was highest in ST9 with 285 ± 377 ind./7.5 cm² and lowest in ST5 with 40 ± 25 ind./7.5 cm². In autumn, it was highest in ST1 with 120 ± 49 ind./7.5 cm² and lowest in ST7 with 14 ± 11 ind./7.5 cm². In winter, it was highest in ST6 with 84 ± 59 ind./7.5 cm² and lowest in ST2 with 6 ± 3 ind./7.5 cm². Seasonal variations of the abundance were statistically significant (Kruskal-Wallis, $P < 0.05$) at some stations. Abundance in ST2 was significantly higher in spring than in winter. In ST7, on the other hand, abundance was significantly higher in spring than those in both autumn and winter.

Relationships between abiotic and biotic data

The abiotic variation in the DistLM model was partitioned. All tested partitions explained altogether 44.29 % of variation in the harpacticoid abundance, while 55.71 % of the variation cannot be explained by the tested variables. In marginal tests, environmental variation was responsible for 15.17 % of the explainable variability while temporal variation was responsible for 4.33% and spatial variation was responsible for 2.40 %. The results of marginal tests in DistLM analyzes revealed that harpacticoid abundance was significantly correlated with environmental, temporal ($P < 0.001$) and spatial ($P < 0.05$) parameters (Tab. 6). Although each of the environmental factors could explain only small amounts of variation in marginal tests, they were found to be statistically significant ($P < 0.05$ for s; $P < 0.01$ for GS; $P \leq 0.001$ for WT, DO and pH). In sequential tests, both environmental and temporal parameters were significantly ($P \leq 0.001$) correlated with harpacticoid abundance. Environmental and temporal parameters also explained 15.17 % and 5.89 % respectively, of the variation in abundance. The variation in spatial parameter was no longer significant ($P > 0.05$). Spatio-temporal variability in environmental factors was highly significant ($P < 0.001$) and responsible for 22.39 % of the explained variability (Tab. 6).

Table 5. Biological indices (Mean ± SE) at the stations (S: species richness; H': Shannon's diversity; J: Pielou's evenness).

	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9
S	6.17 ± 0.57	4.92 ± 0.51	4.33 ± 0.60	4.93 ± 0.86	5.50 ± 0.56	5.50 ± 0.90	5.50 ± 0.83	7.00 ± 1.02	5.25 ± 0.85
H'	0.87 ± 0.12	0.87 ± 0.11	0.86 ± 0.13	0.78 ± 0.13	0.96 ± 0.08	0.93 ± 0.13	0.81 ± 0.13	1.06 ± 0.19	0.64 ± 0.17
J	0.54 ± 0.06	0.68 ± 0.05	0.81 ± 0.03	0.64 ± 0.07	0.68 ± 0.03	0.68 ± 0.05	0.60 ± 0.04	0.59 ± 0.06	0.50 ± 0.09

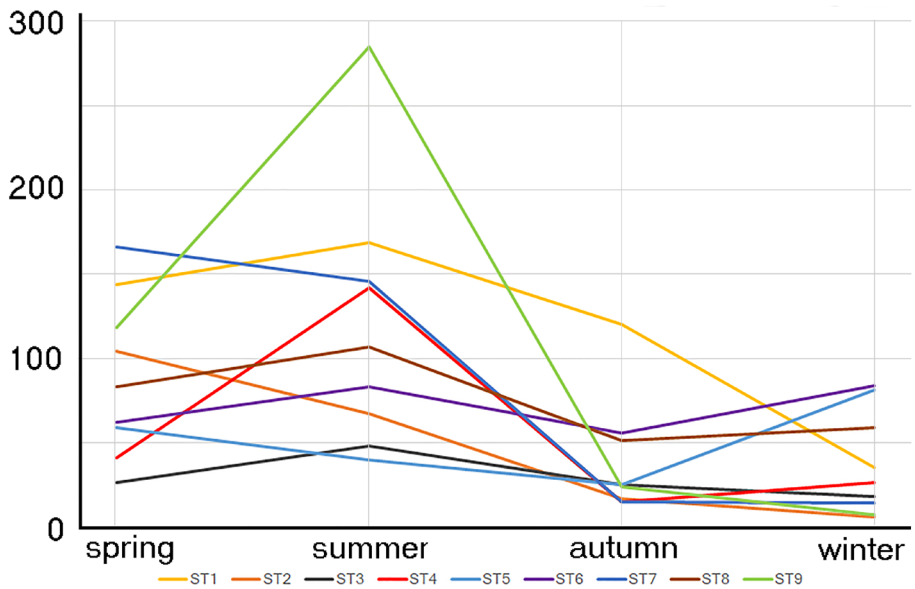

Figure 4. The seasonal variation in the mean abundance (ind./7.5 cm²) of the harpacticoids at the stations.

Table 6. The results of DistLM analyses.

Parameter	P	Proportion	Cumulative proportion
Marginal tests			
Environmental	0.001		
WT	0.001	0.0909	
DO	0.001	0.0527	
pH	0.001	0.0407	
s	0.017	0.0212	
GS	0.004	0.0271	
Temporal	0.001		
Date	0.001	0.0433	
Spatial	0.015		
Latitude (Lat.)	0.015	0.0240	
Sequential tests			
Environmental	0.001	0.1517	0.1517
Temporal	0.001	0.0589	0.2106
Spatial	0.064	0.0133	0.2239
Environmental +Temporal +Spatial	0.001	0.2239	
Best solution: Adj. R^2: 0.1695; R^2: 0.2239; RSS: 2.601			

DistLM analysis was visualized with a dbRDA ordination plot; harpacticoid abundance in repeated sampling of the same stations showed seasonal clustering (Fig. 5). The first two axes explained 17.6 % of the total variance. Among the tested variables WT, pH, DO was mostly correlated with the first axis, while GS, salinity, temporal and spatial parameters showed higher correlation with the second axis (Tab. 7). WT and sampling date contributed most to variation along the first and the second axes, respectively. WT correlated negatively with pH and DO. GS correlated negatively with latitude of the stations.

RDA was performed for 5 environmental variables (DO, WT, GS, pH and salinity) and transformed data of the most abundant eight species. The first two axes explained 88.91 % of the variance (Fig. 6). Monte Carlo permutation tests showed that variations of WT, DO and GS were significant ($P < 0.05$) for the abundance of the species. The abundance of *S. angustipes* and *K. ponticus* was positively correlated with all tested variables except WT. The abundance of *K. kliei* was positively correlated with three parameters (WT, GS and salinity), while it was negatively correlated with DO and pH. The abundance of *Ameira* sp. and *M. norvegica* was negatively correlated with all tested variables except WT. The abundance of *E. soyeri* and A. *parvula* was negatively correlated with all tested variables except pH. The abundance of *L. eulitoralis* was positively correlated with WT and salinity, while it was negatively correlated with three parameters (GS, DO and pH) (Fig. 6).

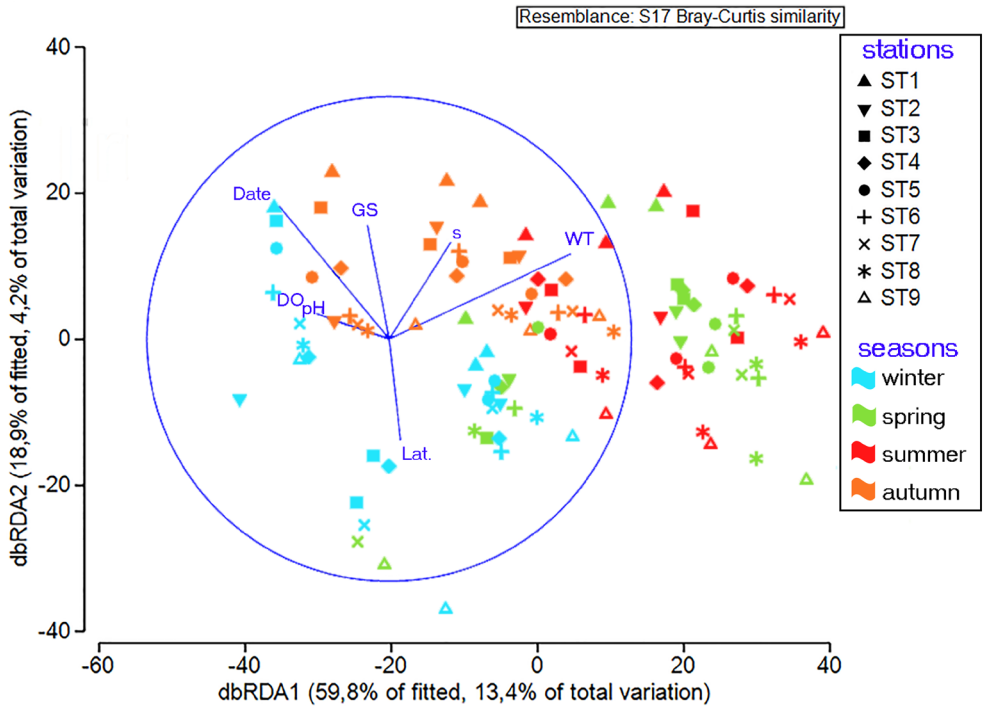

Figure 5. Distance-based Redundancy Analysis (dbRDA) plot for the harpacticoid community and environmental variables.

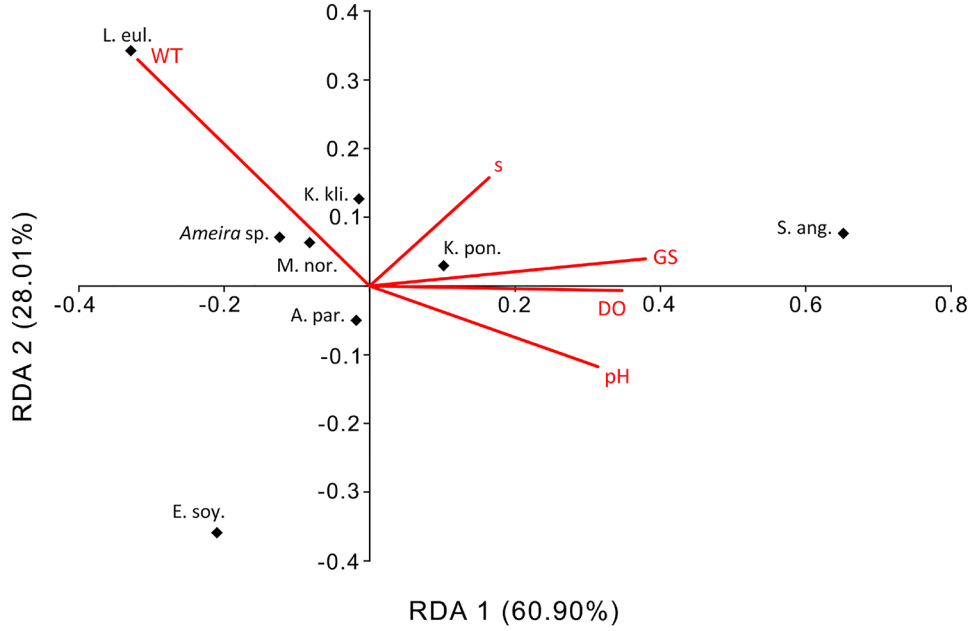

Figure 6. Redundancy Analysis (RDA) ordination plot for most abundant harpacticoid species and environmental variables (Abbreviations: A. par.: *Ameira parvula*; E. soy.: *Ectinosoma soyeri*; K. kli.: *Klieonychocamptus kliei*; K. pon.: *K. ponticus*; L. eul.: *Leptomesochra eulitoralis*; M. nor.: *Microsetella norvegica*; S. ang.: *Sarsamphiascus angustipes*).

Table 7. Correlation coefficients in the dbRDA ordination for the tested variables and the first two axes.

Variable	dbRDA1	dbRDA2
pH	-0.255	0.085
WT	0.750	0.351
DO	-0.302	0.105
GS	-0.090	0.471
s	0.255	0.400
Date	-0.455	0.549
Latitude (Lat.)	0.047	0.420

Discussion

Harpacticoida diversity

Harpacticoid copepod diversity on sandy beaches is influenced by many ecological parameters. This is probably the main driver determining the differences in harpacticoid species composition and abundances observed in different beaches. For example, Wells (1961) reported 55 interstitial harpacticoid species from the Isles of Scilly (England). Harris (1972) determined 13 species from Whitsand Bay (England) within a 2-year period. Mielke (1975) reported 61 species from Sylt (Germany). Thirty seven harpacticoid species were identified by Moore (1979) from 6 beaches on the Isle of Man (England). Sixty species were reported by Mielke (1984) from beaches of the Galapagos Islands. Bodin and Jackson (1989) studied 6 beaches in Galway Bay (Ireland) and Northern Brittany (France), as a result a total of 85 species were recorded. George and Rose (2004) sampled monthly the shore of Chiloé Island (Chile) between 1993 and 1994, and surprisingly only 1 harpacticoid species (*Sextonis mehuinensis* (Mielke, 1985)) was reported; in terms of harpacticoid diversity, this was the first study reporting a monospecific beach. Two beaches on the Island of Crete (Greece) (Elafonisi and Pahia Ammos) were studied for 13 months by Sevastou *et al.* (2011), and as a result a total of 96 species were reported (67 and 64 for Elafonisi and Pahia Ammos, respectively). Comparing the faunistic results of this study with the literature summarized above, species richness of Harpacticoida is high in Sarımsaklı beach, where a total of 66 species was collected. Three species identified in this study (*Arenosetella germanica* Kunz, 1937, *Klieonychocamptus kliei*, and *Delamarella obscura* Huys, Karaytug and Cottarelli, 2005) were reported previously by Karaytuğ and Sak (2006), so the remaining 63 species are new records for the beach. One family (Cylindropsyllidae), with 8 genera (*Proameira* Lang, 1944, *Sicameira* Klie, 1950, *Stenocaris* G.O. Sars, 1909, *Minervella* Cottarelli

and Venanzetti, 1989, *Schizothrix* Huys, 1992, *Protopsammotopa* Geddes, 1968, *Wellsopsyllus* Kunz, 1981, and *Karllangia* Noodt, 1964) and 20 species are also new records for the Turkish marine harpacticoid fauna (Tab. 4). *Pseudamphiascopsis attenuatus orientalis* Noodt, 1955 is reported for only the second time from Turkish seas since its description from the Sea of Marmara by Noodt (1955).

Ecological indices

Shannon's H' was calculated between 0.64 and 1.06 across the stations (Tab. 5). Although the total species diversity of the beach was high, the stations generally had low H' values. Pielou's J was calculated between 0.5 and 0.81 across the stations (Tab. 5). Low values of H' and J in a region indicate that species richness was imbalanced and the community was dominated by few species (Magurran, 2004; Kiernan, 2014). In this study, the genera *Ectinosoma* Boeck, 1865, *Sarsamphiascus* Huys, 2009, *Leptomesochra* G.O. Sars, 1911, and *Ameira* Boeck, 1865 were common and abundant throughout the studied period (Tab. 4). Due to the dominance of these taxa, J values were lower than 0.7 at all stations except ST3, which had the highest evenness of 0.81. Means of both species richness and abundance at ST3 were lower than in most of the other stations (Tab. 4; Fig. 4); however, the abundance of each species at this station was more equally distributed than at other stations.

Effects of abiotic variables on harpacticoid abundance

The scattering of the repeated samples from the same station on the PCA ordination plot indicated the effect of temporal variation on the environmental factors (Fig. 2). Marginal tests in the DistLM analysis showed that both environmental and temporal variables tested in this study were associated with the harpacticoid abundance when considered independently. Sequential tests in the DistLM analysis revealed that the environmental and temporal variables together had strong effects on the harpacticoids (Tab. 6). The significant effects of WT and DO on the community structure and distribution of the interstitial Harpacticoida have been reported by other authors (Coull, 1970; Kotwicki *et al.*, 2005; Mantha *et al.*, 2012; Berraho, 2019). In this study, WT was responsible for 9.1 % of explained variation and had a great impact on Harpacticoida abundance at the studied stations. Temperature influences reproductive activity and postembryonic development of the harpacticoids. Although the optimum thermal requirements of species are different from each other, increasing water temperature generally increases the rate of harpacticoid reproduction and lifespan (Hicks, 1977; Zaleha and Busra, 2012; Punnarak *et al.*, 2017). The higher WT was recorded in spring and summer (Fig. 3) and apparently caused an increase in harpacticoid abundance at the stations (Figs. 4, 5). Harpacticoids are very sensitive to reduced oxygen supply in the sediments (Moodley *et al.*, 2000; Dahms and Qian, 2004; Grego *et al.*, 2014). Correlation between Harpacticoida abundance and DO was found to be statistically significant. It is known that the solubility of oxygen in seawater decreases when temperature and salinity increase (Errahmani *et al.*, 2015). Interstitial elements and microbial components that consume oxygen in the pore water are also effective in the decrease of the DO content (Murray and Grundmanis, 1980; Glud, 2008). The decrease in DO was clearly observed in warmer seasons; this can be attributed to both increased WT and respiration activities of interstitial fauna. In this study, the mean DO levels were higher than 5 mg/L even in warmer seasons (Fig. 3), therefore, it can be speculated that the effect of decreased DO on harpacticoid abundance was not an important community controlling factor. No significant variation was observed in pH at the beach, either spatially or temporally. However, DistLM analysis indicated a highly significant correlation between pH and harpacticoid abundances (Tab. 6; Fig. 5). It was observed that the pH measured in warm seasons (mean varied between 7.85 and 8.05) was slightly lower than in cold seasons (mean varied between 7.98 and 8.08). An increase in sea water temperature results in a decrease in pH (Hunter, 1998). In this study, a significant negative correlation between pH and WT was found (Tab. 3). Zhai *et al.* (2015) reported that most harpacticoid species prefer slightly alkaline conditions between 7.2 and 7.7. During the warmer seasons the pH was close to 7.7. Overall, pH decreased slightly with the effect of increasing water temperature, and generally contributed to the increase in harpacticoid abundance.

It was observed that the abundance of three (*E. soyeri*, *L. eulitoralis*, and *S. angustipes*) out of eight most abundant species examined in the RDA had the highest correlation with some environmental variables. These species were also observed in the ordination plot both far from each other and in opposite positions (Fig. 6); therefore, it can be thought that the ecological requirements or tolerances of these species were generally different from each other. *Sarsamphiascus angustipes* increased abundance at lower WT and higher DO, pH, GS and salinity. *Leptomesochra eulitoralis* showed highest abundances at higher WT and salinity, and lower DO, GS and pH. On the other hand, *E. soyeri* was most abundant at higher pH, and lower WT, DO, GS and salinity.

The relationship between environmental factors and the Harpacticoida inhabiting the sandy coasts of Turkey is unknown. This study demonstrates that the abundance and composition of the Harpacticoida at Sarımsaklı Beach were clearly influenced by seasonal variation of environmental factors, especially WT. Unfortunately, many variables tested in this study were related to physical properties of seawater. However, they explained only 44.29 % of the variation in the harpacticoid abundance based on the DistLM results. The distribution and abundance of interstitial harpacticoids are determined by many other factors (microbial food sources, other meiofauna members such as nematodes, physicochemical gradients, pollutants, etc.) (Giere, 2009). It can be supposed that these factors were responsible for the unexplained partition of the DistLM ordination.

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